Proceedings of The Symposium on Future Developments in Water and Sewage Treatment

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SYMPOSIUM ON FUTURE DEVELOPMENTS IN WATER AND SEWAGE TREATMENT

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PREFACE

Developments in water and sewage treatment must keep pace with the need to provide an increasing supply of water of appropriate quality to meet the growing demands of population, industry, and agriculture. This is not only true nationally but also internationally.

In future, sewage treatment may have to be modified to meet stricter standards, so that more surface waters can be treated for potable supply. In turn, water treatment methods may have to be modified to comply with more stringent standards.

The treatment of both sewage and water is obviously interconnected and any future advances and changes must be viewed within the constraints of the prevailing economic climate.

This Symposium, which can be regarded as a logical sequel to the Institution's 1975 Symposium on the "Maintenance of Water Quality", will endeavour to predict changes that may occur in the next few years from the operational, research, and design aspects of water and sewage treatment. It is an international event, and will attempt to cover many of the problems that will face the water industry in the future both in this country and overseas.

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INTRODUCTION

The Newcastle and Gateshead Water Company operates a variety of treatment plants most of which have been built to the Company's designs. At a time when there is increasing interest in flat bottomed vertical flow sedimentation tanks, it is interesting to review the Company's original design first used some 18 years ago and subsequent highly successful developments.

Hand in hand - often, indeed, in advance of plant developments has come progress in chemical treatment processes, often stimulated by the need to uprate plant or to treat difficult waters. The development of these plants and chemical processes will be reviewed and the strong influence of operational requirements brought out.

SUPPLY AREA, SOURCES AND CHARACTERISTICS OF WATER

This paper concentrates on the treatment of supplies drawn from the principal Tyneside sources, namely the reservoirs to the west of Newcastle and the rivers North Tyne, Tyne and Coquet; these are shown in fig.1. The reservoirs are series linked, so that water arriving at Whittle Dene, the lowest and most easterly group, is a blend and includes a proportion of river derived water. Catcleugh, the most westerly reservoir,supplies about 46 t.c.m.d. into the Tyneside system and its output is soft, peaty moorland

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water. In addition a supply of 6.8 t.c.m.d. from this source is treated at the Gunnerton Treatment Plant, whence it is fed into Hexhamshire and the West. A supply of up to 52.3 t.c.m.d. is pumped from the River North Tyne at Barrasford into West Hallington Reservoir and although this pumping is intermittent, in the winter months it forms a substantial proportion of raw water intake. Similarly, a pumping station on the River Tyne at Wylam contributes up to 82 t.c.m.d. and is used for most of the year. Tyne water from Wylam can be pumped to storage at Whittle Dene reservoirs, direct to treatment at Whittle Dene or Throckley, or indeed into an unfiltered (but chlorinated) trade supply.

The main treatment plants for Tyneside are located at Whittle Dene, where 154 pressure filters treat about 100 t.c.m.d.,while slow sand filters deal with a further 32 t.c.m.d. and at Henderson Filters, Throckley, where flows up to 54 t.c.m.d. can be handled. Because of the conjunctive use of impounding reservoirs and river pumping, filter plants have to deal with several permutations of waters of different characteristics. Thus, although the slow sand filters are fed exclusively with reservoired water, this in itself may contain a substantial proportion of river derived water.

A maximum of 50% of the water applied to the pressure filters undergoes sedimentation, this fraction being derived either direct from the River Tyne or from the reservoirs; the balance is always reservoir water. The Henderson plant accepts either river water direct or reservoir water.

The remaining source for Tyneside is the River Coquet where the works of the Coquet Water Board, designed and operated by the Company but owned jointly by the Company and the Northumbrian Water Authority, abstract and treat 45.5 t.c.m.d. Table 1 summarises the principal characteristics and variations of the several waters.

TABLE 1 - Raw water analyses showing principal characteristics and variations.

Determination	River Tyne	Whittle Dene	Gunnerton	Warkworth
pH value	7.2-8.6	7.5-8.2	6.9-7.8	7.0-8.6
Colour	20 - 200	25 - 60	30 - 80	10 - 80
Turbidity	5 - 200	2 - 15	1 - 10	1 - 150
Alkalinity	40 - 130	78 - 140	22 - 64	60 - 150
Total hardness	90 - 180	100 - 200	36 - 62	80 - 180
Calcium hardness	46 - 140	76 - 160	20 - 46	50 - 120
Total dissolved solids	100 - 260	130 - 260	60 - 120	110 - 260
O.A. value	2 - 20	2.5-10	2 - 8	1 - 20

Results in standard units.

COAGULATION AND SEDIMENTATION

The Company's first entry into sedimentation was made at Henderson Filters. Here slow sand filters were replaced in 1955 by a 36 t.c.m.d. rapid gravity filter plant, the first to be designed by the Company and two of the superseded slow sand filters were combined to form a horizontal flow sedimentation basin having a water depth of 3m. Nominal retention time is about 4 hours but salt dilution flow tests have indicated an actual flow-through time of only 1 to $1\frac{1}{2}$ hours. Although this basin does contribute usefully to the treatment process and cost almost nothing to construct, its irregular plan shape, poor draw-off and primitive desludging arrangements (use of portable submersible pumps at six month intervals) result in substantial floc carry-over to the filters and consequently rather short filter runs. Nevertheless the length of run following this partial sedimentation is about three times that obtained when the alum-dosed water is applied direct to the filters thus there seems to be a reasonably economic apportionment of the total load as between basin and filters. With an applied alum dose of say 4.5 mg/l as Al (i.e. about 50 mg/l gran. alum dose) a settled water residual alum figure of 1.5 to 2.0 mg/l Al may be expected. It is noteworthy that here, as in all Company sedimentation tanks, after the initial rapid mix at the inlet weir, no special flocculation devices are used. It must be accepted that for horizontal flow, the incorporation of paddle flocculators would undoubtedly assist flocculation and subsequent settlement. Nevertheless without such devices floc formation is reasonably good and no difficulty has been experienced in treating any of the variations of water types received.

Meanwhile, laboratory and small pilot plant experiments with upflow sedimentation had established that, given suitable inlet distribution, there was no difficulty in producing and maintaining a stable blanket in flat bottomed tanks. The close contact of the incoming dosed water with the suspension of preformed floc provided all that was necessary to induce floc formation without the need for any form of external flocculation process or reaction time before the upflow stage.

Based on this work the Company's next development in sedimentation was a flat bottomed vertical flow sludge blanket tank made by converting a slow sand basin at the Whittle Dene Works in 1958. Dosed water is fed into the tank through horizontal 0.25m. diameter pipes suspended 0.20m. to centre line above the tank floor and perforated on their inverts with 0.05m. diameter holes at 0.56m. centres. Settled water is drawn off into decanting troughs. The tank is very large in plan, being 32m. x 50m. and deals with flows at the rate of 46 t.c.m.d. It is on the shallow side, water depth being 3m., with the top of the blanket 0.9m. below top water level. The rise rate is consequently low at 1.2m. per hour.

The tank, which in fairness was a very inexpensive conversion, suffered from two defects in its original form. First, the lateral distribution pipes tended to become blocked; this was dealt with by installing wires through the pipes enabling circular brushes to be pulled through periodically. Second, sludge draw-off arrangements were quite inadequate, consisting of a sump at one corner of the tank; proper sludge decanting hoppers were later added.

The distribution pipes are 4.27m. apart with the result that the quiescent zones in between gradually become filled with settled sludge forming lateral mounds. These have a natural angle of repose and assist in the establishment of the desired pattern of up-flow. No septicity or similar problems have arisen from the presence of this thick settled sludge. In controlling sludge levels only the thinner suspended sludge blanket is withdrawn into the decanting hoppers for concentration and discharge. The effect of this initial sludge concentration in the quiescent zones tends to lengthen start-up periods but this has not presented any serious problem and usually within a week from starting off with a completely emptied tank a relatively stable sludge blanket is obtained. With the exposed position in which this large basin is situated, wind disturbance was a problem, to overcome which submerged baffle boards were placed just below the water surface at appropriate distances across the tank thus minimising wave movement and blanket disturbance.

In converting this large basin to upflow sedimentation it was not expected that anything like complete removal of settleable floc would be achieved. Nonetheless, substantial relief is afforded to the filters by this treatment stage and on average about two-thirds of the load is deposited here. With an initial alum dose of, for example, 4.5 mg/l Al (i.e. about 60mg/l Aluminoferric) residual alum in the settled water is about 1.5 mg/l Al.

The success of this simple design stimulated the Company to look further at the development of vertical flow tanks. The construction cost advantages of a flat-bottomed, rectangular, relatively shallow tank were and remain, obvious. Flocculation, as has been noted, has not proved a problem and leaving this aside, it is important that very even flow distribution be achieved, since any differential will lead to eddies and disturbance of the floc blanket. Development effort was put into this aspect, therefore, resulting in the distribution system first adopted by the Company in its design for the Warkworth Treatment Works of the Coquet Water Board in 1960. The four sedimentation tanks at this works have a "chandelier" distribution system illustrated in Fig.2. Although not as simple as perforated laterals, this has the advantages of offering less obstruction to flow whilst giving very even flow distribution. The tops of the distributors are above water level and open to atmosphere, thus offering both an indication of excessive head loss and the means of clearing any blockage.

Water depth in these tanks is 3.66m. with sludge decanting hoppers set to give a blanket depth of 2.44m. The conservative upflow rate of 1.22m. per hour should be seen in context of the shallow depth and hence low construction cost of the tanks. The quality of the clarified water is first class with a residual alum figure of about 0.2 mg/l. Al.

Similar distributors are in use, although on a smaller scale, at the Company's Gunnerton Filter plant. Here up to 6.8 t.c.m.d. of thin moorland water from Catcleugh reservoir is treated; blanket and water depths are similar to those at Warkworth. The tanks operate at rates up to 1.52m./hour and residual alum figures of 0.2 to 0.4 mg/l Al are achieved.

It will be noted that considerable reliance is placed on residual alum as a measure of sedimentation efficiency. Parameters such as colour and turbidity are important in this judgement but the residual alum test in our experience has always provided one of the best operational guides to the correctness of chemical treatment and the performance of the removal processes of sedimentation and filtration.

In 1971 planning and design for the Company's new Horsley Treatment Plant began in earnest. The works were to have an initial output of 114 t.c.m.d. with provision for extension ultimately to 454 t.c.m.d. Like Warkworth, this works would treat river water direct for most of the time and therefore the need for reliable, stable sedimentation was paramount. Accordingly a survey of sedimentation processes was undertaken and this included visits to plants and discussions with engineers and chemists.

It was concluded, at least for the waters to be treated at Newcastle that there was no good reason to depart from the simple flat bottomed tank with chandelier distribution. In order to explore performance at higher upflow rates under varying conditions a pilot tank was constructed from reclaimed "Braithwaite" sections. Higher vertical flow rates require either a denser floc or greater blanket depth and the tank which was 2.44m. square in plan, enabled various water depths to be tried; a developed version of the chandelier was used for distribution. This tank was operated for over a year on river water similar to that which will supply the new works. Various water depths, upflow rates, coagulants and coagulant aids were tried, as a result of which sufficient confidence was gained to lay down design parameters of 2.44m. per hour upflow rate and 5m. water depth for tanks of this type should the decision to use these in the new works be made. It is worth emphasising that 2.44m. per hour gives a 100% increase in throughput over the Warkworth tanks.

In the event, after careful evaluation, the decision was made in favour of flat-bottomed tanks with chandeliers. Amongst the reasons for this were :-

> Economy and speed of construction because of simple rectangular shape, lack of complicated shuttering, relative shallowness and consequent saving in excavation.
>
> No dependence on mechanical plant, with benefits in reliability and savings in maintenance and running costs.
>
> Considerable successful experience of the operation of similar tanks on the Company's raw waters was also a major factor.

As previously noted the tanks will operate initially at an upflow rate of 2.44m./hr. Whilst is is likely that 3.05 or 3.66m. per hour can be achieved, especially by using coagulant aids it was considered judicious to select such rate as would allow a margin for substantial flow variation since such flexibility is essential to the operation of the Company's fractional chemical treatment methods. Commissioning of these tanks is in hand at the time of writing.

OTHER PRETREATMENT DEVELOPMENTS.

The development of fractional alum treatment, in some ways similar to controlled softening by blending, took place in the early post-war years when the Company's pressure filter plants were becoming overloaded to an extent which led to serious breakthrough and subsequent post-precipitation of alum floc in the distribution system. Furthermore, the need to abstract increasing amounts of River Tyne water for direct application to the filters added to the problem by reason of the increased load of suspended solids as compared with the impounded waters. Increased frequency of washing enabled some control of filtrate quality to be achieved although the stage was fast approaching when it would have been impossible to carry out the number of washing operations required. In addition, output was seriously reduced by these very large washwater requirements and the increased proportion of time during which filters were out of service.

Another feature which aggravated the problem was that of washing the whole plant right through from start to finish in one operation - a practice which seemed quite common in those days on pressure filter plants. Unless the washwater is drawn from a separate washwater tank, the resulting disturbance from flow surges acting on dirty filters carrying their full load of alum floc and waiting to be washed causes an immediate breakthrough which persists right through the washing period.

The position was not helped by the fact that although the Company's raw waters are very much peaty in origin, the pH values and alkalinitics are fairly high with the result that relatively high alum doses are required. Attempts had been made by operating staff to alleviate the breakthrough problems and to extend filter runs by bringing the applied dose as far below the optimum as would still give some removal of colour, but the associated high levels of residual alum with such underdosing gave serious after-precipitation problems. It had become imperative if throughput was to be maintained, to find some way of reducing the chemical load on filters, while still producing water of satisfactory colour and turbidity.

The effects of superchlorination and of ozonation both for bleaching and as aids to coagulation were explored but it was found that despite an overall improvement in colour, the critical points on alum coagulation curves remained unchanged. Clearly these chemical treatments were bleaching organic colouring matter without actually reducing the amount of coagulable material. Consequently no benefit accrued from the filtration point of view. Where colour was removed by adsorption on activated carbon then a definite reduction in coagulant requirements was observed. These effects are shown in figs. 3 and 4.

At the time of this work chlorine dioxide was announced in the literature as a new water treatment chemical with $2\frac{1}{2}$ times the oxidizing power of chlorine. The possibilities of this chemical proving superior to chlorine as a bleaching agent for peaty organic matter were immediately explored. Unfortunately it was found, in fact, to be less effective for this application than chlorine. It became evident, in any case, from a consideration of its available chlorine content that the original claims about enhanced oxidizing power were misleading since it is oxidation capacity not power which is $2\frac{1}{2}$ times that of chlorine.

In the course of further research in the Company's laboratory into the chemical behaviour of chlorine dioxide as a water treatment chemical, the discovery was made in 1946 that chlorine dioxide did not react with ammonia and did not therefore produce a breakpoint curve.

Some research was also carried out into water ozonation again for the particular purpose of removing or bleaching organic colouring matter. It is interesting that in some experiments ozonation was combined with microfabric filtration thus providing 30 years ago the forerunner of present day "Microzone" processes. Besides not proving helpful to subsequent coagulation, ozone was found to have limitations as a colour remover and could not itself adequately deal with raw waters of 50° H. or over.

Chlorine had similar limitations. For reasonably short contact periods of say $\frac{1}{2}$ to 1 hour and doses in the range 3 to 5 mg/l a 50% removal of colour presented no difficulty, but to achieve substantially better than that required up to 24 hours contact period with doses of 5 to 10 mg/l. Nevertheless, it appeared that chemical bleaching of colour had possibilities as a useful supplementary treatment and in this respect the advantage lay with chlorine because of the ease of application and the very much lower capital costs. Further work on ozonation was therefore discontinued.

Other supplementary treatments considered for lowering alum requirement included adsorption processes using activated carbon and acidification processes using sulphuric acid so as to bring the raw water nearer the optimum pH for coagulation.

Treatment by acid had possibilities but on grounds of cost it was unattractive, bearing in mind the need for increased supplementary lime treatment for pH correction. In using powdered activated carbon for partial colour removal, with consequent reduction in subsequent alum dosing, the quantities required appeared likely to be very high and thus lead to filtration problems. At new works involving sedimentation and rapid gravity filtration powdered activated carbon has been incorporated, not as a continuous treatment, but to provide a standby organic removal process for emergency use in the event of accidental contamination of rivers upstream of intakes and also to combat occasional tastes and odours. The newer problems of chlororganics, discussed later, have led to further research in the U.S.A. and elsewhere into this particular application of carbon adsorption, from which it appears that granular activated carbon filters are more efficient than application of powdered carbon.

The position remained, therefore, that at the pressure filter plants any attempt to treat the applied water at its optimum alum dose gave satisfactory water only for relatively short periods. Thereafter, there was severe break-through and at the throughputs required it was not possible to control this by increased washing. In other words there was an absolute limit to the load of alum that the plant could accept. If applied in the conventional way to all the water, the actual dose would be far below the optimum dose for coagulation thus leading to imperfect coagulation and poor filtrates. It was obviously better, in view of this limitation, to apply the same absolute amount of alum to such portion of the raw water as would ensure its being dosed at the optimum level and then, after coagulation, to blend with undosed water. Thus the alum could be made to do useful work whereas if distributed throughout all the water, it produced worse results than applying no alum at all.

Originally this system of fractional treatment was applied to the pressure filter installations, the procedure being first to determine the proportion of water to be treated to give the desired results for the subsequent blend. In an installation with filters arranged in separate batteries this would mean, therefore, deciding how many batteries were to receive alum. This was then applied for a predetermined period following which, dosing was stopped and the batteries continued thereafter taking undosed raw water. At this point another set of batteries would have been washed and set away on alum dosing. Thus with staggered washing times and this sequence of alum immediately after wash for a period, then no alum for a further period, the whole plant was worked through in a cyclical manner giving at all times a blended output of the desired quality. The factors which governed this quality were (a) correctness of alum dose during the "on" periods (b) correct selection of proportion being treated at any given time and (c) correct choice of change-over periods and consequently of overall length of run.

It was found that the return of colour in the filtered water from batteries after stopping the alum dosing was gradual, indicating that alum floc deposited on the filter beds at a pH of say 7.0 had a continuing affinity for a time for the colour of applied undosed raw water having a pH of say 7.8 to 8.0. One might say it was possible in this way to achieve a measure of further useful work from spent alum. Another advantage lay in the higher pH of the finished blend as compared with a fully alum dosed water since the chemical balance was less disturbed as judged by the Langelier index.

In practice the proportions of raw water dosed at any time usually varied from one-third to two-thirds, with corresponding savings in chemical costs. For higher raw water colours the alum treatment can be supplemented by moderate-dose, short contact superchlorination, typical results being shown in fig.5.

When the Company developed coagulation and sedimentation basins, in the first place to relieve still further the load on pressure filter plants and second as integral parts of the newer rapid gravity plants, it was decided to apply the principles of fractional treatment at the sedimentation rather than at the filtration stage. This simply meant that the dosed portion of the raw water was flocculated and settled before blending with undosed raw water prior to filtration. By now the treatment was not regarded as a device for relieving overloaded pressure filters but as a desirable feature of any new works treating a variable raw water, enabling the maximum overall economy in chemicals to be achieved especially at times of good raw water quality. Moderately hard rather alkaline waters of low colour can quite easily require

40 or 50 ppm alum for coagulation, whereas fractional treatment can save a half to two-thirds of coagulant cost and still give finished waters not noticeably different in terms of colour and turbidity and with much less risk of alum breakthrough.

Where iron coagulants are used the consequences of breakthrough in terms of discoloration, staining and consumer complaints generally, are more pronounced than with alum and it is understandable that there has always been a reluctance to consider iron salts as coagulants for pressure filters. With the growing emphasis on sedimentation, attention was given by the Company to the relative merits and demerits of iron and alum. Experimental work showed that the same type of fractional treatment with blending would work with iron as with alum coagulation. In chemically equivalent amounts iron coagulants were found in general to perform equally as well as alum and rather better, in terms of speed of flocculation, at very low water temperatures.

The same coagulant and filter aids as would be used with alum were found to work quite satisfactorily with iron and no problems are expected should a works operating on the one coagulant be switched to the other. In fact, the chemical dosing side of the Company's new Horsley works has been so designed as to facilitate such change-overs. As a result of the sharp rise in energy costs of the recent past, prices have moved very favourably in the direction of iron salts and it is estimated at present price levels that coagulant costs can be reduced by more than 50% by use of these.

Considerable pioneering work was carried out first on activated silicate and later on synthetic polyelectrolytes with the emphasis being directed mainly towards their application as filter aids rather than as coagulant aids. The essential purpose of the filter aid is to give control over the rate of filter penetration in such a way that, whatever the applied water conditions, time of first breakthrough and of maximum head loss are made to coincide. Thus filters are operated at maximum efficiency. In new works there is provision for application of polyelectrolytes at both stages, that is as coagulant as well as filter aid, depending upon treatment requirements. It is expected, from past experience, that dosing rates for these purposes, where polyacrylamides are used, will be 0.1 to 0.15 mg/l and about 0.05 mg/l respectively.

Attention was also paid several years ago to polyaluminium chloride (PAC) at a time when it was available only from Japan. This coagulant is described as "a poly nuclear complex of polymerised aquo-aluminium ion with a molecular weight of several hundreds" and is stated to have the following advantages: effective over a wide pH range for coagulating waters of both high and low colours and turbidities, rapid floc formation which is unaffected by low temperature and no need for a supplementary coagulant aid. Further, it was claimed that the PAC dose to treat a given water is only half that of Aluminoferric for the same result.

These claims were confirmed so far as the Company's waters were concerned. It has to be borne in mind in comparing relative efficiencies that the Al content of the PAC used was just over double that of Aluminoferric so it is not surprising that only half as much was required; the product currently available in the U.K. in liquid form is stated to contain only 7.3% Al_2O_3. A principal advantage of PAC was considered to be speed of floc formation as compared with alum and the fact that low temperatures did not affect it. Furthermore, in pilot upflow sedimentation tanks the use of PAC gave much more stable and well defined blankets than did alum even though the sludge density was only about half that of an alum sludge blanket under the same conditions. It would appear that the difference in behaviour is related to the physical structure of the floc. The PAC blanket looks more porous than the alum blanket; it is an easy matter to distinguish between the two simply from their appearance. This difference in blanket density is reflected in the volumes of sludge produced. For equivalent doses, in terms of Al, PAC produces approximately twice the volume of sludge as does alum, a finding not previously reported.

The uncertainty, at the time of carrying out this work, about supplies of PAC in the U.K., precluded any firm commitment to its use in new works. Nevertheless it is viewed favourably and there is provision for its adoption should it become available at a competitive price.

FILTRATION

It has been noted already that the Company operates slow sand and pressure as well as rapid gravity filters. Brief mention will be made of the first two types but the main content of this section will concern the rapid gravity filters.

The present group of seven slow sand filters was constructed in 1897. For many years, cleaning of these was effected by removing, washing and respreading the top inch or so of sand, the bed being loosened by forking at the end of this process.

Difficulties were experienced from time to time due to excessive clogging by algal organisms both in the applied water and growing in situ on the beds. Maintenance of reasonably constant output could only be achieved by more frequent cleaning which added enormously to labour costs. This situation was met by making the total filtering area a variable; that is to say when filtering conditions were good some of the beds, after cleaning, were held in reserve so as to build up a bank of clean filters ready to be brought into use to cope with the less favourable conditions. Coupled with this a shock dose of copper sulphate was applied in turn to the beds, one bed being treated per day; at no time was copper detected in the filtered water. By such means constant output could be maintained at all times without the need for overtime working.

As is usually the case in applying peaty waters to slow sand filters colour removal is generally no better than about 50%, giving an average for the filtered water of 25^{o} H. The filtered water is treated therefore with a moderately high chlorine dose generally in the region of 3 mg/l and after about 2 hours contact dechlorinated to the normal outgoing residual. Chlorination at this level effects further colour removal giving a finished water of around 10^{o}H.

Further contact with chlorine could if required be provided by utilising the time available in delivery mains but it has been found that allowing the residual chlorine to dissipate itself by long contact invariably leaves a taste. Short contact with dechlorination avoids this and bearing in mind the problems of chlororganics from humic acids in peaty waters, discussed later, this must remain for the present the preferred mode of application. It may have to be reviewed in the light of recent developments in the carcinogenicity problem associated with chlorination of peaty waters.

The continued use of these filters was examined early in 1974 and for mainly economic reasons, it was decided that a substantial life lay ahead for them provided cleaning was modernised. For the small capital outlay of £10,000, a hydro cyclone, belt conveyor and small scraper loader were purchased. All three items are mobile and can be moved between filters and indeed to other locations. The full depth of sand from each filter in turn was removed and washed and now, conventional scraping, washing and stock-piling followed by resanding when the overall depth falls to 0.3m. is carried out. Only four men are employed on cleaning duties and since chemical costs are low (superchlorination and dechlorination only) and energy costs minimal, these filters produce the cheapest and, being independent of power supplies, the most reliable water in the Company. The filters are operated at 0.15m. per hour and run for some 7 weeks between cleanings.

Rapid gravity filters are operated at Henderson Filters, Gunnerton and at the Warkworth Works of the Coquet Water Board. The filters at each of these plants are similar, having been constructed in 1955, 1960 and 1962 respectively. The filters are divided by a central washwater channel, the tops of the walls of which form weirs for side discharge of washwater from the beds. Beneath this channel is a duct into whose walls are built the ends of A.C. lateral pipes, perforated top and bottom. These collect filtered water and also convey scouring air and washwater during the cleaning process; filter rates vary between 1.0 and 1.3 mm/s.

Early problems with these filters concerned the development of "dead" patches during air scour and ultimately cracking of the bed. After much work the problem was traced to poor distribution of air, which was simply admitted at one end of the central channel. Some laterals received so much air that the gravel was disturbed, allowing sand to enter the underdrains thus further worsening the problem. The simple expedient of extending the air main over the length of the filter, capping this and perforating it along its invert effected a complete cure.

With the advent of anthracite as a filter medium alterations were carried out to two filters at Henderson Works in 1965. Results were extremely encouraging, filter rates being doubled, with neither loss of quality nor reduction in filter run time.

By 1971, designs for the proposed new treatment works were under detailed consideration. At the same time, policy concerning the future of Henderson Filters was under review and a decision was taken to continue the process of conversion to dual media, first to uprate the plant and second to compensate for the mediocre sedimentation tank at this works. The decision on Henderson gave the opportunity to put into practice the new filter design for Horsley. The left hand portion of fig.6 shows details of the first filter built to the new design and commissioned in December 1971. Within the existing filter structure, false floors were constructed, consisting of precast concrete panels having polystyrene nozzles set in on a 0.2m. grid. Media consisted of 0.6m. of N.C.B. No.2 grade anthracite over 0.3m. of 16/30 sand resting direct on the precast floor. In assessing washwater and air scour rates, design recommendations published by the (then) Water Research Association were taken into account and figures of 7.62mm. per second rise rate and 6.35 mm/s free air were used, this latter being all that the existing plant could provide.

Despite meticulous levelling of nozzles, air distribution upon first blowing without media in place was not even but slot length adjustment of the nozzle tail pipes in the affected areas cured this. It should be pointed out that air entered the void below the suspended floors through ports in the walls of the central duct and that those nozzles which had required attention were at the edge of the filter adjacent to the central duct. The filter itself gave (and continues to give) first class results and sampling of the media has shown no mixing of sand and anthracite.

A second filter was converted some 12 months later, the only difference being that air distribution was by means of a perforated ring main under the false floors; this is illustrated in the right hand part of fig.6(a). Again tail pipe slot adjustment proved necessary, this time to the central two rows directly above the air main.

It was clear that further work was required on air distribution and accordingly, a model filter was constructed using one precast floor section of the type used in reconstructing the filters. A glass panel was incorporated on one side and the model in effect formed a complete "slice" of one side of a full scale filter.

The reason for the disturbed nozzle performance was soon evident, in that violent turbulence occurred where the scouring air broke surface above the distributing main; this is shown in fig.6(c). Various expedients were tried before the ultimate solution, also illustrated in fig.6(c), was developed. This last system was used on the remaining two filters to be converted and has proved completely effective.

What had evolved by this time was a highly satisfactory filter, simple and inexpensive to construct. However, early in 1973 work began on refinement of the washing cycle. It was felt that the side weir disposal of washwater could be improved upon and experiments with washwater troughs have shown savings in washwater quantities. These have been installed on the last filter to be converted; a "secondary lift" system has also been incorporated. This latter consists of a grid of injection nozzles suspended above the expansion level of the media during washing. Air or water can be injected to maintain the vertical velocity of the washwater which otherwise falls on emerging from the expanded bed. Tests are still proceeding on this system to evaluate the benefit in reduced overall washwater volume in terms of secondary lift costs. Early problems with nozzle blockage have been overcome.

A refined version of these converted filters, shown in fig.6(b), has been adopted for the new Horsley Works and commissioning of these is imminent.

Filter control will be covered later in the paper.

DISINFECTION

In 1943 breakpoint chlorination was first applied in the U.K. by one of the Authors who also explored the chemistry involved and presented the first explanation of the phenomenon. This was made possible by the development of suitable techniques for the differential analysis of the free chlorine and the various combined chlorine compounds produced. That work formed the basis of the DPD residual chlorine tests now standard in most countries.

While free chlorine, especially that proportion existing in the form of hypochlorous acid, is now accepted as by far the most active agent for rapid disinfection, the use of the slower chloramine as a disinfectant is still widely practised where adequate contact times are available. In some cases free residual chlorination is applied through the treatment plant with conversion, by the addition of ammonia, to the more persistent chloramines prior to discharge thus providing some safeguard against adventitious pollution in the distribution system.

Consideration of such risks, especially those associated with open service reservoirs, led to the adoption at Newcastle in 1939 of ammoniation in conjunction with chlorination so as to maintain combined chlorine residuals in distribution which, coupled with regular bacteriological sampling, gave the necessary control over water quality. Following the covering of the Company's service reservoirs, it was decided to discontinue ammonia-chlorine treatment and the system at present in use is to chlorinate to a free chlorine residual of about 0.3 mg/l leaving the works. Whilst this gradually dissipates in supply with possibly less than 0.1 mg/l in peripheral areas, maintenance of bacterial quality has presented no problem.

In the ordinary way the Company would have continued along the same lines in the application of chlorine at new works with prechlorination at river abstraction schemes for maximum contact time through the plant and terminal chlorination as a general precautionary treatment. It has become necessary in the light of recent reports on the possible formation of chloroform and other trihalomethanes as by-products of water chlorination, to reconsider the situation. This applies especially where higher doses of chlorine with long contact are applied for colour removal, since it appears well established that naturally occurring constituents of peaty organic matter, such as humic acid, are precursors of haloforms especially chloroform. The carcinogenicity of chloroform has now been acknowledged by the U.S. Environmental Protection Agency who are urging that modified treatment practices be adopted to minimise chloroform formation from the organic materials found in natural and polluted waters.

It has been demonstrated, and recently confirmed by American workers, that the normally slow acting chloramines, which do not form chloroform, can be activated by adding small amounts of iodide to the water although the practicalities of this approach require further investigation.

While the position remains that there is no generally acceptable substitute for chlorine in water disinfection, especially where active residuals require to be maintained for a period, there is no doubt that increased consideration will be given to ozone, chlorine dioxide or even activated chloramine if such becomes available. In addition, mixed treatments, such as for example, chlorine plus chlorine dioxide, ozone plus chlorine, ozone with chlorine plus chlorine dioxide are likely to receive more attention and in addition, selection of points of application will require further thought. Shortening of prechlorination contact periods or applying the chlorine at a later stage of treatment, for instance after coagulation and sedimentation, can result in substantially reduced chloroform production.

There appear to be two general approaches to the problem from a treatment viewpoint. First, to reduce by improved or modified pretreatment prior to chlorination, the level of organic pollutants acting as precursers of the chlororganics. Second, to use other disinfectants in conjunction with chlorine so as to enable chlorine doses and contact times to be reduced. A favoured approach in attempting to achieve the first objective is granular activated carbon adsorption. The indications are that using activated carbon in powder form would require much higher doses than ordinarily used in water treatment.

Chlorine dioxide treatment, although more costly than chlorination, appears not to produce haloforms when prepared free of chlorine. As normally produced for water treatment by reacting sodium chlorite with chlorine, some excess of chlorine remains. Results indicate that formation of haloforms can then occur with these mixed residuals but at lower concentration than would be produced from an equivalent amount of chlorine alone. Use of chlorine dioxide can lead to the presence of trace amounts of chlorite either because of incomplete conversion or because of reversion in the treated water, bearing in mind that chlorite is the first reduction product of chlorine dioxide. Fears have been expressed from time to time of the possible toxicity of chlorite. It is understood that the preliminary indications of work so far carried out suggest that its toxicity is about the same as that of nitrite.

The attention now being paid in several countries to the desirability of modifying disinfection practices, particularly in the direction of mixed treatments by chlorine, chlorine dioxide and ozone has highlighted the importance of having suitable differential tests for all types of mixed residuals. Only the DPD test, as developed at Newcastle, offers these analytical facilities. The range covered includes free and combined chlorine compounds, chlorine dioxide and chlorite, bromine and bromamines, iodine and ozone, thus meeting all requirements for control testing.

SLUDGE TREATMENT AND DISPOSAL

For the past 50 years, the coagulant used at the rapid filter plants at Newcastle has been alum. More recently, coagulant and filter aids have been introduced and other coagulants such as iron and PAC have been investigated. In the field of sludge treatment and disposal the work to date has been almost entirely concerned with alum sludge.

The initial work on the application to waterworks sludge of such processes as heat treatment (the "Porteous" process) and freeze-drying as aids to rapid dewatering was carried out at Newcastle. Because of the evident problems of converting from pilot to large scale operation no further work on such pretreatments was carried out. Subsequent attempts were made elsewhere to operate large scale sludge dewatering by freeze-drying but operating difficulties led to the eventual abandonment of the process.

In attempting to recover aluminium sulphate from waste sludge two lines of investigation were followed (a) drying, roasting and acid extraction and (b) acid treatment of the wet sludge and separation from insoluble residues. There remain some interesting possibilities for future work but, in general, it has been concluded from recent pilot plant work carried out at the design stage of the new Horsley Treatment Works that the only practicable means of sludge dewatering and disposal at the present time is that of filter-pressing after appropriate chemical conditioning. The process is applicable to both alum and iron sludges. It appears from the Company's pilot plant work that PAC sludge is likely also to be amenable to such treatment although pressing times may be longer. In this recent work, centrifuging trials were carried out and whilst reasonable dewatering was achieved, the resulting concentrate remained basically a liquid, which on exposure to rain rapidly thinned. Pressure filter cake has been found to be much more resistant to wet weather.

MONITORING AND CONTROL SYSTEMS

The standard routine control testing of works operation at all the Company's major treatment plants is based on 4-hourly sampling by the operators, supplemented by daily examinations of both works and distribution samples in the laboratory.

Four-hourly works tests include residual chlorine, fluoride where fluoridation is practised, coagulation tests and examination for colour and turbidity.

Daily laboratory examination of works samples serves three purposes:

(a) to control chemical treatment and plant operation - this involves testing for residual free and combined chlorine, residual alum, pH, jar tests for coagulation, fluoride and fluoride solutions.

(b) to check the physical quality of the finished water, that is colour, turbidity and taste.

(c) to ensure that bacteriological quality is satisfactory.

Turning now to monitoring systems in more detail, the most elegant solution to any engineering problem results generally from the best compromise between often conflicting criteria. Where one of the more influential of these is labour cost, then the best solution is likely to be valid only at a particular time. In the present period of sharp wage and price inflation, it is particularly difficult to make a value judgement as to how far to go with automatic monitoring and control of filter plants.

The Company's philosophy has always been the pursuit of simplicity. Thus where it was considered desirable for a plant to be manned continuously - such as the Warkworth Works, which operates on direct river abstraction - there was little to be gained from substantial automation. The corollary to continuous manning is that it is better to give the operator something to do than have him seated inactive in front of a monitor desk. Not only cost, but also availability of labour must be considered; thus the correct solution for the North East of England, where manpower has been relatively plentiful in the past and seems likely to remain so, may not be appropriate to the South East.

There is the additional problem that as simple "hard wired" switching and control systems give way to those dependent on sophisticated electronic data transmission, process computers, etc., so a much higher level of technical expertise in maintenance and repair is involved and almost certainly the resulting systems will be less reliable. The problems of remoteness from the manufacturer's service engineer and the alarming rate at which obsolescence sets in also require to be considered in a water treatment works which, unlike an industrial process plant, has a relatively long life expectancy.

Considering filter operation first, the Company's existing rapid gravity filters all depend on outlet flow controllers set to maintain constant filter rates. These are of module type and their only disadvantage has been lack of capacity when filters have been uprated.

For the new Horsley works, the equal loading system has been adopted. Each filter has an inlet weir fed from a common inlet channel, all weir cills being at the same level; penstocks are provided to shut off the weir apertures during filter washes. On the outlet side of the filter, a butterfly valve is included for isolation during washing, although an adjustable intermediate position can be used during restart after the washing cycle. The filter outlet pipe is so arranged as to prevent cavitation in the filter bed. Thus each filter receives an equal share of influent, flows being redistributed automatically and evenly when a filter is isolated for washing. Water level in each filter rises as the bed becomes dirty and washing is initiated after a predetermined level has been reached, after a pre-set time interval or on excessive effluent turbidity. There is an extra capital cost in that the filter tank requires to be slightly deeper than a conventional filter with effluent flow control, but this is balanced by reduced control equipment costs. From the operational point of view the filter has obvious simplicity and should be largely maintenance free.

One of the less satisfactory aspects of the Company's existing plants is the amount of manual effort required in such operations as unloading and subsequent handling of alum blocks, chlorine drums or cylinders and bagged chemicals. National surveys have shown that strains, particularly to the back, constitute one of the most common and difficult to treat industrial injuries. No new works should rely on manual "humping" and at the new Horsley plant, all chemicals are delivered direct to storage by bulk road vehicle or, as in the case of chlorine, suitable runway beams and hoists are provided.

Whereas there is every merit in reducing the amount of manual work required, the authors believe that there is not such a pressing need to reduce the amount of mental effort required on the part of the plant operator by excessive automation. The new Horsley works is a direct river abstraction plant (with emergency reservoir back-up) and is likely always to be manned - at least until some infallible means of automatic coagulant dose adjustment to changing river conditions is discovered. Concerning application of other chemicals, fully automatic monitoring and control of chlorine dosing has been selected, since not only is equipment for this well proven but also the vital contribution of chlorine to the treatment process justifies the extra expense and complication. To avoid excessive work when flow rate changes are made, proportional flow control of chemical dosing has been included. On the other hand, it was not felt necessary to afford minute by minute control over lime dosing for pH adjustment or of activated carbon dosing, which will be required only occasionally; manual setting of dose has been employed for these.

It is believed that the operator should be encouraged to visit the various sections of his plant during shift and therefore, although routine processes such as filter washing have been automated, some less frequently occurring operations remain under "local manual" control. Wherever possible, direct electrical valve operation has been used together with direct wiring and it is believed that reliability and ease of maintenance will benefit.

Further encouragement not to remain at the control desk has been given by provision of strategically placed local alarm monitor panels. These enable the operator to identify the location of and accept an alarm state, this latter action being recorded by print-out at the control desk; each satellite panel includes a telephone linked through the works PABX exchange to the outside lines.

Naturally, since the Company was laying down a plant the potential development of which would extend well into the next century, the full range of available control and monitoring equipment was investigated. Visual displays impress the visitor, but the provision of the computer to drive a V.D.U. would have more than doubled the cost of the entire control and monitoring system and the final scheme was based very much on the "need to know" rather than the "nice to have" principle. The control desk has been simplified as far as possible, there being no conventional dials and gauges. However, there is provision on the desk for digital displays of pressures, flows etc. on demand and two analogue recorders enable simultaneous recording of selected parameters covered by the system. All items of plant are under central supervision by means of a simple process control unit and automatic data logging is included, together with recording of alarm states. In addition, output flows are transmitted to the Company's central control room at Headquarters.

CONCLUSIONS

It is hoped that the strong influence of operational requirements on engineering and scientific advances has been illustrated. Some of the likely problems of the future have been touched upon and some idea of the Authors' design philosophy has been given. Advances in treatment methods have been considerable over the past two decades and most aspects of settlement, filtration and disinfection are well understood. On the chemical side, micro-pollutants seem likely to require much more attention as demands on surface water sources grow. Regenerative granular activated carbon filters are likely to be used increasingly to counter these pollutants and may provide at the same time sufficient barrier as to obviate the need for expensive bankside storage.

Quality requirements will clearly become more stringent thus placing even more emphasis on the sensitivity, accuracy and reliability of testing methods, the development of which has featured prominently in the Company's research work.

The Authors believe in keeping plant as simple as possible as will have been seen from the description of the new Horsley works. In particular, they have tried to avoid processes and systems which require high energy inputs and which rely on mechanical equipment. As far as plant operation and control is concerned, they believe that much development remains to be done to make electronic software reliable and meanwhile they place more reliance on trained plant operators than on fully automated plant control.

The Company's management has always encouraged initiative in solving problems and developing new techniques. It is believed that substantial benefits have accrued not only to the Company in terms of efficient and economical treatment plant but also to the staff involved whose job satisfaction and personal motivation has been enhanced.

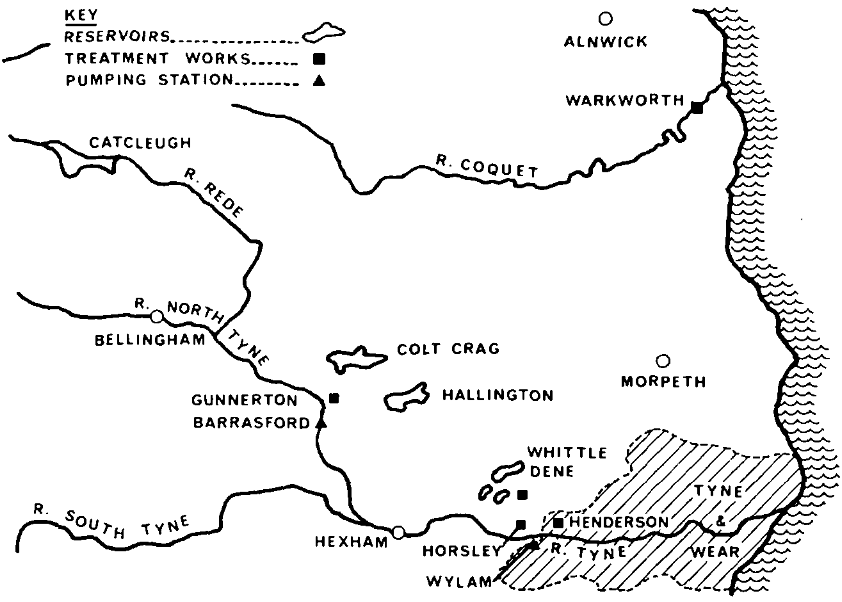

Figure 1 Principal Tyneside Sources

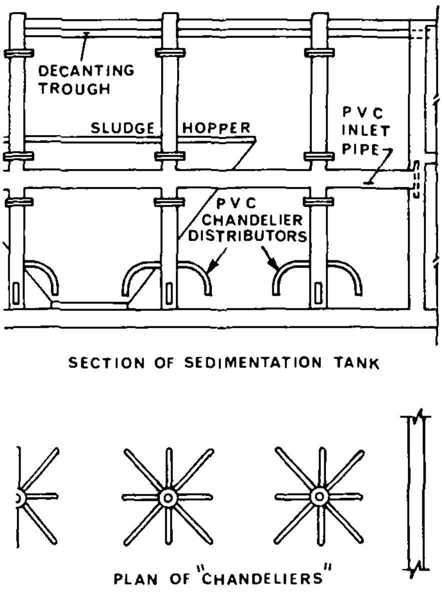

Figure 2 "Chandelier" distributor details

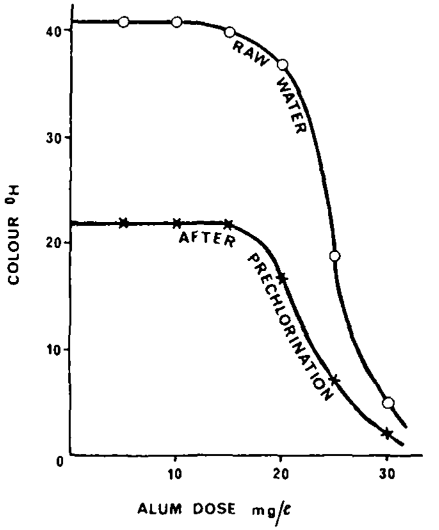

Figure 3 Colour coagulation curves–effect of prechlorination

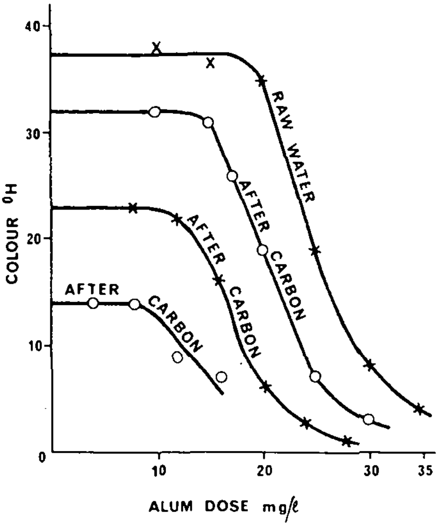

Figure 4 Colour coagulation curves – effect of activated carbon

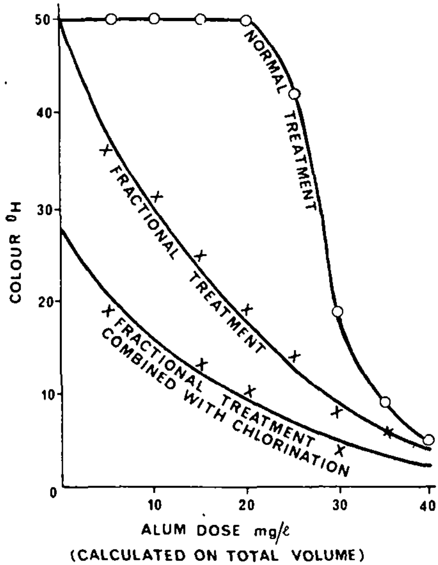

Figure 5 Colour coagulation curves – fractional alum and chlorination

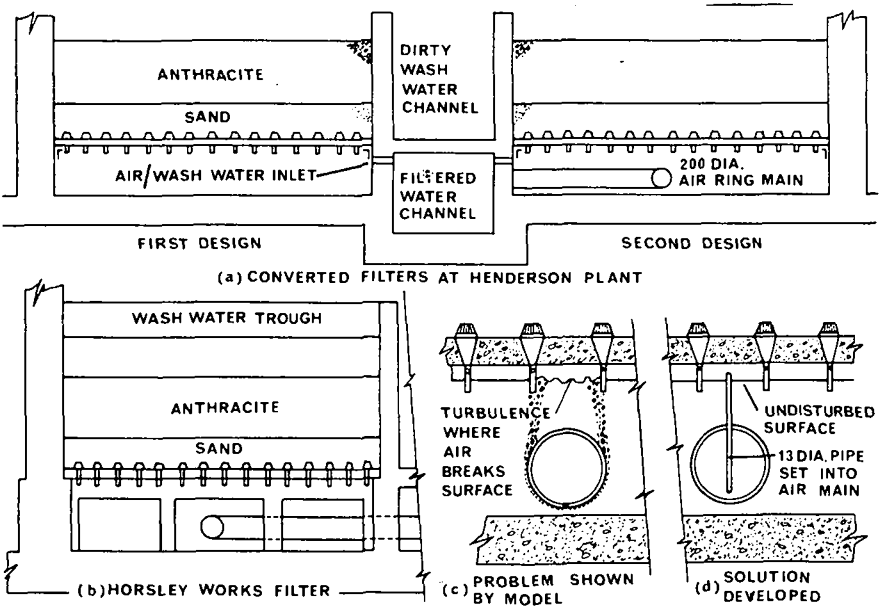

Figure 6 Details of filter design developments

DISCUSSION

Authors' Introduction

The authors said that, although the Symposium was primarily concerned with future developments, it would be appreciated that many aspects of water treatment had been with us a long time and were likely to continue for many years to provide the basic features of future waterworks design.

Filtration would certainly remain an essential stage of treatment, since it represented the final physical barrier in the purification process. Sedimentation was to be regarded as a pretreatment stage which might be partly or completely dispensed with where resulting loads on filters were acceptable. Where sedimentation was included, the two-stage process should be optimized for the best economic result.

The newer coagulant PAC offered interesting possibilities. The paper had referred to solutions of 7.3% concentration, but it should be noted that the product to be made available in the UK in liquid form would, it was understood, contain 10% Al_2O_3.

There was mention in the paper of the authors' review of a whole range of sedimentation tank types. One had to reconcile performance, operational simplicity, reliability, capital cost, and running cost. At one time the achievement of a minimum retention time was a design criterion; now, with the trend away from horizontal flow tanks, this was not used, upflow sedimentation tanks at least being judged now on surface loading. This was too narrow a view since to go blindly for maximum upflow rate could be to neglect the capital cost of providing the tank structure in the overall economic balance.

High upflow rates could be achieved, but not for nothing. Deep or complex construction might be needed, or large energy inputs, in some cases from quite complex mechanical plant, might be required. The best economic balance had to be struck between (say) the reliability of horizontal flow tanks and the higher performance of more complex designs which might require greater maintenance and operator attention.

Retention time might be expressed as tank volume divided by flow rate through the tank and had the dimension of "t". The reciprocal of this expression gave an expression having the dimension "t and the greater the numerical value of this the higher the efficiency of the tank would be, not in mere upflow rate but in terms of output per unit volume of tank provided.

The "chandelier" tanks developed at Newcastle showed up well if efficiency factors were compared for these and other proprietary tanks; they had the advantage of relatively shallow, simple rectangular, flat-bottom construction with no separate flocculation zones and no mechanical devices.

In the conclusions to the paper, reference had been made to the increasing stringency of water quality requirements that the future was likely to hold. A link between low turbidity and freedom from virol contamination had, of course, been postulated and turbidity monitoring of individual filters was employed at the Company's new works, linked to the filter washing cycle. Turbidity would not be the normal wash criterion, but high values would override the more usual criteria and initiate the washing cycle. Turbidity monitoring was of particular importance for dual media filters, which could hold a larger volume of suspended matter than conventional ones since this, coupled with higher rates of operation, could make the consequences of breakthrough more serious.

The current awareness of the chlorinated organics problem would probably lead to future modifications in disinfection procedures. One modification which seemed to be worth further study was that of chloramine activation, a suggestion one of the authors had put forward at the 1975 Symposium.*

Chloramine formation was of course related to the presence of ammonia. This was a chemical which even in the highest amounts likely to be encountered was not harmful to consumers. Nevertheless a limit was imposed (see Table 1, p. 17, Paper 2(a)), because it could interfere with chlorination by forming slow-acting chloramines. The reference made in 1975 to the possibilities of activating chloramine itself by the addition, for instance, of small amounts of potassium iodide had in fact been followed up in America by Kinman & Layton** on a new method of water disinfection which had given improved bacteriological treatment with a mixture of monochloramine and iodide ions.

In connexion with control testing and standards, the routine procedures mentioned in the paper were supplemented periodically by more detailed chemical and bacteriological analyses of works and distribution samples. There was generally a very close relation between quality in the distribution system and the operation of the treatment plant itself.

The importance of bacterial quality had been specially recognized in the UK by the publication of the official Report 71 "The bacteriological examination of water supplies" (current edition, 1969). The long-standing recommendation that chlorinated or otherwise disinfected waters should show no coliform bacteria in 100 ml had been retained in that edition, with the addition, for the first time, of recommended standards for water collected in the distribution system. In the previous edition (1956) it had been stated that laying down standards for distribution samples was difficult. If there were evidence of more than "minimal deterioration", it added, further investigation was required.

Because of the desirability of having a simple system of classification in reporting bacteriological results for distribution samples it had always been the practice of the Newcastle water and public health authorities to apply to such samples the table (reproduced here as Table II), given in the 1956 edition for non-chlorinated piped supplies.

TABLE II - Classification of Non-chlorinated Piped Supplies +

	Coliform Count per 100 ml.	E. coli count ++ per 100 ml.
Excellent	0	0
Satisfactory	1-3	0
Suspicious	4-10	0
Unsatisfactory	greater than 10	0 or more

+ Reproduced from Report 71 (1956 edition), "The bacteriological examination of water supplies", HMSO.

++ The presence of E. Coli immediately places the sample in class 4.

* I.W.E.S., 1975 Symposium on "Maintenance of Water Quality", Cambridge.

** Kinman, R.N., and Layton, R.F. 1976 *Journ. A.W.W.A.*, vol. 68, p. 298, "New method for water disinfection".

After representations made by the Newcastle and Gateshead Water Company, and no doubt by others, the need for officially approved standards for samples taken from the distribution system had eventually been accepted with the result that the following recommendations, which were still current, appeared in the 1969 edition:-

(1) Throughout any year 95% of samples should not contain any coliform organisms or E. coli in 100 ml.

(2) No sample should contain more than 10 coliform organisms per 100 ml.

(3) No sample should contain more than 2 E. coli per 100 ml.

(4) No sample should contain 1 or 2 E. coli per 100 ml in conjunction with a total coliform count of 3 or more per 100 ml.

(5) Coliform organisms should not be detectable in 100 ml of any two consecutive samples.

In applying these recommendations of Report 71 no distinction was to be drawn between chlorinated and non-chlorinated supplies where distribution samples were concerned.

As stated by the authors, their Company's philosophy had always been the pursuit of simplicity and to that end a simple classification based on the current recommendations for distribution samples was worked out and agreed with the local environmental health authorities. This was shown in Table III. One had only to look at Table I, Paper 2 (a), to appreciate that, in future developments, drinking water standards were likely to be extended to a much wider range of parameters than the coliforms. On the other hand, the National Interim Primary Drinking Water Regulations of the U.S.A. Environmental Protection Agency, as required under the United States Drinking Water Act of 1974, based maximum microbiological contaminant levels solely on coliform bacteria. Furthermore, there was provision for substituting chlorine residual monitoring for up to 75% of the required number of microbiological samples for the population served. For this purpose the use of the DPD method, as developed at Newcastle, had been made mandatory.

There would appear to be some divergence between the American and European approaches to future bacterial quality control in distribution. The former seemed to be more in line with the recommendations of the current UK Report 71 in which it was emphasized that it was far more important to examine a supply frequently by a simple test than occasionally by a more complicated test or series of tests.

On overall works monitoring and control, it was difficult to judge how far to go. Water treatment remained a comparatively simple process by comparison with industrial chemical manufacture and the more one automated, the more reliant one became on expensive electronic expertise. All too easily one could go beyond the competence of the plant operator to improvise in the event of breakdown, and in water treatment plants which were often remote this seemed bad practice. Moreover, the more advanced the electronics, the less reliable and flexible might the system become, and there was much to recommend simple hard-wired equipment. The authors had yet to be convinced of the cost effectiveness of having the works under complete process control, since operators were capable of making the routine decisions needed. Visual displays were highly impressive to visitors but their value in normal water treatment operation was less certain. At the Company's new Horsley works,

TABLE III - Newcastle Classification for Distribution Samples

(Coliform Organisms per 100 ml)

Absent	Present					
	2 or less		3 - 10			more than 10
	(whether or not E.coli) Take further sample		E. coli absent Take further sample		E.coli present	
	Coliforms absent	*Coliforms* present	*Coliforms* absent	*Coliforms* present		
S	S	U	S	U	U	U

S - Satisfactory U - Unsatisfactory

In the event of a check sample being required, the next routine sample serves as the check sample where samples are taken regularly at weekly or shorter intervals.

the computer needed to drive a visual display unit would have more than doubled the cost of the entire control system.

Finally, the authors did not believe that the plant operator should be encouraged to sit behind a control desk watching displays of coloured lights. No matter how advanced the automation, pipe joints still developed leaks, pump bearings still disintegrated, and other maintenance work still had to be carried out. The proper place for the operator was with his plant and he should be given every encouragement to visit all parts of the works.

Verbal Discussion

Dr. R.F. PACKHAM (Water Research Centre), opening the discussion, said that the paper showed clearly how the Newcastle and Gateshead Water Company had updated, improved, and adapted its treatment plant to meet new requirements at the same time avoiding innovation merely for its own sake. Many new treatment processes had been evaluated, modified, taken up or rejected. New designs had evolved to meet local requirements and the performance of these had bred confidence to such a degree that when faced with major new works the Company could, after looking at what others had to offer, find no reason for departing from its own well tried approach. There was much in the paper for all sectors of the water industry to digest, but he was sure that the authors would be the first to agree that their solutions to problems were not necessarily of universal application.

Referring to the system of coagulant dosing, described in the paper as "fractional treatment", he considered the term "partial treatment" to be more apt because a considerable proportion of the raw water apparently received no coagulant. The finding that colour was removed from uncoagulated water by the accumulated floc on the filters contrasted with experience at the Water Research Centre, but the discrepancy might reflect differences in the methods used for measuring organic colour. At Medmenham samples were always membrane filtered prior to colour measurement. He asked if the treatment led to considerable pH changes or fluctuations in residual aluminium. Referring to the method of dose control, he asked if rapidly changing raw water quality was experienced and whether this necessitated any modification to the normal procedure described.

On the whole the plant rating at Newcastle seemed fairly conservative, but he deplored plants designed to operate continuously at or near the limit of their performance. Where this had to be done it was essential to compensate for the reduced safety margin by more comprehensive monitoring of performance.

Rather little had been said in the paper about the treatment of polluted sources or sources susceptible to accidental contamination. There would, in the future, be a much greater use of granular activated carbon treatment for such sources. If chloroform in water became an issue in the UK coagulation rather than carbon would be applied for the removal of chloroform precursor in view of the high cost of long contact time granular activated carbon treatment.

Many water authorities had numerous small sources of supply which were likely to remain important for some time. He asked if Newcastle had this problem at all and what their approach to treatment was in such cases. In particular, were they more favourably disposed to automation for small sources?

Mr. R.A. PEPPER (Sunderland and South Shields Water Company) said that the theme of the Symposium was "development", and in this the three reiterative stages of experimentation, evolution, and refinement were essential until techniques were sufficiently accepted for general implementation.

Whilst the authors had been following these stages so successfully in developing the flat-bottomed sedimentation tanks, his own Company had continued to use the more conventional hopper-bottomed classification tanks.

Improvements in the chemistry of treatment, and the introduction of anthracite in place of some sand in the filters, had resulted in the uprating of the Mosswood works and outputs of 28-30 mgd could be obtained through the 27 clarification tanks and 12 filters, originally expected to cope with only 23 mgd.

A common problem related to the handling of sludge and the perfect solution had yet to be found. A system of spray irrigation had evolved at Mosswood. Chlorinated copperas sludge was conditioned with a poly-electrolyte and settled in hopper-bottomed tanks resulting in a thickened sludge at 2.0% (w/w).

This was pumped via agricultural "rain-guns" on to a disposal site under-drained at 7-yd intervals. In rotation sub-areas were ploughed, left fallow over winter, reconditioned in spring, the pH adjusted with lime, fertilized, and seeded with grass, resulting in land with good drainage characteristics and a reasonable growth of grass on which grazing was being allowed, experimentally.

At a new works at Lumley water would be obtained by direct intake from the rivor Wear. There was no bankside storage. Although the Wear was a Class 1, clean river, there were many effluent discharges, and variations in water quality were to be expected. A water quality monitoring station was being constructed some 2½ miles upstream of the intake. This would be unattended, but would monitor continuously the levels of ammonia, turbidity, dissolved oxygen, temperature and total organic carbon in the water. Biological monitoring was also anticipated. Data would be continuously transmitted by telemetry to, and assessed on, a small industrial computer at the treatment works. Initially, this would give information and warning only, but eventually it was intended to use the computer for process control and optimization in the treatment process. Progress would inevitably take time: the reiterative stages already referred to were essential and could not be avoided so as to establish appropriate chemical and biological parameters, ensure that they were being measured accurately, and to prove the reliability of sensors under field conditions.

Thus it might be years before direct loop control of at least some part of the treatment at Lumley was ever achieved. The trained plant operator and works chemist would remain essential; there was no suggestion that either would be replaced. But the continuous monitoring of the water quality and treatment, the assessment of significant variations and rapid indications of possible alternative actions by a process control computer offered considerable potential improvements over the traditional intermittent manual examination and adjustment.

A small pilot biological pretreatment plant had been set up and if results were encouraging, arrangements could be made to convert some of the hopper-bottomed clarification tanks for full-scale use, with possible reduction in chemical demands. At a time when the use of some chemicals was being re-examined - and the authors had drawn attention to this - then the "natural" processes of biological pretreatment appeared to be attractive.

Mr. J.A. WEBSTER (Strathclyde Regional Council) emphasized the importance, when considering operational aspects, of station operators being suitably selected and trained and of the equipment provided being regularly serviced to allow a plant to function efficiently. Operational aspects related to the design of the plant to allow ease of operation and maintenance to meet the desired quality of final water.

The paper related only to the works of the Newcastle and Gateshead Water Company but, of course, there were many stations in remote locations which required to be under the direct control of the trained operators. This aspect should be borne in mind at the design stage, especially with regard to the incorporation of factors relating to dosing for optimum coagulation conditions with, where possible and applicable, a visual indication of the rates of flow of chemical solutions.

The paper reviewed the development of a flat-bottomed vertical-flow sedimentation tank with the incorporation of a chandelier system for distribution of the water. It was desirable to prevent settlement of sludge in static zones at the bottom of the tank, unless provision had been made for its withdrawal during the operation of the tank. He asked how often the tanks required to be cleaned out and if a similar design would be considered suitable for a water with an algal bloom necessitating prechlorination.

What was the effect of a pulsating action in the blanket, occasioned by varying rate of flow on the residual alum carried to the filters. It appeared from tests carried out on a plant operating in this manner in Scotland, that the system did allow a reduction in floc load to the filters.

In connexion with the operation of the vertical-flow tanks, would the authors indicate the desired amount of sludge drawn off to control the blanket expressed as a percentage of the input and the average percentage solids in the sludge effluent? It would seem that in future more attention would be given to the flat-bottomed vertical flow tank.

Regarding pretreatment, he referred to the effect which chlorine added to the raw water might have on the reduction of alum required for optimum coagulation and asked what was the amount of prechlorine used (Fig. 3) which appeared to allow a reduction of 4ppm of alum for a colour of 5^{o} hazen with presumably a low aluminium residual.

He also asked what investigations were carried out on the use of cationic polyelectrolytes, polyamines, to replace part or all of the alum dose.

It was noted that practical treatment enabled a saving of one-half to two-thirds of the coagulant cost giving a finished water not noticeably different in terms of colour and turbidity. Were the authors recommending this treatment as a design feature for consideration which might meet the likely requirements of the EEC standards for final water?

When dealing with peaty waters, as the authors stated, slow sand filters might not reduce the colour to an acceptable standard without further treatment, and problems might arise from algal blooms in the raw water. Had the use of microstrainers been considered?

The paper indicated that extensive consideration had been given to design aspects of rapid gravity filters. Would the authors advocate the advisability of pilot filter tests to take into account the floc leading to the filters and the characteristics of the floc particles to allow the most efficient method of filtration to be achieved?

The secondary lift system under trial in the washing cycle was interesting. Were pilot plant tests carried out, and if so, what was the assessed saving in washwater?

Operational aspects concerning sludge treatment and disposal depended on the choice of process, and the object was to install a workable system at an acceptable capital and running cost. Whilst filter pressing was a reliable method of processing many waterworks sludges, the recovery of alum and the refrigeration process, in operation at a works in Scotland, was one which led to a saving in chemical costs and a reduction in quantity of sludge for treatment and disposal in a very acceptable form.

It was noted that four-hourly sampling was carried out by the operators for coagulation tests. Presumably this was found to be desirable due to the changing quality of the raw water.

He agreed with the Company's philosophy of simplicity in design to make it easier for the operator to understand the working of the process. Emphasis must be given to accurate control of the chemicals required for the water being treated. He himself regarded it as necessary to run a modern station continuously only if the chemical control aspect necessitated this.

With automatic plant control at a station there was still a need for the trained plant operator to devote attention to the key operations of the water and sludge treatment processes.

Mr. M.A. HILSON (North West Water Authority) referred to the fact that the development of fractional alum treatment took place when the Company's pressure filter plants were becoming overloaded. He presumed that this development was inspired by a desire or a need to avoid capital expenditure on additional treatment plant. The adoption of this form of treatment also showed a saving in revenue expenditure and therefore became a deliberate policy.

Whilst fractional alum treatment might give results which were acceptable to the Company, he felt that it was certainly not of universal application. Fractional alum treatment only coagulated efficiently that portion of the raw water that had been dosed and if a water contained undesirable constituents which required coagulation for their removal then that coagulation must be carried out correctly.

It was doubtful whether such a treatment system should be advocated in a Symposium on future developments, in view of the increasing concern with the quality of drinking water and the development of sources of supply starting with raw water of doubtful purity from lowland rivers.

<u>Written Discussion</u>

Dr. P.E. HALE (GKN Birwelco Ltd) endorsed the authors' comments on the importance of simple non-mechanical designs, flexible plants, and the necessity for operator job satisfaction. These were goals that we should all seek to achieve.

He was interested in the references to coagulation and sedimentation, especially the flat-bottomed clarifiers with multiple inlet systems, since this was similar to work he had been involved with in 1968 as a design engineer at Medway Water Board, in Kent. During the design of the Burham treatment works (part of the river Medway scheme designed by the Board) flat-bottomed clarifiers were investigated as an alternative to the conventional hoppers. Three tanks were found in existance (1) the Warkworth tanks, (2) Arnfield works of Manchester Corporation, which were trough-bottomed, 2.9m deep with a rated upflow of 1.26 m/hr, and (3) some modified coke beds at the Hazards Green works, near Bexhill, 2.4m deep and rated at 0.98m/hr, these were subsequently replaced with hoppers presumably due to their shallow depth and low rating.

The available data were examined and the Burham layout finalized as six flat-bottomed clarifiers, four square plant hopper tanks, and two circular plan hoppers. The clarifiers followed a flexible dual inlet arrangement for chemical dosing and retention, and were in two discrete streams to allow for comparative tests to establish the most efficient tanks and chemical doses for future extensions. The final flat-bottomed design was for a tank 6m deep nominally rated at 1.55 m/hr but with a hydraulic capacity of 3.72 m/hr to take account of the increased efficiency in flow characteristics and possible improvements in future chemical treatment.

Following construction between April 1970 and December 1972, the first water went into service in January 1973. During that year the flat-bottomed clarifiers were generally run at about 2.2 m/hr and at one time a single tank was pushed up to 3.0 m/hr. This was not the maximum rating of the tank, but was the limit due to other constraints acting at that time. Alum dose rates were generally about 5 mg/l Al with clarified residuals generally less than 0.5 mg/l. During use the blankets were very stable with level top surfaces free from boiling and break-away and capable of being raised to within 300 mm of the launders without increasing flow carry-over. Unfortunately, there were flow metering problems at the time and no comparative work was done between tanks.

The run rate of 3.0 m/hr confirmed the authors' expectations for the Horsely tanks, and it would be interesting to have any preliminary results from this plant. What were the authors' opinions on the relationship between sludge draw-off (or blanket bleed if this was practiced), and the maximum flow rate that might be obtained in any clarifier, and what desludging arrangements had been incorporated at Horsley?

Mr. B.G. HARKER (Welsh National Water Development Authority) wrote that the authors were to be congratulated on a definitive statement on treatment, operation, and control but while it was obvious that much thought led to the design factors employed, the variations and improvements applied appeared to indicate that there was a strong element of trial and error. The success of the authors in producing efficient plants seemed more due to that inspired guess-work which was the sign of genius. The fact remained that there were few design concepts in water treatment which stated that "do so-and-so" and "such-and-such would happen". In other words, differences in raw waters must inevitably create random factors in design.

The authors referred to improvements in the operation of filters - he himself knew of anthracite filters (completed in 1973) which, while bearing all the apparent hall-marks of careful design, were most inefficient. Constructional errors of as little as 5 mm in floor level seriously affected air scour patterns; all the nozzles had to be replaced and air inlet channels had to be fitted with baffles on a "suck-it-and-see" basis. Other variable factors were sand thickness, anthracite thickness, grain size, filtration rates, wash rates, method of alum dosing, etc.

The above were cited to instance the art rather than the science involved in successful design. Even now, after three years, the operators had to run the filters by feel rather than rule for apparently identical filters could be well-behaved or rogues.

Another aspect of the treatment plant was worthy of mention. The raw water (of river origin) contained a silt which appeared to have some of the properties of a colloid - a fact that was not apparent at the pilot plant stage. The end effect on the resultant sludge only became obvious after settlement, thickening, and disposal into site lagoons at about 8% concentration. Here the sludge promptly turned into a thixotropic jelly which would neither drain nor dry. What text book offered advice in that situation?

However, having consulted the instructions on a tin of non-drip emulsion paint it was decided to give a good stir, the spoon in this case being a Hymac excavator. A few days' fairly haphazard churning and the sludge began to liquify and drain. A repeat session was necessary before the sludge could be excavated and spread to dry on about an acre of ground. It was estimated that the sludge would cover this at about 75 mm per annum. Some improvement had subsequently been achieved in sludge quality by the addition of polyelectrolite, but the difficulty was by no means overcome. Could the authors suggest a line of approach to the problem, since the present solution was hardly elegant?

Finally, he referred to centrifuging, which the authors had dismissed as ineffective. Yet, when applied to the above sludge straight from the thickeners, pilot centrifuging trials were completely successful, producing a firm "cake" which dried quickly and was unaffected by rain. This was a contradictory tale, which underlined the fact that there were few positive rules in water supply.

<u>Authors' Reply to Discussion</u>

The authors, in reply to Dr. Packham, agreed that their paper was not to be taken as presenting treatment methods of universal application. No two raw waters were identical, and methods must be adapted to suit particular requirements. It was hoped that the days when treatment plants were bought off the shelf had gone for good. The paper had attempted to emphasize the need for flexibility and original thought in approaching specific treatment problems.

Any judgement as to whether a particular treatment was "partial" or not could only be based on the degree of success achieved in attaining the desired treated water quality. For instance, operation of filters at very high rates or omission of a sedimentation stage were not necessarily to be regarded as partial treatments. On the particular point about colour measurement, the authors would not expect to find any significant discrepancy between Medmenham and Newcastle, since there were similarities in the techniques used for differential colour/turbidity measurement.

Regarding possible fluctuations in pH or residual alum, these did not occur where blending in the fractional treatment system took place before filtration. In pressure filter operation, the application of undosed raw water to a filter carrying adsorptive floc from a previous period of full alum dosing generally led to a detectable increase in residual alum but this being in the soluble form was free from the disadvantages of insoluble or colloidal residual alum.

Where rapidly changing raw water quality was encountered, chemical dose control presented no different a problem from that experienced elsewhere under similar conditions. The fractional pretreatment might require adjustment, but the ability to do this rapidly was of course an advantage of the process. It was agreed that this form of treatment, especially when applied to peaty waters, might along with others require to be reviewed should chloroform become an issue in the UK.

Mr. Hilson had raised doubts about the general application of fractional alum treatment. It would be appreciated, from what the authors had previously said, however, that anyone contemplating this or any other novel modification of conventional procedures, should ensure that the finished water met the desired quality criteria.

Mr. Pepper had described the system of sludge disposal by spray irrigation and subsequent cultivation as used by the Sunderland and South Shields Water Company at its Mosswood works and which would be used also at its new Lumley plant. The method had obvious attractions and no doubt the overall cost of the system relative to other methods had been evaluated. The Sunderland Company was fortunate in having been able to acquire the necessary land which would not have been possible at the new Horsley works at Newcastle because of extreme reluctance of the landowner to part with any but the absolute minimum site area and the high value placed thereon.

The river monitoring station described by Mr. Pepper was of considerable interest as an alternative to bankside storage which could, in some circumstances, lead to actual deterioration in water quality. No bankside storage was provided at Horsley, but the works could be fed from the nearby Whittle Dene group of reservoirs in the event of pollution or power failure at the river intake. Monitoring was included, not at an upstream station as in the Sunderland case, but at the intake. At present parameters were restricted to pH, turbidity, and level and these afforded advance warning to the plant operator of changing river conditions. A relationship of practical value between coagulant dose and various raw water parameters had been sought in vain not only at Newcastle but elsewhere; progress at Sunderland with the on-line process control computer would be watched therefore with great interest. The present "automatic" coagulant dosing described by the Japanese and consisting of comparing current data with a considerable volume of historic parameter values and corresponding coagulant doses stored in the memory of a computer seemed expensive, cumbersome, and inelegant; no doubt it worked, however!

Whether or not the biological pretreatment plant referred to by Mr. Pepper would work at all times in our cold north-eastern climate seemed to be questionable. Apart from the fact that biological processes were not always amenable to control, they were recognized as being rather temperature-sensitive and generally gave poorest results, for example in nitrification, when the need was greatest.

In supporting the authors' comments on training, servicing of equipment and flexibility both Mr. Webster and Dr. Hale raised a number of points concerning the operation of the "chandelier" clarifiers. The inlet distribution arrangement in the flat-bottomed tanks at Newcastle effectively minimized the build-up of static zones of settled sludge. The growing acceptance of this design suggested that these findings were supported by experience elsewhere. As a routine measure, wholesale cleaning was carried out about every 12 months.

Algal blooms in raw waters had not been troublesome at Newcastle, but where counts had occasionally been higher than usual the chandelier tanks had dealt satisfactorily with them. The authors had no first-hand experience of the pulsator system, but such developments were of great interest. The advantage which would be sought would be increased upflow rate rather than reduced floc load to filters.

The amount of sludge draw-off depended upon alum dose, raw water quality, and degree of floc removal from the applied water. The volume of the sludge withdrawn from the Newcastle tanks represented about 2% of the throughput, and its solids content would be between 0.05 and 0.1% w/v.

Mr. Webster, along with Dr. Packham, had raised the problems associated with small works. The Company operated a number of these throughout Northumberland, of which some were unmanned. Six small pressure filter plants with outputs of up to 0.45 tcmd were fed from a reservoir having peaty moorland water. These plants were rated conservatively and all equipment functioned without electricity using pressure hydraulics energized from the raw water main; effectively, therefore, the plants operated automatically. However, such automation was not regarded as a complete substitute for routine calls on a daily basis for sampling and plant inspection. A further small works having an output of about 6.8 tcmd was manned only during the day. Some of its dosing plant was electrically powered, but standby chlorination was available from a Chloros supply which cut in automatically on power failure.

Wherever possible, unmanned stations were being linked to the Company's central control room by means of automatic dial telephones or by battery-powered VHF radio transmitters linked to tape recorders having prerecorded messages.

The authors welcomed the contribution from Mr. Harker as further evidence of the need for a flexible approach in the development of water treatment processes. Furthermore, as he had indicated, even the best designs depended for their effectiveness on the integrity of the construction. As regards the sludge disposal problem, his success in centrifuging on a pilot scale would appear to offer a promising line of continuing investigation for the particular sludge he described. It had to be borne in mind that the quality of the separated liquor if disposed to a watercourse would require careful examination.

Sludges produced by coagulation generally acquired thixotropic properties at some stage of dewatering. It was necessary to decide in the light of the handling methods used whether or not the liquefaction resulting from stirring or churning was advantageous. As indicated, the authors favoured filter pressing, now thought to be of general application following developments in chemical conditioning, which conclusion agreed with that of the Joint Research Panel's final report on sludge disposal.* Although the Panel did not at that time recommend centrifuging for coagulant sludges, the authors hoped that this would not deter Mr. Harker from pursuing his own trials.

* *Journ. I.W.E.*, 1973, vol. 27, p. 399, "Disposal of waterworks sludge: final report of research panel no. 14".

1(b) OPERATIONAL ASPECTS: SEWAGE

H. V. Lee, B.Sc.*

INTRODUCTION

The methods at present used for the treatment of sewage are well tried and established. In order to look at possible future trends it is necessary to examine existing practices critically and objectively, and the formation of the Water Authorities should afford the opportunity to do this more effectively. The areas of treatment where improvements are required are usually fairly obvious. With increasing demands for more water and cleaner rivers it is no longer permissable to examine any plant in isolation, but it is necessary to consider all plants in the wider context of divisional and even regional requirements. Public awareness and interest is increasing, and the slightest problems with regard to odours and other nuisances all bring about numerous complaints. One requirement of fundamental importance is a closer liaison between the operator, scientist and designer. It is essential that plants are designed in such a way that they can be easily and efficiently operated. To achieve this the designer must take cognisance of the operator's views and the operator must be prepared to supply operational data about existing plants. Current economic and political trends will also influence design. It is only by this sort of close co-operation that existing short comings can be identified and attempts made to find remedies.

Transmission

Most treatment plants are designed to treat a particular dry weather flow, and most sewers constructed on the combined or partially separate systems have overflows which are designed to discharge to a stream all flows in excess of a multiple of dry weather flow. What is dry weather flow? There are many definitions, none of which is universally satisfactory. In an urban area the dry weather flow is usually defined as the flow after a certain number of days without rain, but excluding Saturday, Sunday or holidays, thus taking into account the workings of local industry. Whilst being appropriate for urban areas it is not suitable for rural or dormitory areas where peak flows can be expected at weekends. The use of any definition of dry weather flow is suspect during prolonged dry weather when the amount of infiltration water is reduced and when people conserve water by careful usage and by watering gardens with water already used for washing clothes and bathing. During the recent hot dry summer, flows arriving at some treatment plants were as low as 94 litres/head/day. A more useful and realistic figure would be the average daily flow. This is just what the name implies the average daily flow arriving for treatment, and provided the period used for the averaging is realistic, e.g., 12 months, variations due to climatic changes should not be too great. It must, however, never be forgotten that even in dry weather the rate of flow is not uniform. The normal diurnal variation can produce rates of flow considerably higher than the average. A knowledge of the magnitude of this peak is essential for optimum design and efficient operation.

It has been normal practice that, where treatment plants were designed

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for an ultimate population, construction was usually carried out in several stages. However, if pumping were involved the pumping station, pipework and pumps capable of dealing with the ultimate flow were usually installed in the first stage. Small rural works were designed without any storm treatment facilities and were constructed so that up to 6DWF would be given full biological treatment. These two factors mean that the pumps when operating, pump at a rate many times greater than the normal rate of flow of sewage. The result is a virtual tidal wave sweeping through the treatment plant followed by hours of standstill. As a consequence a poor effluent is produced and the plant usually gives rise to odour complaints. To quote a particular example a works with a flow of 920 cubic metres/day received flow at a low level and all flow had to be pumped. This particular plant had storm water treatment facilities and yet was constructed with pumps at the inlet capable of pumping at the rate of 12,960 cubic metres/day. Thus the whole of a day's flow was capable of being delivered in a little over 100 minutes pumping. The requirement is for either a pumping arrangement that will cater for variations in flow, i.e., a screw pump or for a system which allows easy interchange of pumps. This problem of fluctuations in flow caused by installed pumps is more frequently encountered on the smaller works. Medium sized and large plants are not so subject to these problems possibly because of the greater area drained and the increased length of the sewerage system.

Wide fluctuations in flow either caused by pumps or by the normal diurnal variations can cause treatment problems. Strength also varies and the product of flow and strength varies by a considerable amount. Numerous references in the literature refer to the need to balance flows to obtain a reasonably even dosing to the biological plant. All the methods in common use involve the utilisation of other plant, e.g., storm tanks. It is true to say that storm tanks are in general under utilised, but if used for balancing, the capacity available in times of storm will almost certainly be less than adequate and would result in an additional amount of pollution entering the receiving stream. The use of balancing would result in a more uniform rate of flow through the plant with a probable resulting increase in efficiency of biological plant. However, it has not been proved that the overall effect upon the river would be beneficial. The use of balancing would result in a greater quantity of effluent being discharged to the stream at night. The photosynthetic activity in the stream is at its lowest at this time and depletion of oxygen could result. A critical examination of the needs of the stream and the effect of the balanced flow on the stream needs to be carried out. If it is concluded that a need for balancing exists a simple reliable method specifically provided for the purpose, is required.

Increased standards of living have led to the installation of main drainage for many rural communities. One particular trend has been the construction of a regional treatment plant rather than several small plants. This type of scheme usually involves the sewering of more than one village and probably requires some pumping in the system.

The provision of such facilities should improve the living standards of the people but there can be a particularly serious adverse effect. From the very nature of the schemes the sewage takes a very considerable time to reach the treatment plants. In these circumstances the sewage turns septic and sulphides are produced which give rise to odours. After several complaints had been received about odours a thorough investigation of the sewerage systems serving the treatment plants in the division was carried out. It was concluded that there were in excess of three dozen sites which could give rise to septic conditions and hence produce complaints. Investigations were carried out on two methods of sulphide control, and equipment was installed to treat the flow in two rising mains. One method utilises hydrogen peroxide solution and the other sodium hypochlorite solution. The solution is injected into the rising main by metering pump whenever the main pumps are in operation. It is intended to operate these plants for a period of 12 months to assess the effectiveness of the systems and the operational costs. Sketches of the sewerage systems are shown.

The section of the system A which is being examined and treated with sodium hypochlorite solution is between points X and Y. This rising main is 4.000 metres long and has a capacity of approximately 32,400 litres. Electrical recordings of pump starts and periods of running indicated that approximately 25,900 litres were pumped each day. The average detention period in the main was therefore 30 hours. Very high sulphide levels have been recorded at point X. Complaints have been received from other areas of the system.

System B is different in that there are no really long mains. The problem here is stage pumping and long detention periods resulting primarily from the fact that the pumps are rated much higher than the flows. As a result pumping is intermittent and sewage stands for considerable periods in sumps. The section marked VW is under investigation and is being treated with hydrogen peroxide solution.

There are other methods of eliminating or preventing sulphide nuisance by air or oxygen injection. If it is decided to provide sewers in a situation where septicity could result the provision of a suitable method of control should be designed and provided at the same time.

Provision of first time rural sewerage schemes is expensive, and estimates in excess of £1,000 per house are now quite commonplace. In view of the high capital costs and the continuous expenditure that would be necessary to provide both chemicals and energy, the necessity and the desirability for the construction of such systems must be critically examined. The use of individual septic tanks has not given rise to serious pollution of the rivers or caused a danger to public health and the continued provision of such schemes, particularly in the present financial climate must be unlikely for a number of years.

The provision of several small plants would reduce the length of the sewerage systems, and possibly the cost, and result in the treatment of fresh rather than septic sewage. Data is available on small package plants and a greater use of reliable and simple plants might be advantageous. Another possibility is the application of the concept of the village septic tank. This would reduce even further the capital costs although the effluent quality might be suspect, which may or may not be a serious problem. Operating costs should not be too high provided that sludge removal was not done too frequently, say at yearly intervals. Village cesspools would be expensive.

It is obvious that alternatives are available and that a detailed cost analysis of the various possibilities would be required.

Preliminary Treatment

Of all the tasks carried out on a treatment plant the disposal of screenings is probably the most objectionable. On small rural works, serviced by mobile gangs, the provision of screens would cause numerous problems. It is essential in such a case that none of the equipment provided is susceptible

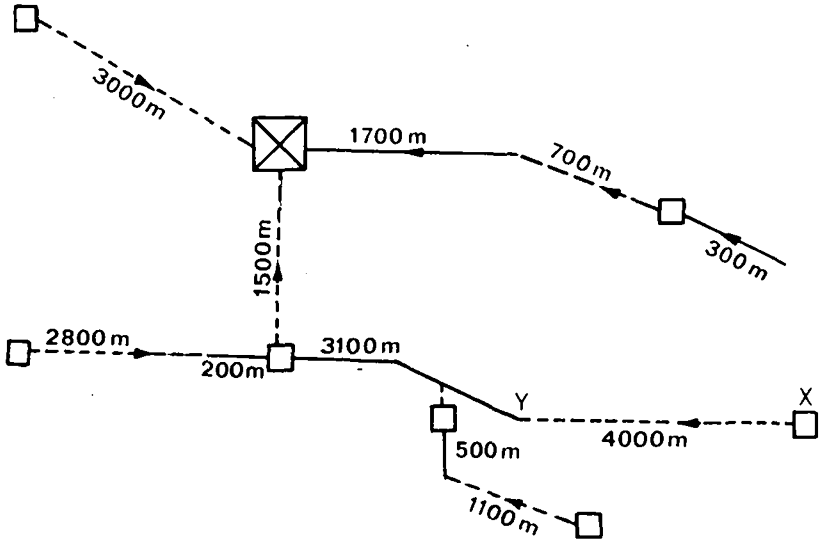

Figure 1 Sewerage System A

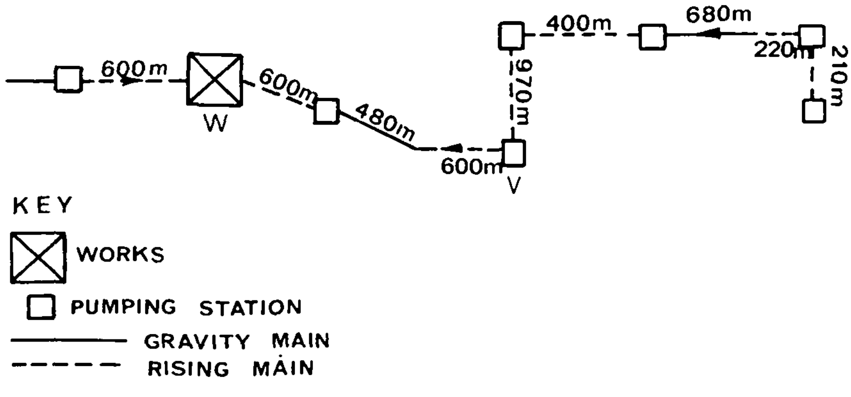

Figure 2 Sewerage System B

to blockages. The disposal of sludge from such plants to agricultural land can give rise to problems. Fields littered with plastic residues are unsightly and screens may be used with advantage to remove this material from sludge whereas screens at the inlet would be an embarrassment. Material which would normally be removed by detritors or similar plant is also disposed of with sludge from rural works. Metal objects such as wire and razor blades have been known to have been disposed of with sludge. If the disposal is to farmland, and in particular to pasture the consequences could be serious. The provision of simple grit channels would increase the labour involvement on these plants. It may well be that this extra cost is inevitable.

On the larger manned works, screens, disintegrators and comminutors are used. The problems associated with the disintegrated screenings matting together are well known. Attempts have been made to alleviate this by passing the screenings after disintegration back through the screens. This certainly improves the situation but does not completely cure the problem.

After going to the expense and trouble of removing screenings it does seem illogical to cut them up and return them to the flow. Plants for the baling of screenings, with a view to possible incineration, do not appear to have found universal popularity. The known reluctance of operators to accept new and relatively untried plant is understandable. Breakdown of equipment when installed on a full scale treatment plant is always a thing to be avoided if possible. Greater use of extended pilot plant trials is one possible answer.

If a suitable and reliable plant for the handling of screenings could be installed, the screening process could and should possibly be taken further. The use of fine drum screens to take out even more material would become increasingly attractive. The greater the amount of material that could be easily removed at this stage, the greater the benefit in the later stages of treatment.

Plant for the removal of grit on larger works is an essential to efficient operation. Such plant has been provided for a considerable number of years but problems do still occur. Grit is still deposited in channels, tanks and eventually digesters. Little or no information is available on methods of measuring the effectiveness of detritus removal, possibly because little is known of the quantities involved.

A particular problem on the larger works provided with equipment for the removal of both screenings and detritus is the excessive quantities to be handled in storm conditions after prolonged dry weather. It is a problem that does not appear to have an easy acceptable solution. The general requirement for treatment plants is for simplicity and reliability, and this is particularly the case in preliminary treatment equipment.

Sedimentation

Sedimentation tanks effect a considerable proportion of the purification carried out at any treatment plant and the basic process has changed little over the years. Considerable discussion has taken place in the past over the respective merits of rectangular and circular tanks. Choice of either kind is usually dictated by site conditions or by personal preference. On small plants the provision of scraping mechanisms cannot be justified and would generally be regarded as another item of machinery to require attention and possibly give trouble. The basic hopper bottom tank has given useful service and will continue to do so. Small plants require frequent visits from mobile gangs in order that desludging of the primary tanks can take place. The cost of providing labour for this work is high and is continually rising. There is a need for a simple reliable automatic method of desludging these tanks. Several proprietary methods are available ranging from those making use of simple timers to others incorporating some method of assessing sludge thickness. Trials of this type of equipment are being carried out at a treatment plant within the division, but the use of anything other than a simple timing mechanism on a small rural works is probably an over sophistication.

Tanks fitted with scrapers are an accepted part of medium and large plants. The remarks relating to automatic desludging on small plants are certainly applicable to other works that are not manned round the clock. Where for any reason it is necessary to provide continuous manning on a shift basis the installation of automatic desludging equipment is perhaps not essential. The operators must be given work to do and it must be work that they consider both satisfying and important. The use of a semi-automatic, remotely operated system using electrically operated valves and television scanning has proved both useful and acceptable.

Mention has already been made that the choice of either circular or rectangular tanks is usually a matter of personal preference. In general circular tanks are constructed with a shorter detention period than rectangular but the sludge withdrawn from rectangular tanks usually has a higher solids content. The sludge from circular tanks has usually to be consolidated before further treatment. Development of the circular tank by increasing hopper sizes and using scrapers intermittently may produce a sludge that does not require further dewatering. Elimination of the dewatering or consolidation process would be advantageous.

Greater consolidation of the sludge in the primary tanks would suggest that perhaps it would be possible to remove more solids by the use of chemicals. Use of chemicals was once quite widespread but gradually their use declined. Recently with the interest being shown in the physico-chemical processes the use of chemicals in the primary sedimentation process is receiving increased attention. There is no doubt that in certain circumstances greater purification can be achieved but the plant required for the efficient use of the chemicals should be provided. Perhaps the waste sludges from water purification could find a use on sewage treatment plants.

<u>Humus Settlement Tanks</u>

A very common type of humus tank constructed on many small rural works is the horizontal flow rectangular tank. Whilst it is almost universal practice to provide hydrostatic desludging in the case of primary tanks this is not so for humus tanks. To remove humus sludge from this type of tank it is necessary to drain completely and clean the tanks manually. The tank contents and the sludge are usually pumped to the works inlet. Deterioration of effluent quality often takes place because (a) a considerable proportion of the humus tank capacity is out of service and (b) a substantial increase in the rate of flow requiring treatment results from the pumping back of the tank contents. The situation is therefore unsatisfactory on two counts, (a) high labour requirements (b) deterioration in effluent quality.

The previous remarks about hopper bottomed primary tanks and simple reliable automatic desludging equipment apply to humus tanks as well as primary tanks.

The use of hopper bottomed tanks cannot be regarded as a cure for all ills. Rectangular tanks show a particular advantage over the hopper bottomed tanks when pebble bed clarifiers are to be installed. The clarifiers installed in rectangular tanks are much easier to clean and wash down than those in hopper bottomed tanks. Each particular situation needs to be individually examined before a choice of tank is made.

The automatic desludging of humus tanks by use of simple equipment must be a real possibility. The sludge from a humus tank, being more consistent in both quality and quantity than primary sludges, should be easily withdrawn by automatic means.

Biological Filtration

Significant process improvements are much more likely in the activated sludge process than with biological filtration. The use of the conventional methods of uprating filtration plants, i.e., recirculation or alternating double filtration, could be more widespread. The use of recirculation could also provide some balancing by increasing the dose rate at times of low flow. Its use on small rural plants would be an advantage. Some recirculation can usually be provided on existing plants by the continuous use of sludge return facilities. This has not been found completely satisfactory because the system was not designed for the purpose. To obtain consistently satisfactory results purpose built systems are required which do not result in the overloading of any individual unit.

Much has been written about the use of plastic media to increase the capacity of plants. There is no doubt that the use of a suitable media can result in increased loadings being achieved and the capacity of existing plants can be increased relatively cheaply. Care must be taken in the choice of plastic media. Some media is difficult to walk upon and the routine servicing of the distributor would be difficult.

Research to provide a design for reliable distributors which could be serviced without having to walk across the surface of the media may well be worthwhile.

Much has been written about "new" processes and techniques but even those that are well tried and established are not really used as much as they could be. The importance of controlling the periodicity of dosing is well known but much more control could be carried out in practice. Greater use of electric drives with speeds that are easily changeable would give more even distribution and control of dosing, thus going some way to alleviating difficulties caused by fluctuation in flow.

Activated Sludge Process

The provision of simple activated sludge plants for small works has interesting possibilities. Extended aeration plants should be capable of construction and operation without the use of either primary or secondary settlement. It has been previously mentioned that the routine desludging of primary tanks on small works is labour extensive. The use of plants of this type, if successful, must show considerable savings in manpower requirements.

A plant to serve a small isolated rural community is at present being constructed without primary settlement tanks. The basic concept of the plant is that the rotor is to be installed and fixed with the optimum immersion of the cones. A simple timer is provided so that the rotor can be operated intermittently; experience will decide the best sequence. Settlement is to take place in the centre channel with the thickened sludge passing back into the main portion of the ditch through side vents situated near the bottom of the channel. It is hoped that surplus sludge will consolidate in a consolidation chamber provided.

The increased use of oxygen, either in plants designed to use oxygen alone or as an addition to the air supply to increase the capacity and efficiency of plants, is likely to increase. These developments are more likely on the medium and large plants than small ones. The trend on small plants must be for simple extended aeration systems. In the past the tendency has been for effluent to be treated sufficiently for ammonia to be oxidised to nitrate. The discharge of effluents containing nitrate has been welcomed, providing as it does a supply of oxygen to delay the onset of septic conditions. The possible adverse effects of nitrogen in any form on the receiving stream are now receiving considerable publicity and attention. Activated sludge plants may have to be operated in such a manner that nitrogen removal is achieved rather than just oxidation.

Some years ago experimental work was carried out using a very high recirculation of mixed liquor in an activated sludge plant. It was found that some removal of nitrogen took place and that the need for operational techniques such as stepped aeration and incremental loading was eliminated.

On several works biological treatment is carried out in two stages. Plants using two stage biological treatment have been found easy to control and to produce good quality effluents. The adverse effects of variations in strength and flow are moderated by the first high rate stage leaving the second stage to deal with a flow of more uniform strength. The use of such plants could find considerable application on medium and large plants. Either activated sludge or biological filtration could be used as the first stage. It is in two stage applications that plastic media packed in tall towers could be used to advantage. The figures quoted below relate to the performance of two partial activated sludge plants.

Both plants make use of air, Plant A using fine bubble diffusers and Plant B coarse bubble. Plant A has a detention period of 1.7 hours and Plant B a detention period of 0.75 hours. The effluent from these plants is further treated upon biological filters. The considerable amount of purification achieved in these plants results in a fairly even loading being applied to the filters, and enables very high quality effluents to be produced.

	Plant A	Plant B
B.O.D. Influent	123	170
B.O.D. Effluent	15	44
S.S. Influent	110	156
S.S. Effluent	18	50
NH_3 Influent	24	36
NH_3 Effluent	22	35

Sludge Treatment and Disposal

The future disposal of sludge should be geared to conservation and recovery by disposal on to agricultural land. The use of land for this purpose presupposes that the sludge is suitable and is not toxic. Disposal to agricultural land should be carried out according to the guidelines set out in ADAS 10. (1)

Generally the disposal of raw sludge in this way is not as acceptable as the disposal of digested sludge. It could be argued that a pre-requisite of disposal direct to land is digestion of all sludges.

The use of aerobic digestion of sludges is an alternative to anaerobic digestion as a possible pretreatment prior to land disposal. Whilst it would be impractical to provide anaerobic digestion at all small plants much simpler tanks and equipment could be used for aerobic digestion.

The use of central or group digestion plants is worthy of study. At such sites the sludge from small remote plants, which are not and should not be constructed with screens, could be screened before disposal. This would remove the plastics, polythene and other contraries which at present are distributed on to farm land when raw sludge is spread direct. The danger to farm animals of this type of material cannot be overemphasised. The continued and increased use of this method depends upon the farmer being completely satisfied with the "product".

A disadvantage of any centralised digestion scheme would be the double handling of the sludge. The use of aerobic digestion at the plant producing the sludge would not suffer from this drawback. Disposal would be possible within relatively short distances.

On rural works the provision of extended aeration plants would enable surplus sludge to be aerobically digested. Modification of this type of plant to eliminate primary sedimentation would produce a sludge, all of which had been aerobically digested without the provision of additional plant. On large plants the use of sludge gas for power generation would preclude the use of aerobic digestion.

Some sludges, because of the concentration of toxic materials present, are not suitable for disposal on to agricultural land. Disposal on to tips is becoming increasingly difficult and tips are becoming harder to find. It seems certain that the incineration of these sludges is the method of disposal that offers the best solution. The preparation of sludge for the incineration process would appear to be possible by a number of different ways, the choice of which will be largely determined by local circumstances and economics.

Tertiary Treatment

Tertiary treatment facilities on small plants are limited in scope and variety by the size of these plants, and by the lack of continuous manning. In general some aid in the humus tanks, e.g., clarifiers pebble bed or a land treatment area are the methods used.

There can be difficulties in the cleaning of pebble bed clarifiers and the use of prefabricated portable clarifiers is attractive. Light wire cages filled with small spherical plastic balls placed in the tank on supports and easily removed for cleaning is a possibility.

Land treatment on small plants is either by grass plots or lagoons. The provision of these facilities should not be contemplated unless it is clearly established that high quality effluent is necessary to protect the river system. All too frequently grass plots and lagoons are used to make up for the deficiencies in the conventional treatment plant.

Lagoons can be operated with less demands on labour than grass plots. Some facilities for bypass and cleaning are essential. The labour requirements of grass plots are high, and satisfactory operation is possible only if considerable attention is given to them. It is essential that sufficient facilities are provided so that the resting and grass cutting necessary can be carried out whilst still being able to continue with tertiary treatment. Grass plots have the property of being able to continue the biological oxidation . process with the production of high quality effluents. The siting of these units often leaves much to be desired. A considerable amount of servicing is needed and yet access to perform the necessary maintenance is frequently inadequate.

On medium and larger works the volume of effluent makes the use of land treatment impracticable. Some concentrated method is required. The two basic methods are microstrainers and rapid gravity sand filters.

Greater improvement in the basic process seems possible with sand filters than with microstrainers. The use of upward flow and pressure filters should continue to increase. The use of multi-media rapid gravity filters promises considerable advances. The substitution of 0.3 metres of sand by anthracite produced significant improvements in the performance of a sand filter installation. A comparison was made of the performance of the dual media filter against the sand filter.

Both were fed with identical feed for the same length of time and samples of influent and effluent examined for BOD and suspended solids. In addition, the head loss on each filter, when taken out of service for backwashing, was recorded.

A summary of the results is as follows. The average daily flow to each filter was 13.54 Ml per day at a dosage of 5.6 cubic metres/square metre/hour. The influent to each filter had a BOD of 21mg/l and a suspended solids of 21mg/l. The effluent qualities were almost identical, the sand filter effluent averaging BOD 9mg/l and SS 8mg/l whilst the dual filter effluent averaged BOD 8mg/l and SS 7mg/l. A significant difference in head loss prior to backwashing was noticed, the sand filter averaging 2.02 metres and the dual filter 1.30 metres.

In view of the significant difference in head loss further trials were carried out to determine the maximum throughput of the dual media filter. Dosing was carried out until the head loss had reached 2.02 metres, before backwashing took place. An average flow of 18.64 Ml/day was treated. The high quality effluent was maintained with a BOD of 6mg/l and SS of 7mg/l.

It is interesting that the sand filtration technique is a water treatment process which has been successfully adapted to sewage treatment. Perhaps a close examination of other water purification practices would suggest other such possible adaptations.

A major problem in the operation of rapid gravity sand filters is the growth of slimes and biological films in the sand. These can be cleaned by taking the filter out of service and treating with chemicals. The development is urgently needed of an in-line method of continuously treating the backwash water with chemicals to prevent rather than to remove the slime.

Control systems for the rapid gravity sand filtration process have been developed to a high degree. Control can be achieved either by relation to head loss or by means of timers. The simpler of these two methods is the use of timers. The whole process of filtration and backwashing can be easily controlled.

Adequate provision must be made for the disposal of the washings and in particular the "sludge" from the washings. The application of the washings directly to percolating filters had been found to be unsatisfactory resulting in ponding and effluent deterioration. Disposal to the feed of an activated sludge plant which is the first stage of a two stage process, has been satisfactory. If such a two stage plant is not available disposal to the primary tanks is the alternative and especially if the back washings contained residues of chemicals used continuously to control slime build up.

Physico Chemical Treatment

Considerable research over recent years into physico chemical methods of treatment has taken place. The question which will inevitably be asked is whether or not these processes will be used to supplement or even supercede the existing processes. It is reasonable to assume that, as more and more research is carried out, developments will take place which will make the processes more attractive to both designers and operators.

The physico chemical processes should show distinct advantages over the conventional biological treatment processes in certain specific instances and vice versa. Biological processes, should be superior in dealing with organic loading than the physico chemical processes. Removal of specific 'impurities' e.g., phosphates would be best carried out by physico chemical means. Greater use of these processes will result from the ever increasing demands made upon the rivers. The use of coagulants to increase the efficiency of the sedimentation process and to remove nutrients before the discharge of effluents to streams should increase. In each case a careful study would be needed to assess the feasibility and the economics of the process. The trend would seem to be leading towards a mixed biological and physico chemical plant.

Automation, Labour and Training

At first glance the highly technical subject of automation would appear to have little in common with the more mundane topics of labour and training. On closer examination it is obvious that the three topics are interrelated. The more automation is used, the lower the requirements for labour and the greater the change in character of the labour. The traditional sewage works operative and labourer will tend to be phased out, as more and more skilled technical staff are required to service automated equipment. The degree to which works operation should be automated is a contentious subject. Views have been expressed ranging from complete automation and computerisation to virtually no automation. The ideal situation is somewhere between these two extremes. Labour is expensive and if reliable automation can be provided to reduce these costs, advantage should be taken of it.

Computerisation or even semi-computerisation can only be considered for medium and large plants. Small plants must be developed which are simple, reliable and which require minimum of attention. A very useful aid to the operation of these plants would be the installation of fault warning or even plant state systems which report to a central master station. Many of these are on the market, the main problem being that progress in this field is so rapid that equipment is obsolete almost before it is installed. Mention has been made of the need for increasing numbers of technical staff to service and maintain the complex equipment now being installed. There will, however, always be a need for operators with less technical ability. Training for the technical staff is adequately covered by the present technical colleges. The *extension of the National Water Council Training Schemes to sewage treatment* operations is a welcome move and the use of the various courses should improve the knowledge and effectiveness of the operatives.

The traditional technical college and university courses provide adequate training for chemists, electrical, civil and mechanical engineers. The traditional route for operators was to obtain a basic qualification in a particular discipline and to move later into operations and management. A need exists for courses specifically geared for operators. One college in the Midlands has started to offer such courses.

Increased automation will change, or enable changes in plant operations to be made very quickly as the flow varies and conditions change. Unfortunately quality data is not so readily available, being obtained by the analysis of samples taken and submitted to laboratories. Attempts have been made to produce equipment to continually monitor the strength of sewage at various stages throughout treatment. None of this equipment has found universal favour and the need exists for the development of such equipment.

Conclusions

Operators of treatment plants are well known to be cautious and suspicious of change. Known and well tried methods are favoured. Changing circumstances, increased demands for water and a greater public awareness of environmental issues will create a pressure for change.

There are many new techniques and modifications to existing methods of treatment which could be used with advantage. The proving of these techniques and modifications by extensive pilot plant trials is essential. The fundamental need of operators is for simple, efficient and reliable plants.

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REFERENCES

1. Ministry of Agriculture, Fisheries and Food, "Permissible levels of toxic metals in sewage used on agricultural land". ADAS Advisory Paper No. 10, 1971

DISCUSSION

Author's Introduction

MR. H.V. LEE said that writing a paper on future developments presented certain problems. Prediction of operational developments was particularly difficult, bearing in mind political, social, technological and industrial evolution, and the reluctance on the part of operators to accept change. Simplicity and reliability had a particular appeal, and he did not see any startling new developments or processes exerting a major influence on sewage treatment operations; the theme of the paper reflected this. Operational changes took place slowly, development was cautious and gradual. The processes used for sewage treatment had been in use for many years, and it was probably true to say that not all of these were clearly understood. Over the years research had been carried out into the basic processes and our understanding of them was constantly improving. It was in the greater understanding of the techniques used, followed by refinements in both design and operations, that the greatest opportunity for development existed. This slow gradual development must lead to optimization both in terms of treatment efficiency and in the costs involved.

In the printed introduction to the paper the suggestion was made that areas where improvements were required were usually obvious. This was demonstrably true where poor quality effluents were being produced. The situation was not so clear cut in the other cases and the problem of assessing performance or efficiency could be considerable.

Assessment of efficiency, or performance appraisal, was a contentious subject. Much had been said, and even more hoped for, from what was a difficult subject to get even basic agreement on parameters or comparative measures.

One obvious basic parameter must be compliance with the effluent consent standard. The lack of complaints with regard to odours or nuisances could be regarded as another possible parameter. In both such diverse cases as these, and others like them, there was no direct relationship to cost. Parameters being suggested invariably had a cost basis, e.g. cost of removing each kg of BOD of COD or the cost of sludge disposal per kg of dry solids. Application of parameters such as these to existing plants could give rise to numerous difficulties. The sewage arriving for treatment would be of widely varying quality, conveyed by sewers with different flow characteristics from areas with considerably different run-off ratios. The multiplicity of plants in use, treating sewage by many different processes and producing effluents of different quality, must introduce further complications. The law of diminishing returns must apply. It has relatively simple and inexpensive to remove BOD or COD by treating crude sewage in a primary sedimentation tank. Removal of the last traces by means of tertiary treatment was considerably more difficult and much more expensive.

Parameters such as these or some similar methods of appraisal were likely to find increasing use; indeed their use was being examined. To ensure that such parameters were meaningful it was necessary that operational staff were involved in their choice. A quite definite requirement would be a costing system capable of producing reliable cost data suitable for expenditure control. Productivity, system and process design evaluation were all factors which would make a beneficial contribution to the optimizing of the treatment process.

Maintenance on sewage works had been with few exceptions at best inadequate. Only on the large plants where workshop facilities were available and skilled maintenance staff employed had the level of maintenance been satisfactory. In the past small rural plants had suffered from inadequate maintenance, probably because so much of the plant could not be removed from site for proper attention. Better quality workmanship and hence a better service was obtained if full workshop facilities were available. To enable full use to be made of such facilities greater use of equipment designed for easy removal and interchange was needed. Submersible pumps connected to rising mains by flexible hose could be more easily removed and serviced off site than conventional pumps. The use of replacement or serviced modules in electrical switchgear was a possible extension of this principle.

Since reorganization of the water industry suggestions had been made that standardization of plant and equipment was desirable. Justification of these views was invariably financial, although some benefits design and maintenance wise would also accrue. How practical were these suggestions? Perhaps some standardization was possible, but was there not a danger of putting constraints upon the inventiveness of the designer. Should the design of plants be dictated by the types of machinery available, and if so, was this desirable?

We were living in an era of change. The general public was taking a greater interest in the environment and demands for cleaner rivers for recreation and amenity were increasing. Changing circumstances and increasing demands for water would create pressure for change. In the present economic situation, with impending cuts in public expenditure, development might be curtailed because of financial pressure. It was to be hoped that the steady improvements made in recent years to the quality of rivers was not going to be lost. It was, however, difficult to see how any schemes, designed primarily for river improvement, could have a high priority. In these circumstances it would be necessary for operators to squeeze the last drop of capacity from their plants. To do this more effectively, operational data from all plants should be widely published. Invariably published results were success stories - very little data was published which described failures. Data about a process modification that did not work, or a piece of plant or machinery that was unsatisfactory, was as useful as data about successes.

<u>Verbal Discussion</u>

MR. K. GUIVER (Southern Water Authority), in opening the discussion, said that he was in agreement with nearly all the views expressed in the paper and in particular the need for satisfactory liaison between the different disciplines involved. The formation of ten large new water authorities on reorganization had brought together more expertise to deal with sewage purification problems than ever before. The public had a right to expect that the expertise would be used to the best effect in solving problems and this meant liaison not only between chemists and engineers, but also from the biologists, statisticians, and others now employed by the authorities. Such peripheral activities as security and safety precautions on works were included with expertise and it was essential to take advantage of it whenever possible in designing new works or solving problems of old ones. The liaison required had also to take into account the need for close contact between head offices of the new authorities and the divisional staff. The larger size of the authorities gave rise to some problems on communications but once again it was vital that work being carried out in one particular division was made known to other divisions so that the results obtained could be utilized wherever benefits might accrue.

Turning to specific points, he asked for further information on the comparative results of the use of hydrogen peroxide and hypochlorous acid to eliminate septicity in sewers. A considerable amount of work had been done on oxygen injection in rising mains in order to overcome septicity, but the factors which had been taken into account in deciding on the two used by the author would be of interest. Septicity was an obvious increased risk wherever centralization of sewage treatment works meant the construction of long lengths of sewers.

Balancing of flows by the use of storm tanks was another interesting concept mentioned in the paper. The Water Research Centre were proposing experimental work on this aspect and it certainly seemed that more regular use of storm tanks which were used relatively rarely for high flows, could give rise to benefits, subject of course to the increased pumping costs that would be involved in returning storm tank contents for full treatment. He did not think that the author's concern about the effects in rivers of the lack of photosynthesis over-night need be too serious. Many rivers in England received discharges at a number of points along their lengths and it was always likely that the time of retention in a river meant that effluent would be flowing along it during the night hours.

Another point that might be of interest was the Severn-Trent Water Authority's attitude to package treatment plants. The maintenance of such plants often presented difficulty in terms of producing a consistently satisfactory effluent. With some of them remaining within District Council responsibility it was not always possible that they were regularly visited and controlled to achieve satisfactory results. He asked whether it was general practice in the author's area to assume responsibility for small plants wherever possible, or perhaps even to accept contributions from developers who might wish to install such plants in order to improve the Authority's own works in areas where development was restricted due to the lack of adequate sewage disposal facilities. Rural works particularly were often in difficulties with regard to maintenance and it seemed likely that there could be advantage in obtaining some uniformity of design in such cases. For instance, the construction of humus tanks at higher levels than primary settlement tanks could prove of benefit in terms of humus sludge return and recirculation. This meant, of course, the need for pumping of the primary settlement tank effluent on to biological filters, but pumping at some stage of the works was often needed in any case. A continuous bleed from the humus tank in such cases might also allow some denitrification to take place and reduce the potential problems from high nitrogen contents in the final discharge.

Problems with screenings had also been mentioned. This was still one of the most unpleasant tasks on any sewage works and even where cleansing and bagging of screenings was carried out there were still difficulties in final disposal. He asked for the author's opinion on whether any benefits might arise from the long lengths of sewers involved in centralization schemes where there was likely to be greater disintegration of solids within the sewer. He also referred to the problems that might arise from the water authorities raising objections to refuse tip licensing in terms of being able to dispose of both screenings and sludge to such tips. It appeared that there was a very real need for a practical approach to co-operation in overcoming such problems.

Finally, he asked for further details of any aerobic digestion of sludge carried out within the Severn-Trent Authority. Both the number of plants involved and the success which had been achieved by them in improving sludge disposal to land would be of interest. Although some experimental work had been carried out in a number of areas on aerobic digestion, little had been published of the results. Care would still have to be taken with regard to trade effluent control and the prevention of high toxic metal concentrations developing. But the process did seem to have possibilities in terms of small works, where problems arose with smell nuisance and the acidity that developed from raw sludges.

MR. B.J.E. HURLEY (Thames Water Authority), referring to the question of co-operation, suggested that such liaison be extended to include managers from all disciplines. Much effort had been wastefully expended in the past by not including the necessary inputs from planning and financial colleagues.

Concerning the elimination and prevention of sulphide nuisance, he would be particularly interested to learn of the reasons for the selection of sodium hypochlorite and hydrogen peroxide, rather than air or oxygen in the two examples cited by the author. Were they chosen because they were demonstrated to be more potentially cost-effective, or were they selected because of personal preference? In this context he asked the author's view on in-sewer treatment and of any advantages that such processes might offer in the general context of sewage treatment.

Concerning the sections in the paper on particular unit treatment processes and the problems encountered with them, together with the myriad of suggestions as to how the problems might be overcome, this was a common theme of symposia. It had become almost fashionable to lay the responsibility for many of these problems at the doors of the antecedent authorities. Though this might be true in some unfortunate cases, it would seem to be imprudent to continue to sustain such arguments, particularly since it was now almost three years since the industry had been reorganized.

Though it was accepted that both old and new unit processes would require detailed appraisal, such analysis should be considered in the context of a systems engineering approach.

Much had been learned in recent years with respect to conventional treatment plant and many significant improvements in process development had taken place; however, parochial prejudices rather than any form of economic restrictions had prevented full advantage being taken of the application of such developments. Indeed, despite the merging of expertise on reorganization, there appeared to be little evidence to support an exchange of process research and development across the clean and dirty water interface.

Concerning the future utilization and disposal of sewage sludges, the industry had been considerably blinkered, almost myopic, in its previous views with regard to those strategies for which it had opted. This had no doubt been due in the main to policies which had been primarily concerned with keeping the "pile" down and which had completely ignored the marketing potential of such valuable products. His own Authority was examining a range of potential sludge marketing outlets, both traditional and non-traditional, which would serve to provide a basis for the security of the whole sludge disposal operation in future years.

Finally, he took issue with the author on the question of automation. The notion that the answer on this subject lay in some convenient niche between no automation whatsoever and full automation was an example of muddled thinking.

MR. G.S. CLAPHAM (Wessex Water Authority) said that reorganization had made it possible to centralize treatment of sewage and from an operational point of view this had many advantages. However, consideration should be given to the river system as a whole in assessing the benefits or otherwise of centralization. It could be more beneficial to retain the small treatment works with lower discharge standards, and thus utilize the self-purification capacity in the river, than to concentrate the discharge of a large amount of effluent possibly needing treatment to a higher standard.

Concerning the fixing of standards, it would seem beneficial if variable standards for the discharge of treated effluents were directly related to the needs of the receiving water, taking into account dilution, river use, self-purification, season, and not to fixed arbitrary standards.

The author had suggested that average flow should be adopted in the design of new works rather than dry-weather flow. This would not make any significant difference to the design. What did matter were the assumptions made for the allowance for the future in population and water usage. Planned extensions should cover periods up to about ten years. Also, planning authorities could make a more positive contribution in assessing future populations to ensure effective deployment of available resources. Careful assessment was necessary as a too greater provision for the future would result in capital to lay in the ground unused and produce operational difficulties.

Concerning storm water tanks, considerably more use could be made of them, particularly when one considered that they were in use only about 6% of the time. With adequate consideration at the design stage they could be used as additional settlement tanks or as balancing tanks with simple, flow activated, automatic penstocks to effect the change of use as necessary. As long as one tank was kept empty to accept the "first flush" of the normally strong storm sewage, the remaining tanks could be usefully employed.

Finally, he suggested the adaption of a common name for "sewage works". Various names were used at present, but he suggested "sewage treatment works" as the most descriptive and appropriate.

DR. J.D. SWANWICK (Water Research Centre) referred to the author's statement that sludge utilization on agricultural land should be done according to ADAS 10 recommendations. Whilst not disagreeing with that, he reminded the author of the cogent arguments put forward elsewhere for a modified approach and invited him to comment further on his Authority's approach.

Concerning aerobic digestion he asked whether, in view of the various disadvantages of the method recently confirmed in full-scale trials in which WRC was co-operating with two other authorities, the author's own Authority had any plant or was planning to install the method.

The author had referred to methods used in water purification which might be adapted to sewage treatment. Without wishing to debate the original use of particular methods, there were clearly some of interest to both the clean and used water fields and where reorganization of the industry had stimulated the pooling of expertise. One such technique was dissolved air flotation, which was attracting considerable interest in water supply in this country and which was also being assessed as a possibility for sewage treatment. Such application would not be new and he had seen the method in successful full-scale use at the San Jose Santa Clara WPC plant, in California, ten years ago.

The freeze-thaw process had potential advantages of great interest in both the supply and waste water fields. The problems were broadly similar to both, although the reversible nature of the effect on sewage sludge complicated this application. The use of the term "freeze-drying" by the early workers and referred to by Dr. Palin reflected the critical difficulty of dewatering freeze-thawed sewage sludge without damaging the weak flocs, and it was also a reminder that the process was being investigated before that now understood as freeze-drying was in wide use.

MR. B.H. ROFE (Rofe, Kennard & Lapworth) drew attention to current trend of management thinking and suggested that a slogan for progress could be "down with management, up with the workers!" This could be particularly directed to those responsible for the design and construction and creation of small rural sewage works - which formed the main part of the author's paper and which was clearly distinct from the somewhat different problems in the larger urban schemes.

One important factor in the design of rural works had always been the degree of automation incorporated in the design, i.e. the works were designed to run automatically without attendance except for maintenance. This automation did not involve any sophisticated or elaborate electronic devices but consisted mainly, in a well designed works, of gravity control and mechanical reactions to certain sequences of events - the essence of this was careful and thorough attention to the details of hydraulic design.

A second factor was the type of operator who was available to run these works - usually a person of only average intelligence but some practical aptitude who was well able to maintain a works designed on the principles described above - but probably not capable of dealing with extensive mechanical, electrical, or chemical problems which would require attendance of other men trained in this type of work.

The author had indicated that research should be carried out into retention of sludge in aerobic conditions. He himself had been responsible for the design and commissioning of an extended aeration plant in a rural area in Wales which discharged into a tidal basin near a holiday area. Because of this it was necessary to retain the sludge for periods up to six months in order not to discharge during holiday periods and this had been successfully achieved. Some details of this had been published, but more information could be made available to those interested.

Finally, he suggested that there had been tendency to over-centralization in rural areas in the last few years and gave an example of a recent extensive scheme in the South of England which had required enormous sewers over large distances and which would only become economically and operationally viable, as compared with alternatives using existing and augumented local sources, over a period of 25 years on the assumption of increased consumption which might well not be realized. The consequent reduction in discharge of sewage effluents in the upper reaches of small rivers and the dangers of septicity in large raw sewage trunk mains should not be overlooked.

DR. R.F. PACKHAM (Water Research Centre), referring to the remarks of a previous speaker, said that dissolved air flotation had developed originally as a waste treatment process and had only been applied to drinking water treatment relatively recently. Application of recent research results might lead to improvement in the performance of the process on wastewater treatment.

Author's Reply to Discussion

MR. H.V. LEE, in reply to the discussion, wrote that both Mr. Guiver and Mr. Hurley had asked for details about the work done with sodium hypochlorite and hydrogen peroxide. The two chemicals had been chosen because they were readily available and could be used with plant and equipment in common use. It was intended to continue experimental work using other chemicals, in particular oxygen and liquid chlorine. Dosing with sodium hypochlorite at a concentration of 130 mg/l was carried out for 10 days, by which time sulphide was not detected at the end of the rising main. Injection was continued at the reduced rate of 80 mg/l for a further 27 days, during which time no sulphide was detected at the discharge point of the rising main. Injection was stopped but the discharge was monitored for sulphide. After 20 days the level had risen to 4 mg/l and after 30 days to 10 mg/l. Injection of sodium hypochlorite was restarted and continued for six days at 65 mg/l. Sulphide was not detected in the discharge after two days and was still not detectable 30 days later.

In the second installation, hydrogen peroxide was quite effective in reducing sulphide concentrations from 15-20 mg/l to less than 1 mg/l. However, monitoring further along the system showed that sulphide was present in high concentrations, up to 25 mg/l. The long-term efficiency and costs of both techniques were still being assessed.

Mr. Guiver and Mr. Clapham had commented upon the possible benefits to be gained from using storm tanks for balancing. Benefits could be obtained, provided that adequate precautions were taken to ensure capacity for storm water in times of storms. If this were not done, any benefits could easily be nullified.

Regarding the possible advantages to be gained by long sewers causing disintegration of screenings, the problems which would arise because of septicity in these sewers would far outweigh any advantages so gained.

Mr. Guiver and Dr. Swanwick had commented upon aerobic digestion and had asked for details. At the present time the work was limited to a laboratory-scale feasibility study.

In reply to Mr. Hurley, in certain situations the use of in-sewer treatment had considerable merits. The production of satisfactory effluents from overloaded plants without costly extensions must be desirable. However, each possible case must be examined individually.

Mr. Hurley's pleas for an exchange of research and development across the clean and dirty water interface was one which he completely supported. Since reorganization staff had concentrated upon getting to know the plants they were responsible for. A greater emphasis should now be placed upon the need for this interchange.

The author was particularly interested in Mr. Hurley's comments concerning the examination of a range of potential sludge outlets. All too frequently works had been designed with little thought given to the method of treating and disposal of sludge. Sludge treatment was an integral part of sewage treatment and should be considered at the time that biological systems were being considered so that the system as a whole was compatible.

Referring to the question of automation, the view that the answer lay between no automation and full automation was not his but was one which was widely held. His own view was that each case should be considered on its merits and the best system chosen for each case.

Replying to Mr. Clapham, he agreed with his comments about the self-purification capacity of rivers. This capacity should be used as effectively and efficiently as possible. The question of standards was a very emotive one, but the concept that effluents should not be purified to an unnecessarily high level was one with which he could not disagree.

Mr. Clapham had made the point that the allowances made by planners in assessing future populations and flows would significantly affect the size of treatment plant required. This was of course a valid and valuable point. In these times of capital restraint, realistic estimates were certainly needed and Mr. Clapham's suggestion that extensions should cater for expansions up to ten years ahead was most useful.

Mr. Rofe had mentioned the cases of well designed and operated rural plants, and suggested that they could be regarded as being "automated". He agreed. These works had been designed and constructed to take into account all local conditions, including the type of labour available. This concept was correct, and sophisticated electronics were not required at such plants. However, he would like to see incorporated into these plants the installation of some simple alarm system transmitting fault data to a manned works.

In reply to Mr. Rofe's final point, centralization had advantages but it also had considerable disadvantages.

2(a) RESEARCH ASPECTS : WATER

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INTRODUCTION

The last major occasion when the water treatment crystal ball was consulted was the Joint Meeting of the SWTE and WRA in 1970 entitled, "Water Treatment in the Seventies" (1). Nearly seven years later with many cubic metres of water under the bridge and with the Water Industry itself much changed, the exercise is being repeated but, as befits current thinking, the Institution has chosen something of a multifunctional and corporate approach for authors and papers.

The forecasts in 1970 were neither bold nor startling (2) and it is not surprising therefore that subsequent developments have been broadly in line with the thinking of that time. Factors which could not be predicted were the change in economic climate and the attitudes of the reorganised Industry to priorities on the "clean" and "dirty" water side. The considerable influence of EEC Membership was also difficult to foresee. These are discussed further in later sections of the paper.

To look ahead in research is no easy matter in any subject. There will always be a core of effort devoted to the solution of presently known but longer term problems. What is more difficult is to predict tomorrows problems and the potential solutions to be explored. In water treatment many of the research needs result from new findings in relation to health, from the need to use sources of inferior quality and from economic pressures to use cheaper processes. No doubt the quest for "magic wand" solutions will continue and the enthusiasts will be aroused from time to time by a newly reported discovery. Very often when the band waggoning has died down only modest advances are visible. It must be concluded that water treatment is a fairly sober business and that developments will mainly follow the established course of using to better advantage tools which are largely already developed. Such tools can be manipulated by employing a better understanding of unit processes, resulting from good data collection exercises and the use of improved instrumentation and analytical methods.

ORGANISATION OF WATER TREATMENT RESEARCH AND FUNDING

Definitions of Research

Many attempts have been made to define what is meant by research but efforts to produce precise definition are unlikely to be rewarding. A convenient description might be the deliberate scientific investigation of a subject to produce new technical information which may subsequently be exploited to the benefit of society. This excludes data accummulated as the result of routine measurements carried out as part of ongoing operations, although discoveries can be made from this type of exercise. The essential difference is that there is a deliberate choice as to whether research should be done or not and the results of stopping research are not apparent immediately. This puts the financing of research on a different and more precarious footing and support in many cases adds up to an act of faith based hopefully on previous experience of

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return on investment. In many research sectors, and this includes water treatment, this act of faith is pronounced because changes are slow to occur due to conservative attitudes and long gestation periods for new plant. The rewards of research are not always readily visible. At times of economic stringency research funds are often the first to suffer, whereas there is a case, not commonly accepted, that this is when more money should be invested to provide the means for economic recovery.

Changing Approaches to Funding

Increasingly, especially as the economic climate remains stringent, a return has to be shown on work completed before further funds are made available. Research is also subject to considerations of "priority" a term which is often used however, to justify individual whim. With the advent of Rothschild and the customer-contractor principle, Government funding to Universities, Research Councils and other research organisations, is directed to studies where there is a "notional" demand for the results. Although Rothschild recognised that there should still be an element of speculative work,this kind of study is more easily squeezed out when times are hard. Research workers in the environmental field in many countries have found this a somewhat disconcerting time, having experienced the "environmental kick" when public pressure produced a vote-catching topic, at which time it was good enough to be seen to be doing something (or anything) to give the right PR image. Universities at this time, particularly in the USA found rich pickings and were able to indulge in studies, many of which could truly be called speculative. Water treatment research did not benefit so much during this period since more emphasis was put on pollution control and waste water treatment projects. In America this has since been corrected and crash programmes have been instigated to cope with the new problems shown up by water quality and health studies.

Potential Benefits

It is difficult to discuss the organisation of water treatment research without first identifying the likely benefits and therefore the potential sponsors.

Some studies, but not all, can lead to a direct saving in cost. These include methods for increasing rates on existing processes, improving efficiency at present rates and the development of new techniques which might be more rapid or cheaper in construction and/or operation. Reduction of manpower as a direct result of technology advances is another quantifiable goal. However, certainly for surface sources, there are reservations on how far this can be taken, especially if raw water quality continues to decline and our present understanding of process control does not improve considerably. Benefits which are more difficult to quantify are the improvement of water quality, particularly in relation to aesthetic measurements such as colour, taste and odour, improvements in reliability of operation ("peace of mind" benefits) and increases in the safety of water supply. For example, only some of the benefits of solving "dirty water" problems in distribution by changes in treatment can be costed. The value of reducing the risk of chronic disease by water quality improvement is not readily quantified at the present time.

Sponsors and Methods of Support

The sponsors are likely to be (a) the treatment plant user who will benefit directly, (b) the manufacturer who is looking for a more competitive product, (c) the consultant who requires solutions for a client or who seeks improved awareness, (d) Governments with interest in national problems and exports, (e) bodies such as the National Research and Development Corporation with interest in the exploitation of ideas, (f) international bodies such as WHO interested in solutions,often within specific constraints, and (g) organisations such as EEC acting on behalf of its constituent members. In fact EEC has so far supported little research on water treatment projects and has deliberately excluded the topic from its Second Environmental Programme,for reasons which are not entirely clear.

Governments individually or collectively will support work through their own facilities or will place contracts or give support grants. Not often does an individual Government place contracts outside its own country. Manufacturers will mostly carry out work in-house although they may also place contracts or support co-operative work. Consultants will use all three methods. International bodies can place contracts where appropriate expertise exists but must be careful to avoid too uneven a spread between countries. The treatment plant users have more of a choice. Since they are mostly non-competitive there are few barriers to exchange of information and much to be gained from its encouragement. The user can therefore finance in-house work, can place contracts and can support co-operative studies. It is apparent that the reorganised Water Industry in the UK will wish to use all three approaches (3), (4).

In the UK one particular question is the division of support for research between Government (the taxpayer) and Water Authorities (the ratepayers and manufacturing Industry). A Joint Standing Committee has been set up and has agreed on guidelines for the division of funding.

Inevitably there are strengths and weaknesses in each approach. For each organisation to carry out its own studies gives direct control but must lead to expensive duplication unless there are overriding local factors. When placing contracts it is necessary to be confident of the abilities of the contractor and the method of control of the studies. Support of co-operative research gives access to centralised expertise and often sophisticated and expensive facilities. Since costs are shared the individual contributor can get his research done more cheaply. It is essential that the co-operative researcher is aware of those topics which are amenable to central study and the most appropriate research approach to achieve applicability of results to a wide range of situations. Members supporting co-operative work have to feel that they can influence directly the composition of the programme but have to allow the professional researcher considerable freedom in the conduct and management of the research. With mutual goodwill it is possible to create a special relationship with a responsible, service-oriented but independent attitude on the part of the research team and an expectant yet not over-possessive approach from the sponsors. Co-operative research is a widely used approach in the U.K. by the Research Associations but it is not very common overseas. In the United States a Research Foundation has been set up by the American Water Works Association but it is rather slow developing. KIWA in the Netherlands is another notable organisation carrying out co-operative research, but examples in the rest of Europe are few.

<u>Level of Support in the United Kingdom</u>

For many years only limited funds could be invested in deliberate experimental work in water treatment and most of these were put up by the plant manufacturers and pioneer Water Boards and Companies. From the early 1960's more money was devoted to this subject with effort increasing through Manufacturers, Water Boards, Consultants, Universities and the WRC. It can be estimated that in 1974/75 public sector finance for water treatment research was of the order of £400,000 (3), (5), (6). Industry also contributed an unspecified amount. In the same period capital and revenue spending on treatment in England and Wales alone was around £30 million. It is often argued that research effort in this sector is higher in proportion to investment than in others, for example distribution and sewerage. Whilst total investment in a sector will have an important influence on research funding, the importance of the subject areas as well as the prospects of success have to be considered. Water procurement and treatment plays a front-line role in supplying a safe and acceptable water to the public under increasing conditions of stress. Much of the research is of an"insurance policy" nature, ensuring that ,as evidence develops on desirable water quality and as reuse is more widely practised,the tools are available to meet the standards laid down. Unless, as is discussed later in the report, there is a dramatic change of policy on the procurement of potable supplies, it will be essential to maintain at least the present level of effort and it may be necessary to increase it very significantly. This not only includes work on water treatment as such but also related studies on maintenance and improvement of raw water quality.

APPLICATION OF THE RESULTS OF RESEARCH AND DEVELOPMENT

It might be prudent to consider first whether the results of research and development over the past ten years have been applied at all in water treatment plant practice. It is clear that there is considerable evidence of change in design and operation over this period and not all of this can be accounted for by a "suck-it-and-see" approach. The biggest advance has been in the understanding of the principles of treatment and the way in which unit processes work. This is the essential foundation for successful change, since it provides confidence,which is the most important single factor in adopting new ideas. Confidence alone is not enough. Successful innovation also requires; good management, someone in a position of authority who is prepared to go ahead, opportunity, the availability of "risk" money and sometimes a little luck. On past evidence innovation becomes more difficult as the application moves from trouble-shooting to operational improvements to new designs. Experience also shows that the preparation and delivery of a research report is not sufficient. The difficulty of course is that the development phase always involves a much higher investment than the initial research studies. Demonstration has been increasingly called for by means of pilot or full-scale experiments on the local water. The pilot plant in capable hands ,together with good advice on the experimental approach, analytical methods, instrumental measurement and the interpretation of results, has proved to be the single most powerful confidence booster and will continue to be so. This approach has been used by water undertakings, the manufacturers, consultants, Universities and the Water Research Centre to good effect. Particularly fruitful areas have been the selective use of polyelectrolytes, dual and multi-layer filtration, upflow filtration, granular carbon adsorption and flotation.

No single organisation can claim to have played the major research and development role in introducing water treatment innovations to the industry. Much credit must go to the pioneer water engineers and water undertakings who between them have produced notable successes and some failures over the years. On the "customer is nearly always right" basis they have also persuaded manufacturers and consultants to try new approaches. The latter, however, have also made their own contributions often with the injection of practical reality, together with effort from the Universities at home and abroad and the Water Research Centre. It is interesting to note how,over the years,UK plant users are often more impressed with research reported from abroad than by studies in this country, although the developments inevitably have to be "tested" on "British waters".

An approach which merits further attention is that adopted by the WRC in its flotation programme (7). After classical development through laboratory scale, small pilot plant and larger pilot plant studies on Thames water at

Medmenham, a series of demonstration pilot plants has been constructed and commissioned on a variety of waters in co-operative work between the Centre, a number of Water Authorities and a water company. The project is co-ordinated by a Flotation Working Group and the results will be communicated to all Members. In parallel, know-how agreements with manufacturers and the staging of a successful conference (8) have assisted in rational promotion of a technique which although by no means new and already operated on full-scale overseas, has yet to achieve its true role in British practice.

Looking to the future, it has to be recognised that a key role in technology transfer in the regrouped UK Water Industry will be played by the specialist personnel whose job it will be to decide on the appropriate systems for specific applications. Nevertheless the final verdict on success or failure must always come from the supervisory and operating staff.

MAJOR FACTORS AFFECTING RESEARCH NEEDS

Looking ahead it seems increasingly likely that the performance of water treatment plant will be subjected to increasing scrutiny. With greater concern over finished water quality and with little prospect of relaxation in economic constraints there will be greater pressures for the development of the magic wand. Some of these factors of influence are reviewed below.

Potable Water Quality Standards

The move towards the closer specification of acceptable potable water quality is likely to have the greatest influence of all factors on the direction of future research in water treatment. For many years the general criterion of "wholesomeness" allowed a pragmatic approach to be taken to treatment. Processes were selected on the basis of the available raw water source with guidance where necessary from WHO Standards (8) and with acceptable levels for some parameters such as iron, manganese and aluminium, derived from previous practical experience. In this way also the natural tendency to work down to standards was avoided.

Over a relatively short period pressure began to build up for a more exact definition of an acceptable drinking water. The particular concern related to chemical pollutants which might affect health. Bacteriological guidelines were already laid down which were widely accepted, although there was some discussion on the approach of using indicator organisms and on sampling frequency. Increased mobility of the population and improved living standards were also creating pressures for greater uniformity of quality in relation to aesthetic parameters such as colour, taste, odour, iron and manganese. This concern was intensified by the need to use lower quality sources containing increasing quantities of domestic and industrial effluents, and the evidence which was beginning to emerge from health studies carried out in a number of countries, particularly the United States.

Following surveys of drinking water quality in many parts of the United States, the Environmental Protection Agency has introduced legislation which lays down Primary Interim Drinking Water Standards which will operate from June 1977 (10). This represents a major change since the standards will cover the whole of the United States, whereas previous US Public Health Service Standards were inter-State Standards and therefore only applied to water carried between States. In Russia water quality standards have been in operation since at least 1954 and revised figures were introduced in January 1975 (11). In the case of the EPA Standards, utilities will have to notify their consumers if sub-standard water is distributed, whilst in Russia "violation of the standard is punishable by law".

In the United Kingdom the situation changed, almost overnight it seemed, following the issue of two draft EEC Directives, one on the quality of surface waters used for potable supplies (12) and the second on potable water quality (13). The first has now been agreed, and the second has been referred back after serious misgivings had been expressed on some of the proposed concentrations. The various published drinking water standards are compared in Table 1.

The effect of the Surface Water Quality Directive on treatment research is difficult to predict since the concept of using a standard for purposes other than water use is difficult to conceive. Also since the values chosen are based on the average removal in existing processes there would seem to be no direct incentive to develop new treatment techniques. Methods of implementing the Directive in the UK Water Industry are currently under discussion.

The derivation and implementation of drinking water standards is no straight forward matter. Suppliers of potable water would welcome the development of a potability monitor which would sound an alarm when the water is unacceptable or even if significant change has taken place. Since this is unlikely, they would settle for a firm set of figures for concentrations of specific chemicals not to be exceeded at any time, plus adequate monitoring facilities. In practice the measurement of potability cannot be as precise as this and other approaches are necessary. Of particular concern are the chronic or long-term effects of the large number of chemicals which may be present in water supplies, and which come from the raw water or are added in treatment. In some cases, for example the relationship between heart disease and water hardness, the evidence has been gathered by epidemiological studies involving extensive checks on medical statistics and comprehensive water analyses. For carcinogenic effects it has proved necessary to use a number of approaches. Waters can be analysed for specific known carcinogens, for example certain polyaromatic hydrocarbons. Using more sophisticated techniques such as gas chromatography plus mass spectrometry for organics, a wide range of compounds can be identified and toxicity data will be available for some of these. Further toxicity testing can then be carried out on any other suspect compounds found. One problem with this approach is that the present rate of development of analytical methods with increased sensitivity will result in the identification of minute concentrations of compounds, the health significance of which it will be very difficult to assess and whose removal in treatment it may be impossible to measure. Another method is to carry out toxicity tests on concentrates from the raw or treated waters without prior identification of compounds. Epidemiological studies can also be carried out in areas where carcinogens are identified or where water is extensively reused.

In the U.S. Environmental Protection Agency studies some 253 organic compounds have been identified in drinking water, some of them known carcinogens (14). The report of the meeting in Amsterdam on the Health Effects of Water Re-use (15) states that some 1,000 compounds have so far been reported and that there is a need for full-scale toxicological tests on 10 high priority pollutants and for (sub) chronic toxicological study of 50 high priority pollutants.

Whilst the results of these studies may provide reassurance or may point to areas of concern, the translation into actual standards will need the incorporation of practical economic and political constraints. It is unlikely therefore that in the immediate future a precise set of numbers will be produced to cover potentially carcinogenic compounds for use by water suppliers on a routine basis. Undoubtedly particularly hazardous compounds will be added to the list as time goes on and work will be continued to develop suitable analytical techniques for routine use. The primary impact of the health studies will be to provide guidance on the acceptability of different degrees of reuse and on the desirability of excluding particular effluents from potable water sources. The development of blanket parameters, such as total organic carbon and total organic chlorine for organics, which will give some measure of safeguard on a routine basis will be an important objective.

Although it is clearly necessary to adopt a responsible attitude and to use sensible safeguards in relation to health effects and water quality it would be unrealistic for the public to expect a completely risk-free product as with any other food. An element of risk is present in all activities in life. Ultimately decisions have to be made on the basis of risk versus cost. Unfortunately, it is likely to be some time before water quality risks can be quantified,otherwise it would be possible to write down the risks associated with water produced using increasingly complex treatment and the corresponding costs. Such risk analysis has been carried out in other fields. Pochin, for example, (16) shows that relative risks have been approximately estimated for some occupational and non-occupational human activities, Table 2. Perhaps in time the relative risks involved in drinking a life-time quantity of waters of different quality and other foods will appear alongside these figures.

This is clearly an area in which the water treatment specialists will expect guidance from medical experts and in the United Kingdom this will be provided by the newly formed DHSS/DOE Joint Committee on the Medical Aspects of Water Quality.

Strategy for Drinking Water

In view of the above considerations it is possible that more attention will have to be paid in the future to the choice of source and the treatment technology, particularly if medical evidence hardens. To retreat from the present policy of using lower reaches of rivers involving considerable indirect re-use would produce severe practical and financial difficulties. However, the public may well decide that they are prepared to pay much more for water if the apparent risks can be significantly reduced. They may demand in time first hand water rather than second. The alternative must involve increased technological sophistication for pollutant removal. This removal can take place at the factory, at the sewage works and at the water treatment plant. Removal from the water cycle at source of many of the chemicals resulting from industrial processing must be an important part of pollution control. Further removal at the sewage works is desirable but may not be economic for some pollutants. It is worth noting that wherever the removal of a pollutant takes place considerable thought has to be given to the ultimate safe disposal of the materials removed. Reliance on the water works must be the corner stone of health protection regardless of source. Reliance upon simple water treatment and extensive pollution control measures must introduce hazards due to the degree of operational reliability and the chance of accidental spillage.

The increasing cost of introducing sophistication at the water works can be significant in relative terms. Table 3 shows estimated costs of different degrees of treatment taken from the WRC River Trent Treatment Study financed by the Severn-Trent Water Authority and the Department of the Environment (17). The cost almost doubles if granular activated carbon treatment is introduced for blanket removal of organics, where residence time needs to be appreciable. The cost of further marginal improvement in organics content by the use of reverse osmosis is much more significant and would have a noticeable effect on the total cost of water supplied to the consumer. Cost increases of this order coupled with unquantified reduction in risk have to be considered against the fact that some 3% of water supplied domestically is actually consumed or used in the preparation of food. Looking well ahead, as more is demanded of treatment technology and with the probability that further questions will arise from the medical investigations, there may be a need to reconsider policy for drinking water, either in terms of a reversion to purer sources or the viability of separate supplies by pipeline or container in areas of known risk. If this comes about the demands on treatment research could change appreciably.

Economic Conditions

The degree of availability of finance for capital and operating costs can have a considerable impact on the direction of water treatment research and development. In times of stringency at home, with the exception possibly of health related matters, there is little incentive for R and D to improve quality at additional cost. There is instead pressure to increase the use of existing installations by uprating, whilst keeping the product quality within acceptable limits. The development of cheaper alternative processes or processes with different ratios of operating to capital cost may also be supported, thus leading to lower total discounted costs. At such times, however, there can be increased incentive to export and studies to produce more competitive systems may be sustained.

FUTURE RESEARCH ON PROCESSES

Removal of Hazardous Chemicals

Whether or not the decision concerning potable water supplies involves purer source waters or more advanced technology there is a need to continue and probably expand present research and development on the removal of hazardous chemicals by conventional and new techniques. Changes in policy cannot be implemented instantly and there is a need to know how to modify current technology and how to introduce further stages at least as an interim measure. There is a need therefore to look at all new methods as they are developed so that their possible future role in treatment can be assessed.

Organic Compounds. The principal difficulty in work on organics removal stems from the growing list of substances of concern, the minute concentrations involved and the lack of firm guidance on the concentrations required in the treated water. The 250 compounds identified in finished waters in the United States EPA Studies (14) involves concentrations for individual chemicals between 0.001 µg/l and 366 µg/l. Russian health authorities have listed 400 compounds of concern in raw waters. Predictably the widest range tends to occur where raw waters contain high concentrations of organics, some of which are not removed in treatment and which may be converted to more active forms by chlorination. The list of identified compounds will continue to grow as evidenced by the total non-volatile organic carbon (NVTOC) levels found in finished waters. In the US survey these ranged from less then 0.05 mg/l to 12 mg/l. Clearly some of this organic carbon emanates from natural organic materials rather than industrial chemicals.

In the River Trent Study (17), (18), raw water TOC concentrations between 5 mg/l and 9 mg/l were reduced to 0.5 mg/l (Figure 1) with full chemical treatment plus fresh activated carbon using long retention times and at a cost as given in Table 3. Reverse osmosis produced a consistently better TOC concentration ranging from 0.1 to 0.5 mg/l but at much higher cost. The exact composition of the penetrating organics in each case is not known although with reverse osmosis they will mostly have molecular weights less than 200 and may still be carcinogenic. How much of a threat to health is represented by this residue of 0. 5 mg/l of unknown organic compounds has yet to be resolved but it should be pointed out that many river supplies with conventional treatment produce waters with TOC concentrations which are unlikely to be less than 1 to 5 mg/l. At present only three granulated activated carbon filter installations are in operation on water supplies in the UK and these have short retention times mainly for taste and odour control. A survey in the United States (19) showed that at least 37 plants are using granulated activated carbon filters ranging in size between 0.014 and 1.7m^3/sec mostly with short retention times. Powdered carbon is widely used for taste and odour control but this has been shown to be ineffective for removal of trace organic compounds even at quite high doses. This approach is not acceptable as a health hazard barrier.

There is a clear research need to identify additional organic compounds, to measure the removal of total organics and specific compounds in conventional and carbon bed treatment and to look at other combinations of treatment including ozone, ion exchange and reverse osmosis including improved membranes. Some of this is already in hand both in the United Kingdom and abroad. Some reassurance has already emerged. In the River Trent study for example, it was shown that for specific pollutants conventional treatment plus carbon could reduce to very low levels; detergents, phenol, polyaromatic hydrocarbons and pesticides. It is to some extent fortunate that water treatment processes tend to be non-specific resulting in the removal of a wide range of compounds the identities of which are often not known.

Inorganic Compounds. Substances of particular concern in relation to health include nitrates, heavy metals (particularly lead), arsenic, cyanide, selenium, fluoride and hardness.

High nitrate levels are of concern mainly in relation to methemoglobinemia in infants, but there is also some, (as yet unconfirmed) evidence, that high nitrate levels may assist the formation of carcinogenic nitrosamines. Nitrate concentrations in some ground waters and surface waters in the United Kingdom have exceeded the WHO lower recommended limits particularly during low rainfalls in 1976. Modifications to the activated sludge sewage treatment process can reduce the volumes of nitrate discharged to rivers but cannot affect the contribution from agricultural and other non-point sources. Ion exchange processes have been developed for groundwater systems using conventional resins. One of the problems with this approach is that currently available resins are not nitrate specific. This leads to the simultaneous removal of other ions such as sulphate which gives high regeneration costs and can lead to undesirable changes in treated water quality. Work is therefore in hand on the development of a nitrate specific resin (20). For surface water, high rate fluidised bed biological denitrification, using methanol as a source of carbon for bacterial growth, has given encouraging results in pilot plant trials at the Water Research Centre. The system is also being studied on a larger scale at the Thames Water Authority's Lea Bridge Works. Further work will be required before the process can be used confidentialy on a full-scale.

High ammonia concentrations can occur in rivers receiving substantial volumes of effluent particularly during periods of low temperature. The main problem is interference with disinfection and the use of break-point chlorination may raise questions in relation to chlorinated organics and can be expensive. Biological nitrification using a fluidised bed has proved to be an economic and effective high rate process (21) as originally developed on the River Severn (22). Little further research is required but application of the latest developments to full-scale practice is needed. In a wider sense the potential of the fluidised bed reactor needs exploring further. Used for many years in floc blanket sedimentation it is capable of fulfilling a wider role as a rapid reactor in water treatment.

With the exception of lead, heavy metals have not posed a problem for water treatment because they are usually absent at source or present at concentrations less than the limit of detection. Although lead concentrations are also usually insignificant in raw waters some waters can dissolve lead from service pipes. The possibility of a water treatment solution to the problem depends on the standard finally set by EEC but some work is necessary on chemical adjustment for plumbosolvency control. At present much more attention is also being paid to a more detailed analysis of water at the tap. This might point to the desirability of controlling other trace materials in supply by adjustment to water quality during treatment.

Where metals including lead, mercury, chromium, copper, barium, nickel and zinc are present above acceptable concentrations in raw water, there is good evidence that variations on conventional treatment, adsorption on bone char or the use of granular activated carbon can all reduce these materials to low concentrations (14), (17), (23). In the Trent Study for example it was possible to hold the final concentrations of the above metals to below 10 µg/l in the final water. Arsenic can also be removed by excess lime softening but selenium VI is more difficult and has only so far been found to respond to removal by reverse osmosis. If recommended concentrations are decreased further some work on other techniques including the development of new adsorbents may be necessary.

Asbestos. Although considerable quantities of asbestos fibres have been found in some raw waters overseas, there is as yet no firm evidence on the hazard to health which asbestos in water might represent. Epidemiological studies in high asbestos areas in the United States have so far not shown conclusive relationships with cancer. American evidence shows that conventional filtration is effective in removing fibres. In view of the expensive and sophisticated analytical methods required for asbestos, better evidence is necessary on the health hazard involved before routine measurements are introduced.

Radioactivity. There is little evidence that present and predicted levels of radioactivity represent a hazard in water supply. Softening is the recommended process for radium removal and no special research is required.

Bacteria and Viruses. Although concentrations of bacteria undoubtedly increase as raw waters with higher proportions of effluent are used, there is ample evidence that significant removal occurs in rivers, during storage and by conventional treatment, particularly slow sand filtration. Additionally, an efficiently operated chlorination stage having a free residual and an acceptable real contact time provides adequate protection for human consumption. For river supplies with a high re-use factor pre-chlorination followed by post-chlorination is commonly used as an extra insurance. The recent evidence on the possible health risk due to chlorinated organics has caused some re-thinking in the United States, firstly, on whether chlorine should be used at all and secondly, if used, how this can be done satisfactorily at the point of minimum organics concentration. In fact the situation is aggravated in the United States by the common practice of chlorinating effluents. Alternatives to chlorine include ozone and chlorine dioxide. Ozone is a very effective disinfectant but is expensive and could lead to the formation of organic fragments which themselves might be hazardous. Furthermore ozone does not give a residual in distribution systems. Chlorine dioxide is an effective disinfectant in the pure form and can reduce the amount of chlorinated organics produced. Since, however, it is widely produced on a water works in a way which gives excess chlorine, some chlorinated organics cannot be avoided. Much stronger evidence is required on the health hazards posed by organohalogens and on their sources before present practice is radically changed. It seems more likely that, if evidence is convincing, the way forward will be to remove more organic materials in treatment and to use the proven chlorination procedures at the end of the process. Pre-chlorination is likely, however, to be reviewed.

The question of viruses in drinking water is a much debated subject. There is no doubt that there is a whole range of viruses present in sewage effluent and that some of these will be found in rivers. It is also known that they are more chlorine resistant than bacteria. There is evidence that they are effectively removed by a well-operated chemical treatment plant and by slow sand filtration (17), (24), (25). The absence of cases of water borne outbreaks of virus diseases in the United Kingdom gives reassurance that viruses at present do not pose a particular threat. However, there seems to be a case for research studies on the removal of viruses in different types of treatment, particularly relating to direct river abstraction schemes. Use of alternative disinfectants, particularly ozone, could provide a more effective virucide but is subject to the reservations concerning organic materials and lack of a residual discussed above.

Other Process Developments

Process developments in conventional treatment were reviewed comprehensively by Young (26) for the "Water Treatment in the Seventies" Conference in 1970. During the six years following that Conference some of the innovations have been put into practice but changes have been slowed, initially by reorganisation and latterly by financial stringencies. Some incentive to experiment has been provided by the 1976 drought and emergency plants have been constructed in some areas.

A recent survey carried out by WRC of water treatment in EEC countries (27) revealed few surprises concerning treatment outside the UK. No revolutionary processes were found to be in operation perhaps indicating that information exchange is already fairly good between Member countries.

Coagulation. The more rational use of coagulants and coagulant aids is developing based on the water to be treated and the type of plant. Needs in this area would seem to be the application of existing knowledge rather than any extensive research.

Flocculation. Separate flocculation is required for flotation and for high-rate settlers such as the Lamella separator. Development of effective hydraulic units would represent progress in this area.

Sedimentation. Progress has been made in understanding the behaviour of the various sedimentation methods and different tank designs, and, as a result improved performances have been achieved by process modifications. The true role of inclined plate and lamella systems has yet to be established but operating data will become increasingly available which will enable this role to be assessed. If claims are fulfilled this type of unit could be a serious competitor to conventional upflow tanks and in some cases to flotation.

Flotation. Overseas this process is already operated on full scale (8). The WRC programme aims to demonstrate applicability on a wide range of UK waters. There is no doubt that the process has attractions in terms of flow rates, speed of response, sludge solids concentration and algal separation. Total costs are likely to be competitive with low and medium rate floc blanket systems but might be bettered by Lamella sedimentation. Future work should involve the commercial development of full scale units in viable situations.

Simple Treatment. A case for the use of simple processes arises normally where an otherwise acceptable water contains only one contaminant at an unacceptable level. For example, low turbidity coloured surface waters as widely found in Scotland and Northern England, or groundwater containing iron, manganese or nitrate. It seems extravagant in these cases to apply full treatment at considerable expense also producing a sludge problem. No magic solutions have yet been produced however and as standards of finished water are tightened the possibility seems less likely. Ozone and chlorine must now be used with care where organics are present even where these are of natural origin. Some work is in hand in a search for possible new cheap adsorbents but the use of some form of filter which involves at least the cost of a containing structure seems inevitable.

Filtration. Although a number of novel designs of filter have been developed in the last few years the bulk of water in the United Kingdom is still treated by slow sand or rapid downflow filters.

Experiments by the Thames Water Authority have shown that increased rates can be used on slow sand filter beds without significant loss of quality. This improves the relative cost position of these units. There are clearly advantages from a bacteriological and possibly a virological viewpoint and the biological step has many benefits. This type of filter however is not effective in removing dissolved colour and it is doubtful if it is efficient in removing some of the more refractory organic compounds. More data collection on this aspect is desirable.

In the field of rapid gravity and pressure filtration the dual layer downflow system is becoming more common place. Upflow units are being used selectively and in combination with a downflow bed have much to offer. Other newer forms of filter have not gained ground so far. The continental approach of deeper higher rate beds deserves comparative testing but it seems unlikely that bed depths can necessarily compensate for increased shear due to higher rates of flow. Head losses are also increased.

It is in the matter of the hydraulics of filter control where changes may be expected. Declining rate filters show some promise (28), (29) as shown in early work in the USA, South America and more recently in pilot plant studies at the WRC. The South American studies have also led to simpler forms of filter. Full scale conversion trials on the declining rate principle are warranted and some are currently in hand.

On the question of backwashing a more careful appraisal is now being made and the need to fluidise the bed for effective washing has been demonstrated. In the United States more attention is being paid to air and water washing rather than water alone. Both in the UK and overseas the merits of simultaneous air and water wash,which is already incorporated in some designs are being looked at further. The optimum degree of mixing in dual and multi-media beds is a question still to be resolved but this has not prevented the wider application of this type of unit.

One practice which has arisen in the USA and has also been used in other countries in Europe is the replacement of part or all of a sand bed with activated carbon to effect filtration and organics removal in one bed. Although this leads to capital savings over separate systems care has to be taken in meeting the requirements of both duties in the same unit (30). This approach is unlikely to be acceptable if long retention times are required.

Plant Control. As labour costs have risen increasing attention has been paid to automation in water treatment as in many fields of processing. Although many hydraulic and mechanical functions, such as flow control, backwashing and materials handling are now commonly automated, little real progress has been made in the automatic control of chemical dosing itself. There is still a need to understand fully the response of a plant to changes in dose and to establish the link between raw water quality and optimum coagulation conditions. One approach (31), using computer analysis of past river water quality and related plant conditions has been used successfully but does not amount to full closed-loop control. The principal difficulty still is to enumerate the possible contaminants in the raw water which can affect plant performance. The matter was discussed during the WRA Conference . Control Systems in the Water Industry in 1975 (32). A pilot filter system described by Conley and Evers (33) has been used in the USA but not so far in this country. The WRC has an active programme in which these factors are being investigated.

Salinity Removal. Leaving aside the question of nitrates (considered on page 2 (a)9 and hardness it is unlikely that widescale salinity reduction will be required particularly in view of the proposed EEC standards, although extensive indirect reuse in rivers and recycling in industry tend to increase salinity levels. Reverse osmosis and ion exchange with part treatment and blending are the most appropriate processes, the Trent Study showing that, for surface waters, the anion membrane in electrodialysis is highly susceptible to organic fouling even with very extensive pretreatment. The main deterrents to the use of membrane processes are, firstly cost and secondly the problem of concentrate disposal. Indeed if reverse osmosis finds a role in water treatment in the future this is more likely to be for the removal of trace materials rather than salinity, the latter being an undesirable but unavoidable feature.

Sludge Treatment and Disposal. Efforts continue to be made to develop processes which avoid the production of sludge and to perfect methods of coagulant recovery where chemical treatment is used. Both these approaches reduce the amount of sludge to be disposed of and therefore are worth pursuing. Another method of disposal gaining favour in the United Kingdom particularly since reorganisation, is discharge to sewer. Work by the WRC in conjunction with Thames Water Authority and by others has shown that there is little detrimental effect on sewage treatment and anaerobic digestion with up to 20% alum sludge although there may be some effect on the filtrability of digested sludge. Of the more conventional approaches filter pressing after thickening is the most widely applied although investigation of the use of newly developed centrifuges and dissolved air flotation thickening is in hand.

Water Use in Industry

The 1976 drought has sharpened interest in industrial water use. Much can be done by careful inventory of water uses within the factory and many of the large industries have effected savings in this way. There is some scope for a fresh look at some processes to convert, where possible, to a dry basis often with concomitant savings. Recycling and cascade approaches have to be looked at carefully, however, on grounds of cost and the effect on processes, on water courses, or on sewers receiving increased discharge concentrations (34). Increased awareness of the technology of water treatment and water use in many processing industries could lead to savings in cost and volume of water used. The most important factor to industry is constancy of quality. In many cases treatment processes have been installed within factories to deal with a specific quality of feed-water. Significant and unannounced changes in quality can have severe effects. As demands on available resources intensify and,as the need to transfer water over large areas increases,more attention will have to be paid to water conditioning by industry.

Appropriate Technology for Developing Countries

It is difficult to be convinced that there is a great need for research specifically on processes for use in developing countries. Shortage of available technology seems to be the least problem in extending the amount of water receiving treatment. Potential solutions exist, particularly processes which are less sophisticated and are able to use locally available materials, such as slow sand filtration. One of the prime needs apart from the provision of money is for studies of human motivation concerning the desire for better quality water supplies and the maintenance of existing systems. Transfer of technology must be achieved on a "pull" rather than a "push" basis and resistance against the provision of highly sophisticated systems, even when pressurised by the customer, would go far towards improving the situation.

SUMMARY OF MAJOR RESEARCH NEEDS IN WATER TREATMENT

1. Unless and until the present strategy for drinking water supplies is drastically changed there will be an essential requirement for substantial research effort on water treatment processes.

2. The present level of funding is modest in comparison with the vital role currently played by water treatment in increasingly difficult circumstances.

3. Emphasis will be directed towards the removal of health-significant contaminants which are often present in trace concentrations.

4. The studies will involve the development of new techniques and approaches as well as the measurement of efficiency of removal of trace materials in conventional processes including chemical treatment and double filtration.

5. Particular emphasis must be given to organic materials including those present in the water and compounds formed by reactions during treatment.

6. The acceptance of more stringent water quality standards for potable water could have major implications in water treatment both in terms of practice and cost.

7. Supply of a risk-free potable water is a desirable goal but may not be realistic in view of the present uncertainties concerning the long term effects of trace materials. Application of advanced treatment techniques will have to be considered ultimately on the basis of cost versus reduced risk.

8. There is a need to determine how far advanced technology can be relied upon to produce an acceptable potable water in the face of deteriorating raw water quality and increasing reuse.

9. Present practices may need to be closely scrutinised on lower quality sources as medical evidence accumulates.

10. Care should be taken that this necessary emphasis on health-related research does not overshadow and squeeze out work on conventional treatment including a small but essential amount of speculative studies. Such work has relevance to overseas and home markets.

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REFERENCES

1. The Society for Water Treatment and Examination and The Water Research Centre, 1970. Proceedings of Conference "Water Treatment in the Seventies" Reading.

2. Packham, R.F. and Miller, D.G., 1970, Proceedings of Conference, "Water Treatment in the Seventies", Reading, 14. Water Research Centre, Henley, England

3. Water Research Centre, 1976, Register of Research in the Water Industry. In Press, Henley, England

4. Stott, P.F., 1975, Water 1, 16

5. Water Research Centre, 1976, "Annual Report 1975/6", Henley, England

6. Department of the Environment, 1975, "Register of Research", HMSO, London

7. Zabel, T.P., and Rees, A.J., 1976, Paper 10, WRC Conference on Flotation for Water and Waste Treatment, Felixstowe. The Centre, Henley, England

8. Water Research Centre, 1976, Conference on Flotation for Water and Waste Treatment, Felixstowe. The Centre, Henley, England

9. World Health Organisation, 1970, "European Standards for Drinking Water: 2nd edition.," Copenhagen, Denmark

10. United States Environmental Protection Agency, 1975, "National Interim Primary Drinking Water Standards", Federal Register, 40, No. 248 59566

11. USSR, 1973, "All - Union State Standards 2874-73" State Committee of Standards of USSR, Council of Ministers

12. European Economic Community, 1975, Council Directive, Official Journal of European Communities No. L194, 26

13. European Economic Council, 1975, Proposed Council Directive, Official Journal of European Communities, No. C214, 2

14. US Environmental Protection Agency, 1975, "Preliminary Assessment of Suspected Carcinogens in Drinking Water", US EPA, Washington

15. WHO International Reference Centre for Community Water Supply, 1975, "Health Effects Relating to Direct and Indirect Re-use of Waste Water for Human Consumption", The Hague, Netherlands.

16. Pochin, E.E., 1975, British Med. Bull. 31, No. 3., 184

17. Water Research Centre, 1975, "Water Resources Research - River Trent Treatment - Part III Final Report" (In Press). Henley, England

18. Melbourne, J.D., and Miller, D.G., 1973, Proceedings of Water Research Centre Conference, "Activated Carbon in Water Treatment", Reading, England.

19. Symons, J.M., 1976, Summary of Granular Activated Carbon Practice Data, USEPA, Cincinnati, USA

20. Gauntlett, R.B., 1975, Wat. Treatment and Examination, 24, 172

21. Water Research Centre, 1975, Removal of Ammonia from River Water; Part 2. Technical Report TR3, The Centre, Henley, England

22. Pugh, N.J., 1949, J. Inst. Wat. Engs. 3, 173

23. Water Research Centre, 1975, Annual Report for 1974/5, 30, The Centre, Henley, England

24. Poynter, S.F.B., and Slade, J.S., 1976, The Removal of Viruses by Slow Sand Filtration. Advances in Water Technology (in Press)

25. Robeck, G.G., Clarke, N.A. and Dostal, K.A., 1962, J. A.W.W.A. 54, 1275

26. Young, E.F., 1970, Proceedings of Conference "Water Treatment in the Seventies," Reading, 33 Water Research Centre, Henley, England

27. Water Research Centre, 1976, "Water Purification in the EEC - State of the Art Review."(In Press) Pergamon Press, Oxford, England

28. Cleasby, J.L., 1969, J. A.W.W.A. 61, 181

29. Arboleda, J., 1972, Proceedings of Symposium on New Methods of Water Treatment Asuncion Pan American Health Organisation, Centre for Sanitary Engineering and Environmental Sciences, Lima, Peru

30. Love, O.T., Robeck, G.G., Symons, J.M., and Buelow, R.W., 1973, Experience with Activated Carbon in the USA. Proceedings of the Conference on Activated Carbon in Water Treatment, 279. Reading. Water Research Centre, Henley, England

31. Lewis, W.M., 1968, J. Instn. Wat. Engrs. 22, 137

32. Melbourne, J.D., and Butcher, R.A.F., 1975, Control and Instrumentation used in the Operation of Water Treatment Plant, Paper 13, WRC Conference on Instruments and Control Systems for the Water Industry, Reading. The Centre, Henley, England

33. Conley, W.R., and Evers, R.H., 1968, J. A.W.W.A. 60, 165

34. Miller, D.G., and Newsome, D.H., 1967, Chem. Eng. Progr. Symp. Series, 63, 13, Am. Inst. Chem. Engrs. New York, USA

TABLE 1 - Standards for Drinking Water
(a) Chemical Standards
mg/litre except where stated otherwise

Constituent	WHO European (9)	US Primary Drinking Water Standards (10) Maximum Contaminant Levels	EEC Proposed (13) Guide Level	EEC Proposed (13) Maximum Admissible Conc.	USSR All Union State Standard 2874-73** (11)
Arsenic	0.05	0.05		0.05	0.05
Barium	1.0	1.0		0.1 ‡	
Selenium	0.01	0.01		0.01	0.001
Chromium	0.05 (Hexavalent)	0.05		0.05	
Lead	0.1	0.05		0.05	0.1
Cadmium	0.01	0.010		0.005	
Cyanide	0.05			0.05	
PAH $\mu g/l$	0.2			0.2	
Fluoride	0.9 - 1.7*	1.4 - 2.4*		0.7-1.5*	0.7 - 1.5*
Nitrate	11 - 22 (as N)	10 (as N)		50 (as NO_3)‡	10 (as N)
Sulphate	250		5	250‡	500
Carbon Chloroform Extract	0.2 - 0.5				
Copper	0.05			0.050 1.5 after 16hrs at tap‡	1.0
Iron	0.1		0.1	0.3‡	0.3
Phenols	0.001			0.0005	
Manganese	0.05		0.02	0.05‡	0.1
Zinc	5.0			0.100 2.0 after 16hrs at tap	5.0
Magnesium	30 if $SO_4 \geqslant 250$ 125 if $SO_4 < 250$		30	50 (MRC 5) +	
Hydrogen Sulphide	0.05			Nil	
Chloride	200 - 600		5	200‡	350
Anionic Detergents	0.2			0.1 (lauryl sulphate)	
Ammonia	0.05		0.05 (as NH_4)	0.5 (as NH_4)	

Constituent	WHO European	US Primary Drinking Water Standards	EEC Proposed		USSR All Union State Standard 2874-73
		Maximum Contaminant Levels	Guide Level	Maximum Admissible Conc.	
Total Hardness	100 - 500 (as $CaCO_3$)		35	(MRC 10) + Hydrometric titre	7.0mEq/l
Mercury		0.002		0.001	
Silver		0.05		0.01	0.05
Turbidity		1.0(TU) (5.0 in some circumstances)	5 (SiO_2) 0.1 JTU	10 0.3	$\ngtr$ 1.5standard scale
a) Chlorinated Hydrocarbons :					
Endrin		0.0002			
Lindane		0.004			
Methoxychlor		0.1			
Toxaphene		0.005			
b) Chlorophenoxys:					
2,4 - D		0.1			
2,4,5 - TP Silvex		0.01			
Colour (Pt units)			5	20‡	$\ngtr$ 20 units
Odour			0	2 @ 12°C 3 @ 25°C	At 20°C when heated to 60°C $\ngtr$ 2
Palatibility			0	2 @ 12°C 3 @ 25°C	$\ngtr$ 2 @ 20°C
Temperature			12	25‡	
Conductivity			400µs/Cm	1250µs/Cm‡	
pH			6.5 - 8.5	9.5 (MRC 6.00)†	6.5 - 8.5
Total Mineral Content				1500‡ Dry residue (MRC10)	1000
Calcium			100		
Sodium			<20	100‡	
Potassium			$\leqslant10$	12‡	
Aluminium				0.05‡	
Alkali Level CO_3H			30		

Constituent	WHO European	US Primary Drinking Water Standards	EEC Proposed		USSR All Union State Standard 2874-73
		Maximum Contaminant Levels	Guide Level	Maximum Admissible Conc.	
Nitrites				0.1 (as NO_2)	
Kjeldahl-Nitrogen			0.05	0.5 N+ (excluding N in NO and NO_3)	
Silica			5mg/l SiO_2 above natural level		
Substances Extractable In Chloroform			0.1 dry residue		
Dissolved Oxygen			5(asO_2)		
Oxidability			1 O_2($KMnO_4$)	5‡	
BOD_5			50% of initial DO		
TOC			Reason for increase in usual concentration to be given		
Nickel			0.005	0.050	
Phosphorus			0.3	2.0 after isolation	
Antimony				0.01	
Mineral Oils				0.01 residue	
Total Pesticides $\mu g/l$				0.5	
Individual Pesticides $\mu g/l$				0.1	
Other Organo Chlorine Compounds $\mu g/l$				1.0	
Beryllium Be^{2+}					0.0002
Molybdenum Mo^{2+}					0.5
Polyacrylamide					2.0
Strontium Sr^{2+}					2.0
Uranium (Natural and 238)					1.7
Radium - 226					1.2×10^{-10} curie/l

Constituent	WHO European	US Primary Drinking Water Standards	EEC Proposed		USSR All Union State Standard 2874-73
		Maximum Contaminant Levels	Guide Level	Maximum Admissible Conc.	
Strontium-90					1.0×10^{-10} curie/l
Hexamethaphosphate					3.5 as PO_4
Tripolyphosphate					3.5 as PO_4

* = Depends on Atmospheric Temperature

+ = MRC Minimum Required Concentration

‡ = Recourse to Exceptional Maximum Admissible Concentrations Possible (EMAC)

** = For toxic substances (except fluoride, nitrate and radioactivity) and for taste producing compounds the total concentration expressed in fractions of maximum tolerable concentrations of each should not exceed 1.

e.g. $$\frac{c_1}{C_1} + \frac{c_2}{C_2} + \ldots\ldots\ldots\ldots + \frac{c_n}{C_n} \leqslant 1$$

c_1 etc is detected concentration C_1 etc is standard

TABLE 1 CONTINUED - Standards for Drinking Water
(b) Bacteriological Standards *

WHO European Standards (9)

Coliforms absent in water entering distribution

USA Primary Drinking Water Standards (10)

(a) Membrane Filter

No. of coliforms

- $\not>$ 1 per 100ml mean of all samples per month
- $\not>$ 4 per 100ml in more than one sample when $<$ 20 examined per month
- $\not>$ 4 per 100ml in more than 5% of samples when 20 or more examined per month

(b) Fermentation Tube 10ml Standard Portions

No coliforms present in

- (i) more than 10% of portions in any month
- (ii) 3 or more portions in more than 1 sample when less than 20 samples per month
- (iii) 3 or more portions in more than 5% of samples when 20 or more samples/month

(c) Fermentation Tube 100ml Standard Portions

No coliforms present in

- (i) more than 60% of portions in any month
- (ii) 5 portions in more than 1 sample when less than 5 samples per month
- (iii) 5 portions in more than 20% of samples when 5 or more samples per month

USSR All Union State Standard 2874-73 (11)

Total bacteria $\not>$ 100 in 1ml
Coliform bacteria $\not>$ 3 in 1 litre (using liquid media of coli titre accumulation $\not<$ 300)

* All standards specify frequency of sampling often on the basis of population

TABLE 1 (CONTD) - Standards for Drinking Water (b) Bacteriological Standards EEC Proposed (13)

Parameters	Basic	Supplementary	Results Volume of the Sample in ml	Community Values Tap Water (1) Not dis-infected MAC	 Tap Water (1) Disinfected MAC	 Surface Water Disin-fected MAC	 Treated Water Not dis-infected MAC	Comments
Total Coliforms	+		100	5[3]	0	0	0[1]	(1) At consumer outlet
Fecal Coliforms	+		100	0	0	0	0[1]	(2) At catchment
Fecal Streptococci	+		100	0	0	0	0[1]	(3) On condition that enough samples are analysed and results are 95% uniform
Total Count at 37°	+		1	10	–	–	10[2]	
Total Count at 22°	+		1	100	–	–	100[2]	(4) Per type of bacteriophage
Total Count at 37°		+	1	–	0	0	–	(5) Qualitative research result
Total Count at 22°		+	1	–	20	20	–	
Clostridium (sulphite reducing)		+	20	2	2	2	0[1]	
Salmonella		+	5000	0	0	0	0[1]	
Pathogenic Staphylococci		+	100	0	0	0	0[1]	
Fecal Bact-eriophages		+	100	0[4]	0	0	0[1]	
Enteropath-ogenic viruses		+	10000	0	0	0	0[1]	
Protozoa		+	–	nil[5]	nil	nil	nil[1]	
Animalcules		+		nil[5]				

TABLE 2 - Relative Risks of Death from Different Activities (16)

Activity	Death Risk of 1 in 1 Million Level or Duration
Smoking	1½ cigarettes
Drinking	½ bottle of wine
Car Travel	50 miles
Air Travel	250 miles
Rock Climbing	1½ minutes
Canoeing	6 minutes
Typical Factory Work	1-2 weeks
Man at Age 60	20 minutes

TABLE 3 - Estimated Total Treatment Costs (Capital plus Operating) for Different Treatments
p/m^3 Jan 1975 *

Treatment	$0.25m^3/sec$		$0.5m^3/sec$		$1.0m^3/sec$	
	10% Interest	14% Interest	10% Interest	14% Interest	10% Interest	14% Interest
Conventional						
7 days storage coagulation sedimentation filtration chlorination and sludge treatment	3.00	3.66	2.52	3.04	2.22	2.60
Ammonia Removal						
Biological nitrification	0.02	0.03	0.02	0.03	0.02	0.02
Nitrate Removal						
Biological denitrification	0.25	0.26	0.25	0.26	0.25	0.25
Activated Carbon Treatment						
Moving bed 52 minutes contact time, on-site re-generation	2.38	2.76	2.18	2.52	1.99	2.29
Reverse Osmosis (Excludes Concentrate Disposal)						
7 days storage, upflow filtration reverse osmosis activated carbon post treatment for taste and odour pH adjustment and hardening, chlorination	12.85	14.23	12.41	13.64	12.05	13.18
Sea Water Desalination (September 1976)						
Multistage flash distillation. Range of costs depending on fuel costs and whether single or dual-purpose plant			45-59	51-64		

* data reproduced from the W.R.C. River Trent Study, by permission of the Severn-Trent Water Authority and the Department of the Environment, ref 17.

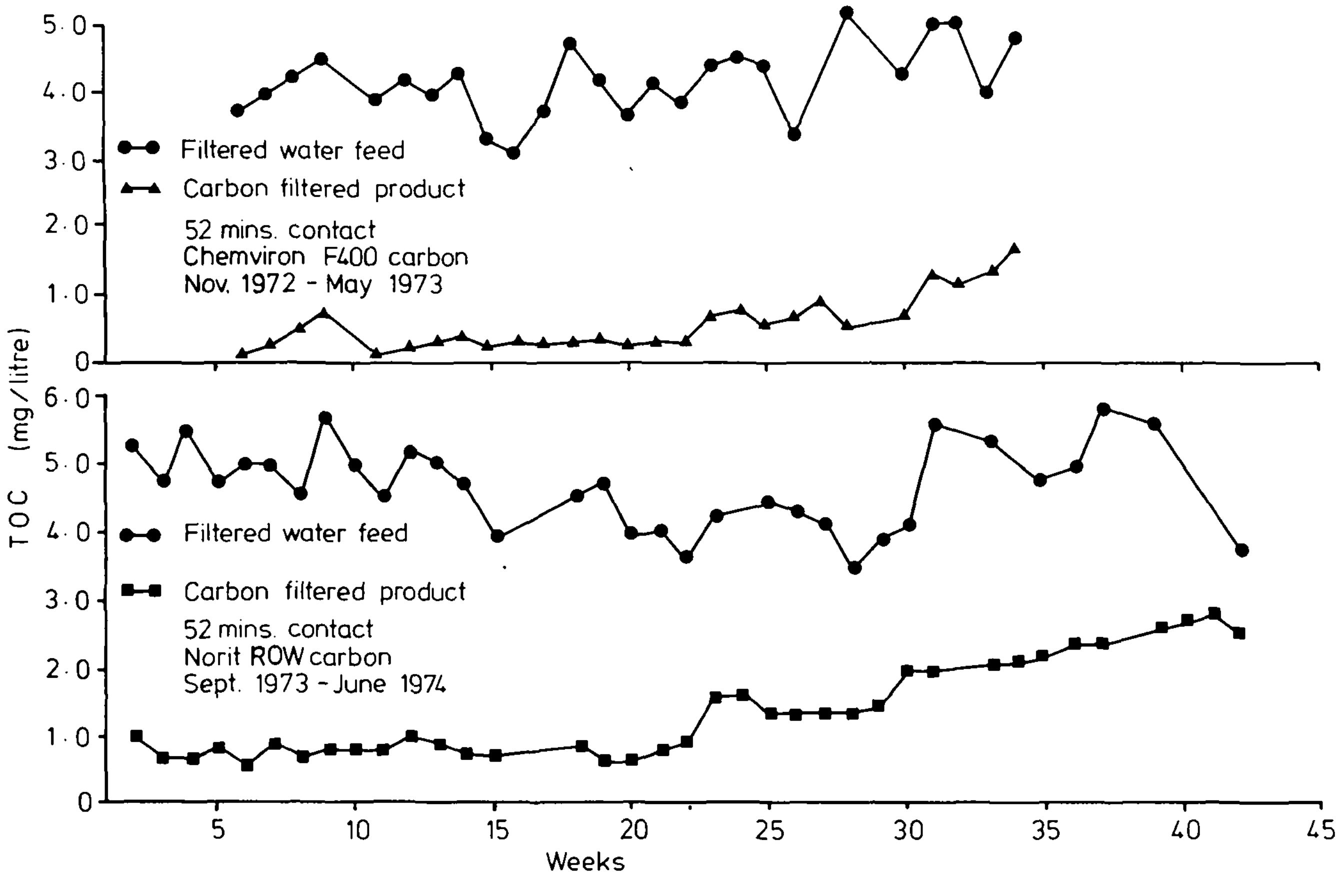

Figure 1. TOC removal in activated carbon filters
(Reproduced by permission of the Severn-Trent Water Authority and the Department of Environment)

DISCUSSION

Author's Introduction

DR. D.G. MILLER, in outlining the salient points of his paper, said that predicting research needs was like trying to foresee future inventions or prescribe medicines for possible future illnesses. It would be hoped that some of the water treatment research in progress was designed to produce preventative medicines.

It could not be emphasized enough that the support of research was essentially an act of faith. The Rothschild customer-contractor principle was sound, but there was a danger of speculative work being squeezed out. In looking at research expenditure it was noticeable that very little water treatment research was being carried out in the Universities in the UK in comparison, for example, with sewage treatment. Furthermore, only one academic establishment was represented at the present Symposium. With cuts in funding at the Universities it might be necessary for the professional institutions to make special arrangements for students to sit in on meetings and even to consider funding a limited number of delegates.

In summarizing the major influences on future research, he referred particularly to quality standards and health studies. The application of standards to drinking water was a new concept in the UK and therefore it was not surprising that there had been considerable discussion to get rational and reasonable limits for the proposed EEC limits. The problems experienced in assessing water quality in numerical terms were similar to those encountered in assigning numbers to peoples' ability - so much was left unsaid. The paper had stressed the considerable influence that the future strategy for drinking water would have on research needs. Mr. McLellan, in opening the Symposium, had asked for a definition of first hand water. It was rather like motor cars, in this case the concern was for the quality of the product with one or more previous industrial or domestic owners albeit with regular servicing. There was clearly no need for panic measures at the present time as were being taken in certain other countries, but the situation had to be kept under review. Dr. Key had eminently summed up the problem of micro-pollutants when he likened it to searching for a black cat in the coal cellar with the light off. A further problem in the future would be the dilemma of requiring higher standards for water while conforming with stringent economic restrictions.

In looking at future research he could not see any revolutionary methods being developed in water treatment in view of the great variety of processes already tried. Much more work was needed on the removal of organic compounds, but to make this effective better guidelines were needed on acceptable levels. On the matter of nitrates, considerable effort should be made to blend supplies in view of the relatively expensive removal processes which also had quality problems. In disinfection he was sure that chlorine would continue to have a major role, although there could be adjustments in the method of use and also greater emphasis on the prior removal of organics. Firm epidemiological evidence was still required on the effects of haloforms.

In conclusion, he re-emphasised that it was unrealistic for the public to expect a completely risk-free water at all times any more than they could expect a risk-free life in general. The problem in the future would be to relate costs of treatment with concomitant reductions in risk.

Verbal Discussion

MR. N.J. NICHOLSON (Thames Water Authority), in opening the discussion, said that the author had adopted a cautious approach - with which he would not disagree - implying that progress would be made largely through the application of existing principles or the better understanding of existing processes. He wondered whether the author had intended to exclude a consideration of problems which arose in distribution systems and for which treatment solutions might be required.

On the level of support for water treatment, the investment in 1974-75 of 1.3% of capital compared not unfavourably with such as the gas and electrical industries. He contrasted this figure with early subscription rates to the Water Research Association of the order of 0.1 to 0.2%. Would the author also concede that some proportion of research on water reclamation had water treatment implications. He shared the author's apprehension that, when times were hard, there was a temptation to reduce research investment. He strongly supported a continuity of level of effort for the longer term.

He would not disagree with the author's views on standards, only adding the need to consider probability levels associated with standards especially for those determinands known to be cumulative. He also added a plea for water standards not to be over stringent when food or air contributed a significant proportion of body intake.

Concerning research management, he agreed with freedom for the professional researcher. On formulating the programme, the needs of the industry must be kept uppermost in mind, with allowances for changes in direction of research programmes.

In connexion with viruses, he could see a need for sustained research effort on removal efficiencies in different unit processes, especially with the continued uprating in filters with consequent greater penetration into the beds. There remained, however, room for discussion on choice of indicator viruses and the sensitivity of detection before comparability with E.coli for bacteria was attained.

He wondered how much remained to be done in application of results; to overcome apathy and resistance to change a more aggressive "marketing" approach might be necessary. In view of the increased apprehension regarding formation of organo-chlorine compounds, it was surprising that ammonia removal via biological sedimentation with its saving in chlorine costs had not found greater favour. On denitrification of river water, he queried the cost figure quoted in Table 3. They appeared insensitive to scale and, in view of the cost of methanol, somewhat on the low side.

Finally, to end with a question on denitrification (so important to users of lowland rivers) he asked whether it might be possible to run a biological sedimentation unit routinely for ammonia removal and by addition of methanol to modify the same unit quickly to remove nitrate if river concentrations became unacceptable. It seemed that flow rates and the bacteria present were very similar in each case. This would help justify denitrifying units for the times when needed, and reducing chlorination costs at other times.

MR. C.A. SERPELL (Sunderland and South Shields Water Company), said that in his references to the application of the results of research and development, the author had mentioned the difficulties of innovation. He himself saw it as the responsibility of water undertakers in the field to take pioneering initiatives which, with the help of the Water Research Centre, would expedite the development of new techniques.

In the matter of pilot plants, there was seldom enough time for them to be properly exploited before decisions had to be taken on the facilities to be provided in the permanent plant. For this reason there was merit in dispensing with the ad hoc pilot plant in favour of constructing treatment works with the maximum in-built flexibility which would enable pilot trials to be carried out whenever the need arose.

With his references to the high priority pollutants mentioned in the World Health Organization 1975 Amsterdam Report, the author raised a doubt about the national strategy of abstracting water from the lower reaches of rivers and the desirability of using "second hand" water for public supply. The view had been expressed elsewhere that the problem was not one of toxic substances, but of toxic concentrations, and it was becoming clear that analytical abilities were outstripping epidemiological knowledge of those concentrations. Until the necessary but inevitably long-term epidemiological studies had yielded results, there was patently a need to make a balanced judgement of the risks involved.

The way ahead must be to determine the level of toxic concentrations which could safely be tolerated and at the same time to develop treatment processes that would produce water in which those levels were not exceeded. If we were to fail in these objectives and the strategy of abstracting water from rivers had to be re-appraised, the economic consequences could be awesome. The scope for research in the development of water treatment techniques therefore amounted to a major financial commitment. It was essential that the effectiveness of the water industry's treatment technology be kept at least one step ahead of the medical findings, and the cost of maintaining that lead could be substantial.

MR. E.R. GARDINER (Bristol Waterworks Company) expressed concern about the time that was being taken in deciding toxic levels of organic compounds which had been said to have a deleterious effect in drinking water. There were several treatment works which had been in production for a decade or more treating water from lowland river sources which must have contributed some organic substances to consumers during this period; he asked if any medical evidence was available in relation to those areas of supply. It was important to get the effect of these substances into perspective with toxological data as soon as possible to allow the planning of treatment for their removal. It had been said that all lowland sources should have an organic removal stage in their treatment, but the cost could not be justified without medical evidence supporting the need for such treatment.

Concerning the use of activated carbon, he described the work which had been carried out by replacing the sand, anthracite, and part of the support gravel in a rapid gravity filter with activated carbon. Its purpose was to establish the length of time required to exhaust the ability of the carbon to remove TOC to a level of 1 mg/l in the effluent from the filter; to examine the feasibility of using granular carbon in the filter; and to check the effect of backwashing facilities on the carbon.

The conditions of flow were such that there was 20 min. contact time in the filter. This period was shown to have been sufficient in achieving removal to 1 mg/l TOC by experiments carried out with a pilot plant filter where samples were taken after 5, 10, 15, 20, and 30 min. contact times from different levels in the filter bed. More than 1 mg/l TOC passed in the filter effluent from the rapid gravity filter after 80 days. In Fig. 1 of the paper much longer runs were achieved although the levels of TOC in the water being treated were generally of the same order as those of the Trent Research programme. In this case F300 carbon was used and not the F400 reported in the paper.

The author's comments would be welcomed on whether he considered that the removal of TOC by activated carbon was proportionally related to the initial cost of the carbon, as it was understood that F400 carbon was more costly than F300. Furthermore, it appeared that in all experiments only one grade of carbon had been used: would some research into the effect of mixed carbon grades in a filter prove to be of beneifit? It had been found with powdered activated carbon that a mixed carbon was more effective in the removal of taste and odour than using a single carbon. The benefit had been both in the lowering of threshold odour values and in cost of the treatment compared with using a more expensive carbon in the powdered activated carbon treatment.

In the area of co-operative research more data could be obtained from work being carried out by the soft drinks industry and the Central Electricity Generating Board. These industries, and possibly others, had for some time been concerned with organics removal and while it was appreciated that the water quantities involved were small compared with public water supply treatment plants, allowing ion exchange and reverse osmosis to be utilized in treatment, the levels and types of organic substances removed by these processes could prove to be useful additional data in the assessment of future design within the water industry. As plants in those other industries were situated in different parts of the country with varying water quality, a broader view of their efficiency could be obtained in co-operation with those industries. Had this avenue been fully investigated with these and other industries?

MR. W.N. RICHARDS (Wessex Water Authority) said that in his Presidential Address to the Institution* Mr. Bays had pointed out some of the problems arising from the EEC Directive on the quality of water for human consumption and the author had shown these standards could not be ignored. They might have far reaching consequences both on treatment technology and on the costs of continuing to supply a "wholesome" water. Unless changes were made to the proposed standards one could be tempted to suggest in Samual Coleridge Taylor's words, that we might have "water, water everywhere, Nor any drop to drink". Unless of course it met the approval of the "experts" in Brussels or we gained exceptions to the maximum allowable concentrations. In view of its interest in water quality, it was puzzling and regrettable to discover that the EEC was apparently unable or unwilling to support research on water treatment projects.

He was in favour of sensible standards and welcomed whole-heartedly the author's comments on health effects and the need to relate risk with cost. The UK water industry had a quality and health record that was the envy of the world. However, complacency should not prevail and advances in medical knowledge must be heeded. Nevertheless, we should not be afraid of questioning

* *Journ. I.W.E.S.*, 1976, vol. 30, p. 241.

fashionable, nonsensical or costly standards. In such cases, as with infants in high nitrate areas, it might be more economical to supply bottled water, rather than treat all of the water.

There was an obvious need for continued and increased research into water treatment; also, speculative pure research should not be ignored. Rothschild's philosophy was not necessarily appropriate when applied to matters affecting the nation's health, welfare, and economic well-being. The author had referred to the "classical" work carried out at Medmenham on flotation. He himself had worked with Dr. Packham on this project and could not remember any customer - only a problem that required a solution. The solution fortunately proved to have advantages that were not forseen but amply justified the Centre's speculative efforts.

Dr. Palin had spoken highly of poly-aluminium chloride and he concurred. This chemical had apparently been developed accidentally by a Japanese fertilizer company. In France, investigations were being carried out to develop new improved coagulants of a similar nature. Was this aspect of colloid chemistry being followed up in the UK and could it be said that our scientists were working to produce an optimum coagulant for a given water type?

Finally, the author had implied that when it came to procuring new supplies, a change in policy might be required. He asked should we employ "relatively high rate" slow sand filtration, perhaps after ozonation? Were the problems of water re-use sufficiently serious to affect our long-term resource planning options or could we rely on treatment technology to remain one step ahead?

MR. G.J. HOLLAND (Severn-Trent Water Authority) said that in his introduction the author had said that water engineers universally seemed to hold the opinion that the water they supplied was wholesome, and he had indicated that he could not necessarily embrace that same overall view (or degree of implicit faith!). Perhaps future research would reveal legitimate doubt. He himself could not embrace the generally held view point that research was always gainfully used. The paper had concluded with a list of ten major research needs, and he suggested that an additional line should be pursued, one which applied generally in research, but which would be very relevant in the field of water treatment. Notwithstanding the excellent work of the information service of the Water Research Centre, and the dissemination of information at the type of symposium then being held, he was not sure that the fruits of research sponsored by the water industry were being fully exploited. Should not some research effort be put in to establish to what extent this was happening? If this led to existing research findings being put to good additional use, this would help to maximize the return on research investment.

Researchers in America, Europe, and Russia were making rapid strides in using advanced analytical techniques to demonstrate the complexity of organic constituents present in many water supplies. GLC-mass spectrometry techniques had been used to identify many hundreds of such constituents, but the present limitations of spectral library facilities meant that only a small proportion of the range of substances revealed by such means could be readily identified. When organic isolates from water were not on MS library file, laborious and lengthy work was needed for their identification. What facilities were being developed to co-ordinate the findings of researchers in various countries who were currently meeting this as a common problem in water research.

The research findings on identification of organic substances in water would always extend far beyond the range of compounds which had known physiological implications, and where the health aspects were understood. He asked the author how he saw some rationalization of the implications of this state of affairs.

DR. G.I. BARROW (Public Health Laboratory Service, Truro) commented on some of the microbiological aspects of potable supplies from the viewpoint of a medical and public health bacteriologist. Although microbiological standards were intended primarily to safeguard health, it was now becoming fashionable to extend their scope to other environmental areas. It was important to realize that there was a distinction between monitoring and surveillance. Monitoring was used to ensure that specified quality criteria, preferably based on evidence and experience, were not only being attained but maintained, and samples must therefore be examined sufficiently regularly and frequently to permit speedy remedial action. In contrast, surveillance was concerned more with longer term trends and their ultimate effects on water quality and then on health and safety. Although monitoring was directly concerned with public health and preventative medicine, some of the current analytical work, though desirable, was perhaps more in the nature of research and surveillance.

The risks of actual or potential health hazards could only be reduced (in the light of current knowledge and likely cost benefit) to acceptable levels, which would inevitably vary from place to place and time to time. Universal standards, in contrast to objectives, were still a long way off. There might be a danger in trying to look too far ahead, and neither trivial nor unusual diseases should be sought in order to justify arbitrary standards without good medical or epidemiological reasons. He agreed with the author and other speakers that sensible liaison between all concerned was essential. With the current economic climate in Britain, money would be well spent maintaining the present quality of most potable supplies.

Finally, he mentioned that the well-known Report No. 71 on "The bacteriological examination of water supplies" was to be revised, and he would welcome constructive.comments on any changes in content or application which users might think helpful.

DR. E.J.M. KOBUS (KIWA Ltd.; the Testing and Research Institute of the Netherlands Waterworks) said that the paper covered many topics which were not only interesting for the UK but also for overseas countries as well. One of these was the organization and the funding of research for the public water supply. The author gave three approaches for the funding of the water research, one of which was the co-operative research which was widely used in the UK. The KIWA water research effort was also organized on a co-operative basis. The research department of KIWA carried out a research programme for the Dutch water companies, which was financed by the Netherlands Waterworks Association from contribution paid by the water companies. The programme could be influenced by the water companies, since it was drawn up by the Research Committee of the Netherlands Waterworks Association.

The author had mentioned that each approach for the funding of the research, and of course also the co-operative approach had its strengths and weaknesses. The strengths of the co-operative research in terms of less duplication, centralized facilities and expertise and relatively low costs for each contributor were well known. One of the weaknesses of the system was the liaison between the scientists in the central institute and those in the water companies. KIWA had tried to solve this problem by guiding each project by a small working group consisting of specialists of the water companies and the KIWA staff members involved. KIWA had more than 10 years' experience with these working groups and considered them valuable to keep the research focussed on the daily practice in the water companies.

He asked how the Water Research Centre approached this problem and especially whether the Centre had experience of other means of maintaining close contact between the Centre and the industry.

MR. P.G. DAVEY (Severn-Trent Water Authority) said that his remarks could apply to both the papers on research, since they appeared to make little or no mention of developments or research into the very fundamental matter of materials of construction. He was a little cynical where research was concerned, particularly in the water industry, where so much of it appeared to be "pure" rather than "practical". He asked the authors to comment on the need for practical research on materials in order to provide greater flexibility in the design, and modifications to works, particularly where tanks and pipework were involved. In the past, the rigid adherence to concrete and iron now effectively precluded any sensible and economic modifications to existing works because of the trouble involved in demolishing the large redundant monoliths of the past. It was time to adopt a more industrial attitude, and consider the extensive use of lighter and more flexible materials.

MR. F.H. PERRIN (Joseph Crosfield and Sons Ltd.) agreed that excellent pilot plant facilities were available at Medmenham, although a great deal of development work had been carried out at waterworks sites, where facilities existed.

However, the ability to continue to carry out this kind of work was inhibited by the fact that in Western Europe a section of treatment plant, including filtration, could not be isolated easily from the rest and confidence necessary for "risk" money was difficult to establish. He cited an example of a plant treating 7.9 m^3/s (150 mgd) in eight upward flow sedimentation tanks with no provision for isolating even one tank. The manufacturer claimed that such a facility had to be omitted when tendering in order that the quotation should be one of the two lowest which would be considered.

It was believed that a similar situation existed in the UK. If this was so, he suggested that those charged with the responsibility for placing an order for a water treatment plant should refuse to accept any tender which did not have, as an integral part of its design, provision for the complete isolation of one section for experimental work.

Changes in water quality, or the need to evaluate new chemicals, made this facility imperative. Any water undertaking should be concerned to know what happened with its water when treated with new chemicals, not merely what trends were suggested by pilot plant experiments at the Water Research Centre.

MR. W.E. BLACKMORE (Sir William Halcrow and Partners) asked whether some research was being done, or could be done, on the possibility of a dual supply of potable and non-potable water. It was depressing to think that of the 50-odd litres of water per day that each person used, perhaps less than one litre was absorbed; the rest was used for flushing toilets, washing, watering the garden, carrying out industrial processes, etc., none of which activities required the standard of purity which was sought at considerable cost. One was reminded of the recently published conclusion in connexion with water supply to underdeveloped countries, that for a given budget, an abundant supply of not-so-pure water was more conducive to good health than a limited supply of very pure water. The research might be done into the possibility of giving, in the first place, a separate supply of non-potable water to factories, laundries, and other large users of water; and, eventually, to individual households in areas where the provision of new mains gave an opportunity of laying twin mains for potable and non-potable water.

Author's Reply to Discussion

DR. D.G. MILLER, in reply to the discussion contribution from Mr. Nicolson, wrote that it was clear that the responsibilities of the water supplier did not cease when the water left the treatment plant. It was difficult to foresee, however, the requirements for further treatment research compared with the application of established principles, which included the removal of iron, manganese and organic materials together with pH and hardness corrections. In assessing the adequacy of the level of support for research in water treatment, it had to be borne in mind that this was an area where many of the benefits were difficult to quantify. He agreed that there was spin-off in both directions between water reclamation and water treatment.

Mr. Nicolson had questioned the denitrification costs given in the paper. The costs would depend significantly on the degree of nitrate removal and on the ammonia levels in raw water, since the greatest cost was for methanol dosing. For the river Trent study the costs included methanol dosing at 30mg/l and were believed to be reasonable estimates at January 1975 prices. At the high up-flow rates taken (18 m/hr) any economies of scale would appear in the third place of decimals. Use of a single-stage unit for alternate nitrification and de-nitrification was an interesting approach. However, development of a new bacterial colony was unlikely to be rapid and re-cycling would be necessary to take care of methanol breakthrough until conditions had been established.

Mr. Serpell had made some important points in his contribution. Concerning pilot-plants, it really depended on the degree of difference in the options available when treating a new source. Major differences - for example, the use of single or two-stage treatment or the adoption of sedimentation or flotation - could only be assessed by a pilot-plant test and full-scale changes would not be possible. Forward planning was therefore very important. He agreed on the need for balanced judgement in assessing risks, but the difficulty at present was the lack of adequate information on which to make a good scientific decision. This question had also been raised by Mr. Gardner, Mr. Richards, and Mr. Holland. Abstraction from extensively re-used lowland rivers had been practised for many years. No obvious harmful effects had been detected. More recent evidence suggested that a closer look should be taken and research studies were in progress in Europe, South Africa, Israel, and the United States.

There would be no quick answers and in the meantime the option of leaning on advanced technology both at the discharge and abstration point should be examined closely. The old maxim of opting for the better sources was still sound and the relative costs should not ignore possible risks. In the long-run each scheme had to be considered on its merit, but opponents of reservoirs should be informed of the possible implications of the alternative approaches.

Mr. Gardiner had compared the results from the studies on carbon adsorption at Bristol and on the Trent. Chemviron F300 carbon had been used for some of the Trent work as well as Norit material. F400 carbon was more effective than F300, due probably to the higher surface area to volume ratio of the smaller F400 particles. Significant improvements in TOC levels were obtained by increasing the residence time from 26 to 52 min. and a further but smaller improvement resulted at 78 min. There was some evidence from work in Germany that mixtures of carbon could be more effective for organics removal, but the situation with taste and odour problems was undoubtedly complicated by significant biological activity in the carbon. His suggestion that closer contact should be made with other industries concerned with organics removal was a good one and was being followed up, certainly in relation to reverse osmosis.

He thanked Mr. Richards for his comments, which largely supported the points made in the paper. The use of biological treatment methods such as slow-sand filtration deserved more attention, but it could not be assumed that they would be more effective against harmful trace organics. They might well form part of a more comprehensive treatment system in the future. The use of ozone had to be carefully examined in view of its powers of fragmentation.

Dr. Kobus had asked about methods for maintaining contact between the research worker and industry. The Centre regarded as essential the direct contact between its staff and all its different categories of membership, both by discussion and by field research. The UK also had Technical Committees to guide the work in addition to the feedback obtained through the Member Services Division, set up especially to promote contact. The system of voluntary funding also served to keep the Centre on its toes.

In reply to Mr. Davey, he did not understand the reference to "pure" and "practical" research. Most of the Centre's research and that in the Regional Water Authorities was practical, since it had led to considerable operational changes in the industry. He agreed that research on materials of construction for treatment plant had been limited. This was partly brought about by studies such as those carried out by CIRIA, where alternatives to the traditional approach had been costed and found to be more expensive for all but the smallest installations. Development of higher-rate processes with smaller unit sizes might provide more scope for the industrial approach.

Mr. Perrin made a good point about provision of facilities to isolate plant for experimental purposes. However, it must be pointed out that on-site pilot-plant tests had been a prominent part of the WRC programme to cover the effects of local conditions. Major changes in treatment were difficult to achieve on the full-scale.

Mr. Holland had raised the important question of the application of research results. Certain maximum effort was necessary to get work applied. Direct contact between research worker and the industry was crucial in this respect as well as the back-up from the technical liaison officers and information services. The Centre would continue to strive for increased contact. There was little chance of results being applied as a result of pushing research reports through the letter box.

Considerable international co-operation was already taking place between European countries and also with the United States to exchange mass-spectra data. The development of specific libraries relevant to water was more helpful than access to massive data banks which included substances not found in water. Exchange of unknown peaks between workers was also advantageous.

Dr. Barrow had made an important point in distinguishing between monitoring and surveillance, and he agreed that care had to be taken when defining the studies in hand.

In reply to Mr. Blackmore, studies had been made of separate non-potable supplies both to industry and to domestic consumers. Part of the Trent study had examined the former and Professor Ives, at University College, had studied the latter. Some areas of the country already had separate industrial supplies. The question had to be asked, however, whether piping the small quantities of potable supplies to houses which involved a separate reticulation system would be the most economic approach compared with container delivery, although this had also some considerable practical problems.

2(b) RESEARCH ASPECTS : SEWAGE

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INTRODUCTION

Research in relation to future developments in sewage treatment is an extremely wide subject requiring far more than a single paper for its adequate consideration. The present paper is therefore broadly selective by dealing only with technical aspects of the subject and is additionally oriented mainly to the situation in the UK rather than to a balanced global view. No attempt is made to confine the paper within any rigid definition of research and least of all to attempt to distinguish between research and development. In the author's view it is essential for the "research" worker to pursue his work through "development" stages and to stay with it in full-scale application until it is adequately proven. Having developed in the laboratory a decade ago, an antidote for the poisoning of anaerobic sludge digestion by anionic synthetic detergents, the method was offered to a sewage works manager, who having had his 5700 m^3 digester almost completely inactive for many months, on a works closely surrounded by residential development, was in a state of near desperation. As sludge technologists will know, highly active digesting sludge is liable to expand into a foamed state and it was a salutary experience for this "research" worker to visit the works, and standing at the perimeter of an extensive circular flood of bubbling sludge around the digester, explaining to the manager that the treatment was clearly more successful than even the laboratory trials had indicated. Whether an innovation meets with unexpected success or difficulty in its development stages the research worker's continued participation might be vital in securing its optimum utilisation and the experience is certainly important to the innovator.

Research also extends far beyond the introduction of inventions and much of the work to be discussed, illustrates what is probably the most valuable aspect of a research team, namely the ability to provide a scientific basis and understanding of existing methods, and to use this understanding to achieve the most economical application of processes. There are cases where processes developed abroad have been adopted in this country only to result in very costly full-scale installations proving useless or giving disappointing performance because the conditions under which the processes had operated successfully elsewhere had not been adequately analysed and understood. Likewise there are examples where research expertise has been able to predict performance of processes under new conditions and so avoid highly expensive development mistakes. One of the major problems facing the Water Industry is the need to improve the performance of existing overloaded sewage works and research has a major role to play here also.

Reorganisation of the Water Industry nearly 3 years ago provided more opportunity not only to co-ordinate central research but to carry this out in co-operation with the Industry. In addition to the Water Research Centre's programme of over 170 research projects, the WRC Register of Research in the Water Industry (1), produced this year for the first time, shows over 490 projects undertaken by water authorities and water companies covering research, development, monitoring and evaluation and providing the essential continuity from laboratory to full-scale operation.

*Water Research Centre

It might also be noted that compilation of the Register of Research also fulfills a specific requirement identified by the WRC Water Authorities Panel in their report "The research needs of water authorities" (2) - "Difficult though the process might be the Panel felt that a concentrated effort should be made centrally to identify, record and report research and development effort in WAs." This introduction is also a convenient point at which to refer to the Panel's report in relation to the sewage and sludge sector, and against which recent work described in this paper may be considered - "Personal involvement of water authority staff in WRC research management and of WRC staff on the ground in water authorities will need to be increased as this will be the most fruitful and effective measure."

It is of further interest to refer to the first annual analysis of water authority expenditure (3) which showed that the total revenue expenditure in England and Wales in 1974/75 on sewage collection, treatment and disposal, was nearly £320 million and the capital expenditure nearly £280 million. Clearly there is an urgent challenge to the research worker to find means of reducing these costs.

CO-OPERATIVE RESEARCH IN EUROPE

The recent history of water pollution abatement in Europe has been reviewed elsewhere (4) and the efforts to achieve acceptable pollution control have been accompanied by a very active interest in research. The EEC has been a focal point for co-operative research and has initiated work under common actions, involving Member States and partially supported by community funds, as well as under concerted actions open also to countries outside the community but financially assisted by the community to the extent only of the project management. The Centre contributed to the latter type of activity before joining the community, by participating in COST 64b (micropollutants) and COST 68 (sludge processing), and since that time has undertaken contract work for the Environment and Consumer Protection Service of the Commission as well as applying for participation in the Second Environmental Research Programme approved earlier this year. In this Programme, only a minor proportion of the funds will be available for work in the area of sewage treatment and it appears to be the Commission's intention to continue to restrict work on sewage sludge to concerted action. Although therefore, there is little opportunity at present to benefit from Community funding in this important area of work, the Centre is pursuing various possibilities for co-operative work for its technical benefits. Under COST 68, methods developed by the Centre for measuring filtration characteristics of sludge were accepted as European standard methods, and under the leadership of a WRC staff member an international team evaluated the performance of sludge incinerators thus providing valuable reliable information to our own Industry (5). The Centre is also co-operating with several other countries in studying the troublesome occurrence of sludge bulking in the activated sludge process and is gaining considerably from the exercise.

SEWAGE TREATMENT

Sedimentation

Sedimentation of sewage is said (6) to require about 25 per cent of the expenditure on a works providing full biological treatment (and including sludge disposal), to produce a 30:20 standard effluent. It may not therefore be one of the most expensive stages of sewage treatment but it is important and quite small changes in sedimentation efficiency, especially after biological treatment can have a marked effect on the quality of the final effluent.

Possibilities for improving the process have therefore attracted the attention of research workers and one such method has been the use of inclined tubes or plates which have been installed at a number of works, particularly in the USA and Sweden. Several experimental units in this country have been studied by the Centre (7,8), but it was found that if the influent temperature was significantly higher ($0.2^{o}C$) than the bulk tank temperature, the liquid tended to flow predominantly up the first tube and work elsewhere also showed it was difficult to maintain uniform distribution of flow under a large module of tubes even at constant temperature. The Centre's work further showed however, that the method would be suitable for uprating overloaded humus tanks, although it would be less suitable for primary tanks, and would not be suitable for tertiary treatment without the aid of chemical flocculant. The cost of installation in existing tanks would probably be less than that of building a new tank of equivalent capacity but the expected life of plastic modules would clearly be less than the 40 years expected of civil structures. This work was therefore an example of skilled evaluation of a new process possibly avoiding expensive but ineffective units being installed as a result of commercial pressure.

An important recent research development in this sector has been the introduction at the Centre of a new method of measuring settling characteristics of activated sludge using a specially designed stirred settling cylinder and expressing the results as the new parameter Stirred Specific Volume (SSV) at a suspended solids concentration of 3.5 g/l (9). This advance not only provides a much more meaningful measure of settling characteristics than Sludge Volume Index (SVI) which was previously used universally for the routine control of activated sludge plants, but provides a powerful new design tool for future plants.

Biological Filtration

About 95 per cent of the population of England and Wales is served by main drainage and about 80 per cent by full biological treatment. For this percentage, very nearly equal proportions of the sewage are treated by biological filtration and by the activated sludge process respectively, although one noticeable difference is that the biological filtration plants are much more numerous but smaller than the activated sludge plants (10). The process has been extensively studied at the Centre for many years and as an example one eight-year experiment concluded last year assessed the performance of single-pass filters over a wide range of hydraulic loadings ($0.3 - 16\ m^3/m^3d$) using both natural and plastics media having a range of specific surface area from $40 - 220\ m^2/m^3$. This work will provide the Industry with a sound predictive and statistical basis for design of future plants.

The introduction of plastics media has been a major development in this method of treatment in recent years and their further application in the future is likely to require continued research attention. It is of some interest that of the 12 research projects on this process reported by water authorities for the WRC Register of Research, all but 3 concerned plastic media and the Centre is working jointly with water authorities on their works in 8 such projects.

The use of plastic media has been coupled, though not exclusively, with high-rate treatment and this development has also been the subject of extensive research (11,12) at the Centre. One important aspect identified at the Centre has been the characterisation of the humus sludge produced from high-rate plants. Not only is this sludge almost invariably very difficult to dewater, but because it is also highly unstable it tends to putrify rapidly and can lead to recycling to the treatment plant of a considerable proportion of the initial soluble BOD removed in the filter as humus sludge.

Activated Sludge

As with biological filtration, the activated sludge process has been the subject of a sustained research effort at WRC over many years and including kinetics and nitrification (13-16), so that there remain few operational and design problems with which the Centre cannot now assist the Industry. This area of research is now focussing on refinement and proving of a mathematical model of the process which will be of increasing value in the design of new plant. Six water authorities are also at present supporting a total of 13 projects on activated sludge, most of which are concerned with the evaluation of specific forms of the process under particular conditions. One recent introduction by ICI in this sector, known as the Deep Shaft Process is not yet included in either of these research programmes.

Denitrification of Sewage Effluent

The need for removing nitrate from sewage effluents which are to be discharged to water courses subsequently used as raw water sources for drinking purposes has already occurred in some situations and has attracted considerable research effort because of the possibility of much wider need in the future.

The Centre has been particularly active and successful in this area and in conjunction with Thames Water has followed the work initially carried out in the laboratory, through to full-scale trials. This project at the Rye Meads Sewage Treatment Works involved the creation of one or more anoxic zones in the plug-flow aeration tanks by the removal of air diffusers whilst maintaining the sludge in suspension by either mechanical stirring or low-intensity aeration. The effluent at Rye Meads is fully nitrified as would generally be the case at any other works where nitrate removal was required, and when returned sludge was mixed with incoming sewage and allowed to flow through the anoxic zone denitrification occurred and the level of nitrate in the final effluent was reduced by the theoretical maximum of 50 per cent. Attempts to reduce the level still further by the creation of a second anoxic zone however failed because of difficulties in maintaining the second zone. When the work was pursued again in the laboratory with a retention time of 40 min. in a second anoxic zone and with 40 per cent of the incoming sewage being fed to this stage, the nitrate level was reduced by 76 per cent. With improved control on the full-scale it seems reasonable to suppose that a similar result will be achieved in further work and although it appears that a reduction of much more than 80 per cent is unlikely, this would be sufficient to reduce the nitrate concentration in the final effluent to below the WHO drinking water standard (17,18). Low intensity aeration appears preferable to mechanical stirring because of its lower power consumption and there seems to be every prospect of achieving the desired result with only minor modification to the existing full-scale plant.

Developments Involving Oxygenation

A further development of the activated sludge process which can also be expected to be pursued well into the future, involves the use of oxygen instead of air to increase the intensity of treatment (19,20). One of the first systems to be developed involved the sparging of oxygen below the liquid surface. The tanks were covered, so that undissolved oxygen reaching the surface could be further contacted with the liquid. A further development known as the side-stream injection technique involves the solution of oxygen under pressure in a side-stream of liquid which is then returned to the activated sludge tank with complete solution of oxygen and therefore not requiring covering. Such a system was recently evaluated in a joint project between WRC and the Welsh National Water Development Authority at a works producing a poor effluent, apparently as a result of insufficient aeration. The trial was successful in improving the effluent quality and it was found that the tendency to shear the sludge flocs in the side-stream, with the production of a turbid effluent could be avoided if incoming sewage was oxygenated instead of mixed liquor. As a means of uprating a plant it was found that the system could be quickly installed without interrupting the operation of the plant, at a low capital cost, although the running cost was nearly twice that for conventional surface aeration.

Oxygen is now being used also in rising main sewers, where the formation of sulphide under anaerobic conditions can result in severe corrosion of the sewer fabric when aerobic conditions are resumed at the top (21). Not only has the success of the method already led to its installation at about 30 sites in the UK but it was soon realised that the technique had considerable potential for in-sewer treatment of sewage. In one such trial the BOD of sewage discharged from the head of the main was reduced by an amount equivalent to about 80 per cent of the oxygen used and there was a marked improvement in the final effluent quality from the sewage works. Furthermore it has been found that the cost of using oxygen in this way is no more than that of conventional aeration to achieve the same BOD reduction and the capital cost of providing additional conventional plant is avoided. It is to be hoped that further research in this area will enable very considerable economies to be made in the future by the exploitation of in-sewer treatment.

Cost Optimisation of Sewage Treatment

Possibly enough has already been said to indicate the extensive knowledge of treatment processes built up over the years from research and operational experience. It was therefore a commendable initiative on the part of the Construction Industry Research and Information Association (CIRIA) in 1970 to enlist a team of some 20 experts from universities, research organisations, consulting engineers and local and central government to consider the construction of a model to optimise the design of sewage works for minimum cost (22). In view of the diversity of alternative processes available, the decision was made to limit the number of process stages to be considered and 11 such stages were selected for liquor treatment and a further 9 for sludge treatment and disposal. In order to represent the liquor stream, 7 stream parameters were selected together with another 4 for the sludge stream. It is well known that sewage treatment and sludge treatment are closely interdependent and this relationship was built into the model by allowing for the return of sludge liquors and for the production of sludge of varying filtration characteristics. In spite of this refinement, the confinement of the model to conventional process stages restricted its use to situations already well within the capability of experienced designers, but further development of the model should permit the addition of further process modules. If this can be achieved the model will be an invaluable tool in the design of works in the future.

Non-Biological Treatment of Sewage

Although chemical treatment of sewage was used in this country as long ago as in the last century it was discontinued in favour of biological treatment. Interest has more recently been revived however, especially in the USA and because of the distinct possibilities for future developments in chemical and other non-biological methods considerable research effort has been focussed on the subject (23,24). Chemical treatment has been studied on a pilot-scale for several years at the Stevenage Laboratory of WRC and the further development of this work has now been facilitated by a new plant at the Coleshill works of the Severn-Trent WA. This plant was the UK government contribution to the NATO-CCMS scheme (Committee on the Challenges of Modern Society). The experimental capability is further extended by a further pilot-plant at the Davyhulme works of the North West WA. Important differences in the strength and other characteristics of sewage at Stevenage and Coleshill further enhance the value of work done at the two sites. In relating the work to the possibility of producing reclaimed water for potable supply or for industry, sand filtration followed by activated carbon adsorption have been included, but problems have been encountered, in that a significant proportion of the soluble organic compounds were not adsorbed by the carbon and further, under the conditions of treatment, urea was not readily hydrolysed and would also appear in the effluent. Provision for biological treatment has also been included as a means of overcoming these difficulties. Using this full range of process stages the work suggests that costs might not be significantly less than for conventional treatment but that they are likely to be appreciably influenced by the sludge treatment and disposal costs. The addition of lime can double the dry weight of suspended matter recoverable as sludge, although in the author's opinion this need not necessarily represent such a severe penalty as sometimes supposed. For example such a sludge consolidates under gravity more readily than does sludge from conventional treatment and preliminary dewatering trials, for example in a 375 mm solid bowl, scroll discharge centrifuge showed that it could be readily dewatered to give a cake of nearly 40 per cent dry residue. Such a cake would not necessarily occupy a volume significantly higher than a conventional sludge dewatered using lime and copperas as conditioners and if the cake was to be used ultimately in agriculture, its lime content would make it additionally acceptable. If the greater ability of a chemical treatment plant to accept toxic sewage resulted in the relaxation of industrial effluent standards, however, the agricultural outlet would disappear and the economics of sludge disposal would be less favourable. Possibilities for dealing with this type of sludge clearly need careful further assessment.

Another unit process of particular interest in non-biological treatment, is reverse osmosis, which is still the subject of considerable research. Interesting and encouraging results have been obtained, showing that sand-filtered, well nitrified effluent could be satisfactorily treated in commercially produced equipment for over 150 days without significant reduction in flux, without the aid of any cleaning or flushing procedure and without any other pre-treatment of the effluent. An economic assessment however, indicated that the cost for electricity alone was likely to amount to about half the total cost for conventional treatment of sewage. These costs could be reduced by the introduction of membranes capable of operating under lower pressure gradients and in common with the other processes considered in this sector, there are clearly likely to be interesting future developments.

Health Aspects of Sewage Treatment

The whole subject of sewage treatment is essentially oriented to the protection of health, but a specific aspect calls for special comment. Future acceptance of the present indirect reuse policy will increasingly focus attention on the possibility that substances harmful to health might be derived from sewage effluent, either directly or as a result of subsequent water treatment. In studying this problem various methods for concentrating water consitutents have been evaluated at the Centre and a GC/MS/computer system is being developed for the examination of effluents.(25). Any such harmful material identified as derived essentially from sewage effluent would clearly be most effectively removed from the effluent before discharge to a water course and the present research will therefore help also in studying suitable removal processes.

Industrial Waste Waters

As increasingly stringent standards are imposed for the quality of effluents discharged to water courses, attention will continue to be focussed on industrial waste waters containing toxic or persistent materials. The Centre's extensive research experience in this field of treatment is being increasingly oriented to the development of methods for the convenient assessment of treatability.

In this connection the biodegradability of specific materials is of considerable interest and the continued development of biodegradability tests (26), although directed primarily at testing synthetic detergents, is of considerable importance.

Future developments will inevitably see greater emphasis on the recovery of values from industrial waste waters (27) and one such area recently attracting very considerable research is the recovery of metals (28,29). Although such work has been stimulated essentially by economic pressures there is considerable potential environmental gain, especially as a result of reducing the metal content of sewage sludge applied to agricultural land.

The emphasis on utilisation, rather than disposal is likely to apply increasingly to organic waste waters also, and this area is also attracting increased research effort (30,31).

Automation

Instrumentation and automatic control of sewage treatment are areas where future development is inevitable although the problems are proving to be considerable (32). There has been considerable development in the automatic control of industrial processes but whereas in such cases the quantity and quality of the input materials can generally be fairly readily controlled, this certainly does not apply to sewage treatment, except to some extent by flow balancing, and the supply cannot be turned off! Another difference is that with the ability to maintain relatively constant input conditions in many industrial applications, permitting the use of conventional feedback control techniques, the varying quantity and quality of sewage requires complex systems of feed-forward control of process variables to respond to the varying input. Important advances have however been achieved in the monitoring of flow of liquids, sludge and gas, sludge level and solids content, dissolved oxygen and sludge dewaterability. The effectiveness of such systems depends of course on the reliability of the instrumentation, which is one of the problem areas, and the techniques need to be cost-effective. An important advance in reducing the cost of cabling instrumentation to the control unit has been achieved by the use of a centrally located mini-computer to relate to remote sensors using inexpensive transmission lines.

SLUDGE TREATMENT

Although the volume of sewage sludge as withdrawn from sedimentation tanks is only roughly 0.5 per cent of that of the sewage from which it is derived it represents nearly one half the pollution load in the sewage and is still recognised as one of the most troublesome areas of sewage treatment.

It has been the subject of sustained research over the last 2 decades, with the result that many former problems can now be solved or prevented and one of the remaining problems is the co-ordinated application of the expertise already gained. The cost-optimisation model of sewage treatment, already discussed is one example of current research effort devoted to such a development. In the past, when sewage treatment was undertaken by some 1400 local authorities, research effort tended to be focussed on individual works, but with reorganisation one of the main priorities is in the development of regional policies and a large part of current WRC effort is concentrated on this area.

The Water Authorities Panel stressed (2) the urgency of further research on sludge and 43 projects were reported for the WRC Register of Research, representing a broad coverage of the subject and including 13 on mechanical dewatering, 9 on agricultural utilization and 7 on anaerobic digestion.

Sludge Characterisation

Much progress has been possible following adoption of specific resistance to filtration as a measure of the intrinsic filtrability of sludge and experimental work has been further greatly facilitated by the introduction of a technique of measurement in terms of capillary suction time (33,34). By the further introduction of a technique of standard stirring (5) it has been possible to quantitatively simulate in the laboratory, the shearing effect on sludge flocs of full-scale mixing and other procedures.

These techniques have been used to investigate factors influencing the dewaterability of sludges, which particularly in the case of secondary sludge is extremely variable (10).

Treatment Processes

A considerable variety of treatment processes exists, each of which has particular advantages and disadvantages which give some indication as to future developments.

Heat treatment of sludge at a temperature of about 200°C is one of the most effective methods of improving filtrability of all sewage sludges (35). It has the disadvantage of producing a rather tenacious and persistent odour, which coupled with engineering problems on most of the plants which have been built in the UK has resulted in restricted application. Other similar thermal processes involving the simultaneous oxidation with air have also been applied at one or two works in the UK but a combination of high cost and energy requirements suggests that these methods also will not be widely used in future. The production of a strong effluent is another drawback, especially as this has a rather high residual COD which is resistant to biodegradation.

In direct contrast, from the point of view of effluent quality, freezing has attracted much research. This is possibly the most effective method for improving filtrability, especially if the sludge is frozen after it has been chemically conditioned. One major problem with sewage sludge, unlike waterworks alum sludge is that the effect is readily reversible (36). The process has high energy requirements and no satisfactory solution has yet been found to the engineering problems. A recent modification involved rapid direct freezing of sludge in droplet form in liquid butane but extraction of soluble components from the sludge made this process difficult to apply.

Several biological processes have been used. Aerobic digestion, operated in a manner similar to the activated sludge process has been used in one or two small works in this country and is the subject of two joint WRC/WA projects on a full-scale. An appreciable proportion of the solids are oxidised and unlike anaerobic digestion, a very clean effluent is produced and smell is adequately destroyed, but in the author's opinion the high energy requirement, coupled with the need to operate at a solids content not significantly greater than 1.5 per cent, will severely restrict its future application. Heating of the air during compression results in the sludge being maintained at a temperature of about 30°C and this heating effect can be exploited by reducing heat losses by insulation so that the temperature rises to the thermophilic range when the rate of oxidation is even higher. This modification is also the subject of a joint WRC/WA project.

Anaerobic digestion in the mesophilic range is the most widely used process in this country, and serves about half the population (37). The organic matter removed, is converted to a combustible mixture of carbon dioxide and methane which is commonly used to generate enough electrical power to operate the sewage works. The process suffered many problems in the 1960s, mainly as a result of inhibition by synthetic anionic detergents, chlorinated hydrocarbons and heavy metals, to the extent that its future seemed precarious. A systematic research study of these problems (38-41) however, provided remedial measures and the information necessary to avoid inhibition, so that the process now operates with few troubles. There seems to be no reason why it should not continue to be used well into the future, provided the capital cost remains acceptable.

Although sometimes described as a method of disposal, incineration is increasingly being recognised as a treatment process, leaving a residue still requiring disposal. Research at WRC has been mainly concerned with studying the heat balance to relate the type of sludge to the dry residue content required for the achievement of autothermic combustion (42). The Centre's involvement in COST 68 has already been referred to. Although several incineration plants have been built in this country in recent years, the process is generally accepted as expensive and the author does not foresee a proliferation of plants.

Two processes involving sludge treatment jointly with refuse, namely composting and incineration, appear to have suffered from reorganisation of the Water Industry because different authorities are now responsible for disposal of these materials. If this situation had not arisen however, these processes would probably not have been very widely applied, although both have attractive features.

One further method of treatment, namely lagooning is dealt with at a later stage in this paper.

Mechanical Dewatering

Insofar as for many years drying beds were the traditional method for dewatering sludge in this country, there has been a distinct trend towards mechanical dewatering and in situations where dewatering is required, this trend is likely to continue. Understanding of the principles involved in filter pressing and vacuum filtration has been appreciably advanced by studies at the Centre (43-46), especially in the prediction of yield, cloth blinding and chemical conditioning.

The most widely applied method in this country is filter pressing, and this trend will probably continue. There is considerable interest in the various forms of belt pressing although the installation of these methods appears to be mainly confined to the smaller works.

Modern solid bowl, scroll discharge centrifuges have been shown (10) to be capable of satisfactorily dewatering various sewage sludges, using organic polyelectrolytes for conditioning and several units have been installed in the UK. The method is clean, compact and it would appear to be eminently amenable to automation.

<u>Utilisation</u>

There is at present keen interest in the possibilities for utilisation of sludge, and the subject is likely to attract increasing research attention. For example (28) in looking at the feasibility of recovering metals from sludge, incinerator ash would clearly be the richest source. At the Sheffield plant the concentration of copper was found to be about 0.2 per cent in this material and therefore similar to the content in low grade ores at present being processed by solvent extraction in Zambia. Although the presence also of significant amounts of several other metals in the ash would increase the technical difficulties of its recovery, the main factor was that in order to process such low grade sources economically the scale of operation needs to be many times larger than would be possible using the Sheffield ash. The need to operate on a very large scale for economic viability is a major reason for negation of other technically feasible schemes.

There is also considerable current interest in the possibilities for utilisation of sludge as a supplement to fish or animal feedstock, but although there might well be interesting future developments in this direction, the method being extensively used and further explored at present is agricultural utilisation as fertiliser.

Although sludge has been used extensively in agriculture for many years the practice has always been accepted without enthusiasm by agricultural authorities and a major programme of work during the last war indicated that the material was of only limited value as a fertiliser. This work influenced the situation for the next 2 decades. In a recent appraisal of the situation the author was disturbed to find that much of the wartime work had been carried out using sludge of low quality because of very low organic content and high metal content. A reappraisal of the potential value, particularly of digested sludge (47) was based on realistic sludge analyses. In the author's opinion the pattern for modern utilisation of the material especially as liquid digested sludge was set by the schemes operated by such pioneers as Wood, Finch, Lewin and Drew (47), by the work of the latter in conjunction with Coker and by the availability of the first authoritative guidelines (48) relating to the application of heavy metals to land. Although this document, commonly referred to as ADAS 10 is currently the subject of considerable controversy because successful use of sludge is known to have been practised for many years at much higher rates of application of heavy metals, it is, in the author's opinion a major step forward, not only for the advice it gives, but in the establishment of conciliation between agricultural and Water Industry interests. Environmental aspects of the use of sludge on land will clearly be the subject of much further development as will factors such as preliminary treatment of sludge and rates and manner of application.

Brief reference has already been made to the development of regional policies for sludge disposal. The Centre's current joint effort with the Water Authorities staff to develop a regional policy for Yorkshire (49) is of major importance and if further work can be done to develop similar policies for other regions it can be expected to be instrumental in deciding whether agricultural utilisation will be further developed or whether a policy of waste disposal will be favoured.

Other Development Possibilities

One result so far (49) of the Yorkshire exercise has been renewed interest, resulting from the favourable figures revealed for costs, in unheated digestion in lagoons. Apart from the irony, in an age of advanced technology, of the possibility of returning to such an elementary method, it is a stark example of the way developments might move in pursuing rational low-cost principles. Although it will be necessary to ensure that costs are compared only for equivalent treatments (e.g. cold digestion in lagoons is not comparable with filter pressing because the further costs of utilisation or of final disposal may well be greatly different), there are some interesting aspects. Unheated or cold digestion fell into disrepute some 10 years ago because of a large number of cases where the biologic system failed, giving rise to smell nuisance. Although only one such system was investigated in detail at WPRL, laboratory experiments indicated that synthetic anionic detergents provided a plausible reason for such failures, and the one full-scale plant examined, responded readily to stearine amine treatment for neutralisation of such detergents. A supplementary factor in these cases is the sludge rentention time and the inhibitory effect of detergents, within certain limits of concentration, can be alleviated by increasing the retention time. It was significant therefore that a national survey of digester performance (37) showed that nearly 28 per cent of the plants reported had a digestion time of less than 6 weeks and the analysis further showed a greater tendency for problems to occur on such plants than on those with longer retention. It is therefore reassuring that in spite of previous experience, there is no reason why good digestion should not be achieved at the proposed retention period of 2 years, provided the lagoons are correctly designed and managed.

Finally it is of interest to consider another important possibility for development which can be evolved from historical experience. It is well known that in anaerobic digestion, organic nitrogen compounds are degraded to yield ammoniacal nitrogen, which then, in common with the nitrogen in chemical fertiliser is readily available for plant growth, and about half of the nitrogen in digested sludge is in this form. If digested sludge, typically at a dry residue content of 3 per cent, is thickened to 6 per cent before utilisation on land, 25 per cent of the total sludge nitrogen will be removed with the thickener liquor and returned to the sewage flow. Here it will not only increase the load on a nitrifying plant but result in a higher nitrate content of the effluent. Tests in the laboratory showed that if raw sludge, typically at 4.5 per cent dry residue was thickened in the same ratio to 9 per cent, only about 8 per cent of the sludge nitrogen was withdrawn with the liquor. Such a procedure would clearly mean that an additional 17 per cent of the initial content of nitrogen would remain with the sludge for agricultural utlisation and the need for thickening after digestion would disappear. Other advantages would be expected to result in the digestion process (early American work recommended such preliminary thickening); either the solids retention time would be doubled in existing plant because of the smaller volume of sludge or alternatively major savings in capital costs could be made by reducing tank volumes for new works. Energy savings would also be made in heating the smaller volume of sludge, although heat transfer might be expected to be less easy, and the choice of digester mixing procedures might be more restricted - "bottom-to-top" pump recirculation might well be the preferred method. Such a single development would therefore have the advantages of an improved digested sludge for agricultural use, more economical digestion and the elimination of troublesome digester liquors.

Pursuing these possibilities a stage further, the raw sludge thickening might clearly be achieved by mechanical means but the particular application invites consideration of the feasibility of using a biological method. When raw sludge is stored, especially at a temperature of about 30°C, fermentation takes place and within about 24 hours the liberated gas floats the solids to give a surface cake with a dry residue of about 15 per cent. This is the basis of the old Laboon process (50) formerly operated at Pittsburgh, with direct incineration of the thickened sludge. Although this plant was operated on a batch basis it would appear feasible to operate it also on a continuous basis and might be integrated with the digestion tanks so that heating is required only once. In order to achieve an average dry residue content of the feed sludge of 9 per cent, only about half the sludge would need to be thickened.

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REFERENCES

1. Water Research Centre, 1976, Register of Research in the Water Industry. In press, Henley, England.

2. Water Authorities Panel. The Research Needs of Water Authorities. Water, 1975, No. 5, 16.

3. National Water Council. First Annual Report and Accounts 1974/75, 70-73.

4. Truesdale, G.A. European Environment Problems and Solutions in Water Pollution. Wat. Pollut. Control, 1975, 74, 11.

5. Commission of the European Communities. COST-Project 68, Sewage Sludge Processing, Final Report of the Management Committee. 1975, Brussels.

6. Ministry of Housing and Local Government. Taken for Granted. Report of the Working Party on Sewage Disposal, H.M. Stationery Office, London, 1970.

7. Water Research Centre. Notes on Water Pollution No. 68, 1975.

8. White, M.J.D., Baskerville, R.C. and Day, M.C. Increasing the Capacity of Sedimentation Tanks by Means of Sloping Plates. Wat. Pollut. Control, 1976, 75, 21.

9. White, M.J.D. Settling of Activated Sludge. Technical Report TR.11. Water Research Centre, Henley, England.

10. Swanwick, J.D., Fisher, W.J. and Foulkes, M. Some Aspects of Sludge Technology Including New Data on Centrifugation. Water Pollution Manual 1972, 141, Thunderbird Enterprises Ltd.

11. Bruce, A.M. and Boon, A.G. Aspects of High-Rate Biological Treatment of Domestic and Industrial Waste Waters. Wat. Pollut. Control 1971, 70, 487.

12. Bruce, A.M. and Merkens, J.C. Further Studies of Partial Treatment of Sewage by High-Rate Biological Filtration. Wat. Pollut. Control 1973, 72, 499.

13. Downing, A.L. and Knowles, G. Population Dynamics in Biological Treatment Plants. Proc. 3rd Int. Conf. Wat. Pollut. Res. 1966, 2, 117.

14. Downing, A.L. and Knowles, G. Nitrification in Treatment Plants and Natural Waters. Proc. 5th Int. Conf Wat. Pollut. Res. 1970, 1, Paper I-8.

15. Jones, G.L. Bacterial Growth Kinetics : Measurement and Significance in the Activated-Sludge Process. Wat. Res. 1973, 7, 1475.

16. Jones, G.L. A Consolidated Approach to Activated-Sludge Process Design : A Microbiological View. Prog. Wat. Technol. 1975, 7, (1), 199.

17. Water Research Centre. Removal of Nitrate from Sewage Effluents by Biological Methods. Notes on Water Pollution No. 66, 1974.

18. Cooper, P.F., Collinson, B. and Green, M.K. Recent Advances in Sewage Effluent Denitrification : Part II. Paper presented to the West Midlands Branch of the Institute of Water Pollution Control, January 1976.

19. Water Research Centre. The Use of Oxygen in the Treatment of Waste Water. Notes on Water Research No. 1, 1975.

20. Boon, A.G. Technical Review of the Use of Oxygen in the Treatment of Waste Water. Wat. Pollut. Control 1976, 75, 206.

21. Boon, A.G. and Lister, A.R. Formation of Sulphide in Rising Main Sewers and its Prevention by Injection of Oxygen. Progress in Water Technology 1975, 7, (2), 289.

22. Bowden, K., Gale, R.S. and Wright, D.E. Evaluation of the CIRIA Prototype Model for the Design of Sewage-Treatment Works. Wat. Pollut. Control, 1976, 75, 192.

23. Cooper, P.F. Physical and Chemical Methods of Sewage Treatment. Review of Present State of Technology. Wat. Pollut. Control 1975, 74, 303.

24. Bayley, R.W. and Cooper, P.F. Review of Advanced Treatment Techniques for Waste Water. Proceedings of 3rd European Water and Waste Water Symposium, Munich, June 1975, 245.

25. Water Research Centre. Analytical Methods for Organic Compounds in Sewage Effluents. Notes on Water Pollution No. 70, 1975.

26. Eden, G.E. Development of Biodegradability Tests in the United Kingdom. Lipids, Vol. 2: Technology, edited by R. Paoletti, G. Jacini and R. Porcellati. Raven Press, New York, 1976.

27. Borne, B.J. By-products Recovery and Waste Disposal in the Dairy Industry. Paper presented at Symposium on The Treatment of Wastes from the Food and Drink Industry, The University, Newcastle-upon-Tyne, January 1974.

28. Swanwick, J.D. and O'Gorman, J.V. Some Effects of Metals Discharged in Effluents and Possibilities for their Recovery. Chemy Ind, 1973, (12), 573.

29. Wheatland, A.B., Gledhill, C. and O'Gorman. J.V. Developments in the Treatment of Metal-Bearing Effluents. Paper presented to Water and Environment Group of the SCI, London, January 1975.

30. Water Research Centre. Some Methods of Utilising Organic Waste Waters. Notes on Water Pollution, No. 67, 1974.

31. Tomlinson, E.J. The Production of Single-Cell Protein from Strong Organic Waste Waters from the Food and Drink Processing Industries. Water Research 1976, 10, Part I, 367, Part II, 372.

32. Page, H.R.S. and Briggs, R. Instrumentation and Control in Sewage Treatment: The State of the Art in the United Kingdom. WRC Conference on Instruments and Control Systems for the Water Industry, Reading, 1975, Paper 18.

33. Gale, R.S. and Baskerville, R.C. Capillary Suction Method for Determination of Filtration Properties of a Solid/Liquid Suspension. Chemy Ind, 1967, (9), 355.

34. Baskerville, R.C. and Gale, R.S. A simple Automatic Instrument for Determining the Filtrability of Sewage Sludges. Water Pollution Control, 1968, 67, 233.

35. Fisher, W.J. and Swanwick, J.D. High-Temperature Treatment of Sewage Sludges. Water Pollution Control, 1971, 70, 355.

36. Baskerville, R.C. Freezing and Thawing as a Technique for Improving the Dewaterability of Aqueous Suspensions. Filtrn and Separn, 1971, 8, 141.

37. Swanwick, J.D., Shurben, D.G. and Jackson, S. A Survey of the Performance of Sewage Sludge Digesters in Great Britain. Water Pollution Control, 1969, 68, 639.

38. Bruce, A.M., Swanwick, J.D. and Ownsworth, R.A. Synthetic Detergents and Sludge Digestion: Some Recent Observations. J. Proc. Inst. Sew. Purif, 1966, 427.

39. Swanwick, J.D. and Shurben, D.G. Effective Chemical Treatment for Inhibition of Anaerobic Sewage Sludge Digestion due to Anionic Detergents. Water Pollution Control 1969, 68, 190.

40. Swanwick, J.D. and Foulkes, M. Inhibition of Anaerobic Digestion of Sewage Sludge by Chlorinated Hydrocarbons. Wat. Pollut. Control, 1971, 70, 58.

41. Mosey, F.E. Assessment of the Maximum Concentration of Heavy Metals in Crude Sewage which will not Inhibit the Anaerobic Digestion of Sludge. Wat. Pollut. Control, 1976, 75, 10.

42. Gale, R.S. The Sludge Treatment and Disposal Problem. Paper presented at Symposium on Incineration of Refuse and Sludge, University of Southampton, Department of Civil Engineering, January 1972.

43. Gale, R.S. Some aspects of the Mechanical Dewatering of Sewage Sludges. Filtrn and Separn, 1968, 5, 133.

44. Gale, R.S. The Calculation of Theoretical Yields of Rotary Vaccuum Filters. Wat. Pollut. Control, 1971, 70, 114.

45. Gale, R.S. Research in filtration of Sewage Sludges. Filtrn and Separn, 1972, 9, 431.

46. White, M.J.D. and Baskerville, R.C. A Solution to a Problem of Filter Cloth Blinding. Effl. Wat. Treat. J., 1974, 14, (9), 503.

47. Department of the Environment. Agricultural Use of Sewage Sludge. Notes on Water Pollution, No. 57, 1972.

48. Ministry of Agriculture, Fisheries and Food. Permissible Levels of Toxic Metals in Sewage Used on Agricultural Land. ADAS Advisory Paper No. 10.

49. Burley, M.J. and Bayley, R.W. Sludge Disposal Strategy - Processes and Costs. Paper presented to the Annual Conference, Institute of Water Pollution Control, Blackpool, 1976.

50. Laboon, J.F. Development and Design Features of the Pittsburgh Sewerage Project. Public Works, 1960,91, (10), 106.

DISCUSSION

Author's Introduction

DR. J.D. SWANWICK, in introducing his paper said that because of the extensive nature of the subject, he had confined his attention mainly to work at the Water Research Centre. There was, of course, much research going on elsewhere both in this country and abroad and there was a continuing need to relate to this work. One step taken by the Centre in this direction was to prepare a Register of Research in the Water Industry; this contained detailed information on nearly 500 research projects, 135 of which were concerned with sewage treatment and sludge treatment and disposal. In addition there was the WRC Research Programme of nearly 200 projects and both these documents complemented the DOE Register of Research.

In looking to the future we had two big problems. The first was to envisage how technology could develop if allowed to do so, but the second was to foresee what restraints the economic situation would put on technology. Certainly in the present economic situation, and with the high expenditure required in the sewage and sludge sector, there was and there would probably continue to be, strong emphasis on cost saving. Much of the present research effort was devoted to this objective and would probably continue to be so well into the future. It was not surprising therefore that considerable research was going on into economical ways of up-rating existing treatment facilities and into ways of utilizing sewers themselves for partial treatment.

It was also not surprising that in the sludge sector, increased attention was again being paid to the low cost potential of lagooning. This was not a question of just reverting to out-dated practice, because we had learned much about lagoons over the years and there would seem to be attractive possibilities for the adequate treatment of sludge, without nuisance in this manner.

We would need to pay increasing attention to the possibilities for utilizing sludge, for example by recycling or extracting its protein, grease, and so on. But the big problem was likely to be the cost, and such procedures should perhaps be assessed in relation to the direct and economical utilization of sludge on agricultural land, when we utilized its nitrogen, phosphate, organic matter and lime equivalent.

Finally, two particular developments might be mentioned. A characteristic of sewage and sludge technology was the wide range of processes available. Many of these had been studied in depth at the Centre and a thorough understanding of their advantages and disadvantages had been acquired. It was appropriate therefore that effort should now be focused on the logical selection of the most appropriate unit stages to meet the requirements of any particular treatment scheme, and this was being done through the CIRIA/WRC cost optimization of sewage treatment model.

The other development had been facilitated by reorganization and involved for the research worker a rather similar exercise. A major example at the present time was the formulation of recommendations on which a regional sludge utilization and disposal policy could be based. Although the current interest was concentrated on Yorkshire it was expected that with further consideration of local factors elsewhere, the same approach would eventually be applicable nationwide.

Verbal Discussion

MR. E.W. FLAXMAN (Binnie and Partners), in opening the discussion, said that on page 3 of the paper the author discussed the improvement of sedimentation by the use of inclined plates or tubes, and remarked that the "expected life of plastic modules would clearly be less than the 40 years expected of civil structures". Later in the paper reference was made to the use of plastic media in biological filters and it was to be hoped that the same comment about the life of plastics would not be found to apply to filter media. In neither case was the plastic under any significant physical stress and it would be interesting to have the author's comments on why plastic modules operating constantly under water should deteriorate more rapidly than, say, concrete.

Many of the problems of water pollution control related to the removal of solids which, particularly in secondary treatment, had a specific gravity close to unity. Since we often failed to capture them by sedimentation, flotation seemed the obvious and attractive alternative.

Turning to a point of principle raised by the paper, after describing the large sums of money expended on sewage collection, treatment, and disposal, the author continued "Clearly there is an urgent challenge to the research worker to find means of reducing these costs". Was it really a primary role of the researcher to aim specifically to reduce costs?

In asking this question he did not wish to challenge in any way the point made earlier in the introduction to the paper that research workers should follow through with their work to both the development and application stages. We certainly did not want researchers living in ivory towers. What he questioned was whether reduction of costs should be a primary goal of researchers. We lived in an era when financial matters seemed to loom ever larger - often, in his view, to the detriment of more fundamental considerations relating to human resources and potentialities - and the Rothschild report had clearly had its effect. But research basically amounted to finding out what we did not already know and because the answers could not, by definition, be known in advance, nobody - whether he were scientist, accountant, or engineer - could predict what the financial implications of much of our research might be.

This view could be illustrated by three examples suggested by the paper. The theory of nitrification in activated sludge had been successfully developed at Stevenage leading directly to the development of the promising denitrification process, demonstrated on full-scale at Rye Meads. The initial research in this field had been carried out with no intention of making cost savings. Another example suggested by the paper was the effect of Baskervill's doodling on his blotting paper which had resulted directly in the development of the CST apparatus which was one of the most potent tools now available to the operator of a sludge treatment plant. Perhaps the most striking example of all related to those far reaching researches reported by Ardern and Lockett in 1914 in which they described the essentials of the activated sludge process which still bore the name which they gave to it and which was now employed at the great majority of major sewage treatment works throughout the world. Re-reading the three classic papers which they published in 1914 suggested that this most potent piece of research had been carried out without any intention whatsoever of attempting to save cost.

It might seem unfashionable to express reservations to-day about any studies directed towards saving costs, but the point which concerned him was that if research workers were forced into the position where cost savings became a primary goal, we should be in danger of missing the wood for the trees. The sentence in the author's paper which had prompted these remarks had raised a spectre in his mind of the corridors at Stevenage and Medmenham resounding to the heavy tread of an army of accountants and the like, and he hope that the author would be able to reassure him on this point.

MR. I.M. ADAMS (Thames Water Authority) said that sewage treatment, or the lack of it, affected the rivers for which he was responsible more than did the treatment of water for public supply. Previous speakers had discussed water treatment and sewage treatment in isolation and no-one had considered rivers to be other than the raw material for the former purpose or the recipient for the latter. Research was also needed to ensure that effluents discharged to rivers, and also abstractions from them, did not unduly harm the aquatic environment. It did not necessarily follow that a river which was suitable for abstration for potable supply was also a suitable environment for aquatic life in all its forms.

Water authorities were, in collaboration with the DOE, producing a river classification system based on various chemical parameters, particularly dissolved oxygen, BOD, and ammoniacal nitrogen and effluent standards in the future would be set to ensure that the river downstream remained in its designated class. This could well mean that the suspended solids, BOD and ammonia requirements for a discharge were somewhat different from the 30/20/10 or 20/15/5 which had been imposed in the past. In particular it was likely that effluents would be required which had very low ammoniacal nitrogen contents. He asked whether the research mentioned on p.2 of the paper was sufficiently well advanced to tailor a sewage works to produce an effluent to the requirements of the river by, for example, having a consistently very low ammoniacal nitrogen content without as a consequence an unnecessarily low BOD and suspended solids content. The excessive removal of either of these beyond the requirements of the river in these times of financial stringency was wasteful of scarce resources. Cost optimization was discussed in the paper,but not this particular aspect.

He shared the author's views on the need for further research on sludge treatment and disposal and was particularly concerned about the disposal of sewage sludge, in any form, to land. Further research into the agricultural aspects of sludge disposal was needed as a matter of urgency, and such research ought to be correlated with work already being done on the relationship between nitrates in underground waters and surface streams and applications of nitrogenous fertilizers to farm land.

DR. N. HARKNESS (Severn-Trent Water Authority) welcomed the principle that one of the objectives of research was to provide a scientific basis for understanding existing methods as a platform for better and more economic application. There was very often no need to produce better effluent than standard technology was able to provide, especially in terms of BOD and suspended solids, although in some areas nitrogen and phosphate removal might be required.

Microbiological aspects of effluent quality was another area where more information was required, especially in relation to agricultural and veterinary aspects, and this would need close co-operation with other bodies outside the water industry.

Residual organic matter, particularly where some trade effluents were present,could be worrying. There was considerable evidence that where particular types of trade effluents were present in sewage that the BOD_5 was not adequate for design oxygen demand purposes and BOD_{20}, organic carbon, or COD and possibly respiration tests should be taken into account in deriving sludge loading factors.

Sampling at sewage works had to serve many purposes including quality monitoring, data for operational use, and historical data for plant evaluation and future design purposes so that such resources as were available needed to be carefully deployed involving great care in establishing sampling and analysis programmes so that inputs and outputs from particular units were reliably measured bearing in mind diurnal and other changes in incoming sewage and recycled liquors within works. Safe agricultural disposal of sewage sludge was an operation which was likely to require a substantial scientific involvement in the future.

Two areas in which the Severn-Trent Water Authority had been concerned with a polytechnic were in the physical chemistry of sludge conditioning and the chelation of metals within sludges. It was surprising the accumulation of several thousand mg/l of zinc, copper, and nickel which could occur in activated sludge without much effect on respiration and nitrification. Both were important areas and both involved quite fundamental physical chemical work. It would be interesting to hear views on who should fund or undertake such fundamental scientific work - whether universities or specialist research institutions, the Water Research Centre, or the water authorities.

Since many recent developments as contact stabilization, lagoons and land disposal of sludge were based on revaluation of historic methods maybe the work by Stanbridge (1) should be required reading for researchers into sewage treatment.

DR. D.E. WRIGHT (Sir William Halcrow & Partners) said that he wished to discuss the significance to research management of the CIRIA sewage treatment optimization model described by the author on p.5 of the paper. The prime purpose of the model was to aid the designer of sewage treatment works to produce economic designs by enabling him to identify the particular combination of process stages, and the sizes of each stage in that combination, which provided treatment of a given flow and load to a required effluent standard at least cost, taking account of capital, operating and maintenance costs. Such a model had at least two implications for research management and both stemmed from the interactions that existed between various process stages of sewage treatment. The first was the use of the CIRIA optimizing model to *guide applied research.*

(1) Stanbridge, H.H., "History of sewage treatment in Britain", IWPC, (only 9 out of 13 volumes published to date).

One of the basic questions which any applied research organization with active industrial members had to ask was: "What research should we do?". The research information would almost certainly be working within some sort of limit on investment, and would want to be able to construct treatment works which provided the same performance more economically (or give a better performance for the same cost). The research organization itself would certainly have tight limits on its budget. These factors meant that the most careful attention had to be given to identifying those problems which were both important in themselves and likely to benefit most from applied research.

With a framework of the type provided by the CIRIA model which brought together the main technical and economic elements involved in sewage treatment, the research manager could assess which of a number of individual factors bore most significantly on the overall economics of sewage treatment. He could do this by making changes to the individual performance relationships, design or economic criteria, capital or operating costs; the model would then show the effect of these changes upon the overall total annual cash flow. When these arbitrary changes were made in a systematic way - known in the trade as "sensitivity analysis" - it became possible in principle to identify those factors where the reduction of uncertainty (or anticipated improvement to performance) would have the greatest overall economic benefit, and to compare the anticipated saving with the cost of providing the new technology needed, whether this be of a process or constructional character. Such assessments, when considered in the light of the professional judgement of researcher and the designer or operator, could then form the basis of a programme of applied research.

It might well be that the model in its present prototype form was too crude for use in this way. He believed, on the basis of his experience of the model, that it had great potential for guidance of applied research, and he would be most interested in the author's comments on this.

The second area in which he thought the model should have a significant influence lay in the *evaluation of new processes*. The model incorporated performance relations which described the change in the process stream parameter (usually suspended solids or BOD) with the design variable upon which the change principally depended. It was only because the model had these continuous relationships, rather than single point data, that it could seek the optimum solution. Those advocating new processes and wishing to demonstrate that their adoption would confer economic advantage would have to present the data in terms of the relevant process stream parameters and show how these were affected by the process over a *range* of design variables. Performance data at a single flow or loading would no longer suffice. Again, the author's comments would be welcomed.

MR. P. BANKS (John Taylor & Sons) said that neither of the two research papers had dealt with the purposes of research. Quite reasonably, these had been taken for granted. One purpose, implicit although not often mentioned, was that of allaying public suspicion and anxiety regarding the activities of all those at the Symposium.

Dr. Miller's paper, in its reference to research into unknown organics in public water supplied, showed that he was very alive to the problems which would exercise the minds of the public when they got to hear about them. This, he believed, left the research organizations with the difficult question of communication to lay people and not just to their expert paymasters.

There was one area of research omitted from the present paper which bore upon this point very significantly. That was research work into the disposal to the sea of sewage. There was a real risk that money might be wasted in unnecessarily cautious engineering in schemes to dispose of domestic sewage to sea for what he referred to, with his tongue in his cheek, as marine treatment. The only way to avoid this risk seemed to be better education of the public regarding the facts known to research scientists and engineers.

MR. J.W. SHIELL (R.H. Cuthbertson and Partners) said that at first sight he was impressed by Dr. Miller's definition (paper 2(a),p.1) of research as "... the deliberate scientific investigation of a subject to produce new technical information which may subsequently be exploited to the benefit of society", but as he continued to read the paper he began to wonder what were the "benefits" at which we were aiming, particularly, when he read on page 6 that "One problem is that the present rate of development of analytical methods with increased sensitivity will result in the identification of minute concentrations of compounds, the health signification of which it will be very difficult to assess and whose removal in treatment it may be impossible to measure". He wondered whether or not there was in fact much benefit to be gained by spending a lot of money investigating health hazards which we could not avoid and indeed which there was no point in trying to avoid. We all had to die sometime and he doubted if there was really any benefit to society as a whole in eliminating minute health hazards. A better objective seemed to be that of making the current life span more pleasant.

On reflection, therefore, and after reading on p.2 of Dr. Swanwick's paper that "Clearly there is an urgent challenge to research worker to find means of reducing costs" he had come to the conclusion that, at this stage, the main aim of the researcher must be to save money and to make life easier for all by the better application of reasonably well known techniques. In this period of acute financial stringency, the principal aim of the Water Research Centre must be that of reducing the costs of the water authorities which supported it financially.

In this connexion, one definition of a water engineer was a man who harnessed our water resources, in the most economical manner, for the use and convenience of man and that in achieving this object the engineer needed the continued help of the researcher. However, he wondered also if in fact water engineers had not been called upon too often to spend more money than was necessary on harnessing water resources for the use and convenience of fish. He believed that in many cases compensation water to meet the alleged needs of fish had been fixed in the past at much too high a level and he was quite sure that money could be saved if researchers could tell us just what the minimum requirements of fish were during drought conditions. It seemed unfair that in drought fish had a statutory right to a specified quantity of compensation water whilst human beings had to go without.

DR. D.W.M. JOHNSTONE (Thames Water Authority) said that as a divisional scientist, one of his main functions was concerned with the application of research rather than with fundamental research itself. He was therefore interested in the communication of information from the research stage to the application stage, and felt that this was one area where considerable advances could be made.

Over the last decade or so a vast amount of valuable research had led to a better understanding of sewage treatment processes, not least of which had been the considerable advances made in understanding the fundamental principles of the activated sludge process. However, there had been little or no co-ordination in the presentation of this information; an almost infinite number of symbols had been used to describe a finite number of parameters and these parameters had often been defined in ambiguous ways. This had led to a situation in which critical assessment and comparison of published work was difficult, and the situation had done little to expedite application of the research. However, he had been relieved to discover that the Water Research Centre was active in trying to rectify the situation and that Dr. Painter had contributed a paper*. He asked how much progress had been made towards agreeing a standard set of symbols and definitions to be used for activated sludge and what steps would be made to insist upon their use.

MR. J.A. TYLDESLEY (Severn-Trent Water Authority) commented that the author had included a paragraph dealing with the health aspects of sewage treatment arising from sewage effluent, but that he wished to refer to the health aspects on the sewage works themselves. It was known that the spray from activated sludge plants in particular had a very high bacterial content, with no doubt viruses in addition, and this spray drifted across the works. It was not good enough to say that the workers on sewage works were amongst the healthiest people in the country. Housing estates were being extended towards large sewage works to within the possible range of small wind-borne droplets and this situation might not be acceptable. He asked what research was taking place on this aspect of health.

MR. N.J. NICOLSON (Thames Water Authority) said that on denitrification of sewage effluent, the author emphasized his preference for low intensity aeration over mechanical stirring on grounds of lower power consumption and lower conversion costs to an existing plant. In practice, the Thames Water Authority had concluded at Rye Meads that, in order to obtain the reliability needed when converting the whole plant, it was essential to use mechanical stirrers.

MR. B. RHODES (Severn-Trent Water Authority) reminded the author that the parent bodies of the present Institution (the Society for Water Treatment and Examination and the Institution of Water Engineers) undertook certain research activities as agreed by a Joint Steering Committee. He asked the authors of the two research papers whether there was still a research role which the new Institution could undertake following reorganization within the water industry.

MR. J.P. DALY (Department of Local Government, Republic of Ireland) said that Dr. Miller had referred to two EEC Directives in his paper. There were two other directives in course of preparation, dealing with the quality of bathing waters and the quality of water for the support of fresh water fish life. These would have an impact on the future trends of sewage treatment.

Apart from the monitoring requirements, which were enormous, there was an article common to all these directives which stated "Implementation of the measures taken pursuant to this Directive may under no circumstances add either directly or indirectly to deterioration of the current quality of water". This clause was very restrictive and if applied would seem to

* Painter, H.A., 1975, *Progress in Water Technology*, vol. 7, no. 1, p. 209.

inhibit the construction of new sewage outfalls in waters covered by the Directives. He asked the author to comment on the effect of the Directives on the future trends in sewage treatment.

Written Discussion

MR. G.E. HAWKINS (Thames Water Authority) wrote that recent results from joint work by the Thames Water Authority and the Water Research Centre on denitrification at Rye Meads and East Hyde sewage works had clarified the situation summarized by the author on p.4 of his paper.

The WRC's pilot plant had been run at Rye Meads with double anoxic zones, and it was clear that 60-65 % overall denitrification was the upper limit for the Works, rather than the 80 % figure mentioned in the paper. This appeared to be due to the low carbon/nitrogen ratio of the incoming sewage compared with that used at Stevenage.

At Rye Meads, double anoxic zones would be complicated to operate, and it might be preferable to employ higher return sludge/settled sewage ratios. Pilot plant experiments had confirmed that this was practicable, but indicated that the present 90 ft anoxic zones might have to be lengthened. Nitrate concentrations in the Rye Meads final effluent were now averaging 20 mg/l, and the requirement for further denitrification was being assessed.

Contrary to the author's statement, low-intensity aeration had been found to be inferior to mechanical stirring at Rye Meads, the denitrification efficiency of the zones being significantly reduced by the oxygen entering the mixed liquor.

Encouraging results were being obtained at East Hyde in a denitrification project involving an upward flow sand filter with a methanol feed. Although it had a higher running cost, there were advantages in this technique, particularly its flexibility and ease of implementation at the works compared with one based on the activated sludge process. Similar considerations might apply to other situations where sand filters were available and denitrification was only needed at certain times of the year.

Author's Reply to Discussion

DR. J.D. SWANWICK, in reply to the contribution from Mr. Flaxman on the subject of the life of plastics filter media and of plastics inclined tube modules, wrote that the inclined tube modules were said to be strong enough for men to walk on. It was a reasonable assumption therefore that men would walk on them and as they appeared generally to be supported only at the ends and tended to be made of thinner sheet than filter media, he did not think they would last for 40 years! Furthermore, cleaning operations would place extra stress on them.

On the subject of flotation and sedimentation, although flotation was a good method for removing large particles of low density, it was not significantly better than sedimentation for small ones.

He accepted Mr. Flaxman's concern on the subject of research for the purpose of reducing costs, but in saying there was an urgent challenge to find means of reducing these costs, he was not saying this was the only challenge. The research worker certainly needed to justify his work and it could be shown that the savings which could be achieved from application of even a small part of the research done at WRC exceeded by a sizeable factor the total cost of the whole research programme. Other parts of the research could, however, lead to greater expenditure if the end result was a higher standard. The WRC programme still had a good content of fundamental work and was well balanced.

In reply to Mr. Adams, he could not see how the biological oxidation of ammonia might be achieved without a high degree also of carbonaceous oxidation in the conventional activated sludge process and should this be required it would have to be achieved by other means.

In thanking Dr. Harkness for his valuable observations, his answer on the question of funding and carrying out of work on sludge conditioning and on chelation of metals within sludges was that basically much of such work would have to be funded by the industry. But in so far as chelation of metals affected the agricultural use of sludge or other aspects of disposal, there would appear to be a case for funding by DOE. As far as location of the work was concerned, the criterion might be the availability of staff able to undertake the specialized research.

He thanked Dr. Wright for his comments on the cost optimization model for sewage treatment and agreed that the model had considerable potential for guiding applied research. He also agreed with Dr. Wright's observations on the need for performance data over a range of design variables. If the Centre had not been fully convinced of the potential value of the model it would not have committed its appreciable effort to its development.

He agreed with Mr. Shiell that one should keep the health hazard from micropollutants in drinking water in perspective, especially in relation to our exposure to such materials from other sources. His approach to increasing the *average* age of death was, however, to think more about the fatalities in the 30-40 year olds than about those in the 70s. Unfortunately, both groups contributed to the average. He also agreed that more work was needed to determine the minimum flow requirements for fish; it would seem that the drought of last year had helped to provide some answers. Whatever these requirements were, he was sure that Mr. Shiell recognized the immense value of fish as water quality monitors in helping to protect sources for potable supply.

He was not aware of any research going on in this country at present on small wind-borne droplets, but agreed with Mr. Tyldesley that more attention might have tobe given to the subject.

Replying to Mr. Daly, he recognized the concern over the implications of EEC Directives, but pointed out that in this particular case a new sewage outfall would not necessarily increase the pollution of bathing waters.

He thanked Mr. Hawkins for his useful comments and expressed the view that while techniques for denitrification were still being developed, there was bound to be some difference of opinion as to the best way of operating. For example, Mr. Hawkin's preference for a higher sludge return/ settled sewage ratio, might well have advantages, but might cause other problems by increasing the solids loading on the sedimentation tanks. Mr. Hawkin's preference for mechanical stirring rather than low intensity aeration for denitrification in the activated sludge process was also clearly endorsed by Mr. Nicolson. He was prepared to accept that, in the long run, mechanical stirring might prove the more satisfactory. It appeared, however, that the cost and complication of stirring would stimulate further experimentation with alternative methods.

The Centre appreciated the facilities and co-operation provided by the Thames Water Authority for the development of the method used at East Hyde. The method did, however, appear to require some spare capacity in the sand filters and resulted in some methanol remaining in the effluent. There could be advantages in using the method further to remove nitrate after removing the bulk in the activated sludge process.

3(a) DESIGN ASPECTS: WATER

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INTRODUCTION

Whilst part of this paper considers recent and future trends in unit processes, an attempt has also been made to show that other factors exist which can influence development, such as the method used for project execution of treatment plants and the final water quality standards adopted. Also, whereas in the more technically advanced countries there is a trend towards more sophisticated forms of treatment, usually accompanied by a high level of automation, there is at the same time a growing demand in the less advanced countries to provide simple forms of treatment, at minimum capital and operating cost. Apart from the cost factor, the objective in the latter countries is to design the process and treatment plant in a manner which does not require a high level of expertise for operation and maintenance. A flexible approach is therefore needed on the part of the designer to meet the needs of the country in which the plant is to operate.

This paper deals only with water treatment for potable use and makes no attempt to consider industrial treatment applications, although there are many areas where a similar philosophy of design can be applied.

METHODS FOR PROJECT EXECUTION

A number of alternative methods are used for the provision of water treatment plant and associated civil engineering work. The three main alternatives can be summarised as follows:-

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(i) The Authority or consultant prepares complete working drawings for the supply and installation of all process plant, together with a detailed civil engineering design.

(ii) A "turnkey" design in which the Authority or consultant prepares design parameters for the water treatment process, together with a general civil engineering specification for materials and quality standards. A single contract is then awarded for the complete works, including civil engineering design. Under a "turnkey" contract usually two contractors are involved in a joint bid, the civil contractor and the treatment contractor, one of whom comprises the main bidder.

(iii) A design in which the Authority or consultant prepares a treatment plant specification, laying down certain design and performance parameters which are flexible enough to allow treatment plant contractors to offer their own particular designs and to guarantee plant performance and final water quality. The Authority or consultant then prepares detailed civil engineering drawings and separate tenders are invited from civil engineering contractors for the construction of the works.

Method (i) has the advantage that all design parameters for both the process and construction can be decided at an early stage by the Authority or consultant; also, the original design concepts are not subject to changes which can occur because of alternative proposals put forward by water treatment plant contractors. It is also possible to design to make maximum use of indigenous materials and labour, and to limit the "offshore" elements to a minimum.

Method (ii), project execution by a "turnkey" contract, can have many potential drawbacks. Success may well depend on the ability of the two principal contractors to work in harmony throughout the contract. Conflicts can arise because the basic skills, organisation, overheads, and very often the profit margins are usually different between the plant contractor and the civil contractor. One important drawback is that, because of the nature of the contract, the Authority may not be able to gain sufficient time to study alternative plant layouts; bidding prices may be difficult to compare, and detailed information required to compare them may not be procurable. Any change required during the course of the contract is likely to result in a substantial claim. There is also the difficulty of deciding which contractor should take the leading role, that is, the plant or the civil contractor. From the technical point of view it is desirable that the plant contractor should take the lead in view of his responsibility for the process design; but, generally speaking, the civil contractor will have a much greater commercial and financial responsibility in terms of contract value and his influence will be dominant.

Method (iii) is the system most commonly used in the U.K., in some European countries and in many overseas territories having historical connections with the U. K. The system of separate plant and civil contracts has the merit that whilst firm design parameters can be laid down by the Authority or consultant, there is sufficient flexibility in the specification for treatment plant contractors to include traditional designs, or to offer new designs, as appropriate; the civil engineering and structural consequences can then be adjusted and evaluated accordingly. Another major advantage of this procedure is that it allows the Authority or his consulting engineer to maintain a close degree of control over the materials, workmanship and performance of the treatment plant and over the programming and costs of the civil engineering construction to achieve maximum speed and economy.

FINAL WATER QUALITY STANDARDS AND EFFECT ON DESIGN

A survey of 91 developing countries conducted by the World Health Organisation (1) on water quality control standards for community water supplies showed that 37 countries adapted and/or adopted the WHO International Standards for Drinking-Water; 13 countries had standards of their own and 28 countries were contemplating the preparation, or had under preparation, national standards, whilst 12 countries indicated no plans. It is also interesting to note that some countries had expressed the view that quality considerations may be too stringent and could be a factor in holding up progress.

In the U. K., the absence of water quality standards (as distinct from bacteriological standards) has probably not caused undue difficulties to the water treatment designer because of the pactice of relying upon local judgement. Their absence, however, has certainly put the designer in a quandary in many overseas territories and it often seems strange that whereas in nearly every other aspect concerned with water supplies and water treatment there is ample coverage by British Standards and Codes of Practise, the notable exception is water quality.

It is possible to indulge in a discussion in depth on practically every water quality parameter but, when a standard is eventually produced in the U.K., the one single parameter which could have a far reaching effect on design is the final water turbidity figure for drinking water. From discussions with colleagues in the water industry, the general level of acceptance in the U. K. seems to lie between 0. 4 FTU (Formazin turbidity units) and 1. 5 FTU although there are certainly a number of plants operating outside this range. The lower figure of 0. 4 FTU is most likely derived from an approximate conversion of 1 mg/l on the former silica standard scale, and it is suggested that a well designed treatment plant should always be capable of producing water continuously to this standard, or better, unless there are exceptional circumstances.

In the United States, the position on turbidity is equally uncertain or flexible whichever the viewpoint. The USPHS Drinking Water Standards, 1962 had no mandatory standard but there was a recommended limit of 5 FTU; subsequent proposals reduced the turbidity level to a Health Standard of 1 FTU at the plant effluent. This level now appears to be confirmed by the Safe Drinking Water Act proposed by the Environmental Protection Agency which is to be made law in 1976, although there are a number of permissible exceptions for turbidity levels up to 5 FTU. In 1973 there was also a recommended water quality goal of 0.1 FTU by the American Water Works Association, Water Quality Division, although how such a low level of turbidity was to be achieved or measured was not described.

Accompanying this move towards more stringent turbidity standards there has been a great deal of literature, mostly originating in the United States, concerned with virus problems and their relation to water supplies. The general message of this literature (2) is that viruses may be present in treated drinking water and that greater efforts are needed in research to establish the effect of different treatment processes (softening, coagulation, filtration, chlorination) on virus removal. Nearer home, there is known to be a draft Directive by the EEC (3) for discussion with national committees which calls for a drinking standard of less than 1 PFU (virus plaque forming unit) per 1 litre which is understood to be a stringent standard.

In the past it has been confidently assumed that for a polluted water source, disinfection with chlorine both before and after the treatment process will render the water free from pathogenic organisms. Not long ago however, it was suggested by one research worker in the United States that it is possible for viruses to be encapsulated in turbidity particles, thus screening them from the disinfection process, and Gerba et al (4) have shown that viruses can be up to 40 times more resistant to chlorine than bacteria. More recently, it has been suggested that chlorination to control viruses could accentuate carcinogenic tendencies because of the formation of chlorinated hydrocarbons.

Confronted with this evidence, it is sometimes difficult for the practical water treatment designer to know what approach he should take to turbidity levels and disinfection. Should he continue to design as he has done in the past and aim to achieve a turbidity quality of say not more than 0.4 FTU? Or should he try and design for something better? In order to achieve a consistently higher final water standard a different approach to design may well be required, particularly for direct river abstraction schemes. This affords the more widespread use of polyelectrolytes and activated carbon, the more frequent inclusion of slow sand filters in the treatment cycle, or the use of a fine sand of about 0.45 mm or less in rapid gravity filters which could have far reaching effects on filter design. To achieve further safeguards, it also seems possible that the adoption of ozone with or without chlorine may be a required departure from current practice coupled with more sophisticated monitoring techniques.

What seems reasonably certain is that in the U.K. and the more advanced countries, water quality standards are likely to be more stringent in the future rather than the reverse, and this may apply to other physical and chemical parameters apart from turbidity. It remains to be seen whether water Authorities will pay the higher premium necessary for more sophisticated and costly treatment plants to meet the more stringent quality standards.

APPROPRIATE TECHNOLOGY

A new vocabulary for developing countries has appeared in the last few years which can be puzzling to the uninitiated. Expressions are used which include Appropriate Technology, Alternative Technology, Intermediate Technology, Village Technology and Third-World Technology. There appears to be no formal universally accepted definition for any of these expressions but one writer has described Appropriate Technology as the philosophy of approach and the methods used to ensure that the solution to problems takes into account the economic, technological, and social implications of that solution for the people concerned. It is however sometimes difficult for qualified people in less developed countries to accept this philosophy if they think the solution is second best.

In the context of water treatment design for urban supplies (as distinct from small village supplies), the practical interpretation of Appropriate Technology is to produce acceptable drinking water as cheaply as possible with simple designs making use, wherever possible, of indigenous labour and materials. This is obviously a highly desirable approach but caution is required on the part of the designer in attempting to produce a least cost plant solution if it is to be at the expense of water quality.

It is quite often suggested that the quality parameters for developing countries should be less stringent than those expected in the more developed world. The difficulty is that water treatment technology in the conventional potable field has not advanced sufficiently, nor is it ever likely to do so, to enable plants and particularly filters to be designed to continuously produce final water with pre-selected and differing standards of quality. For example, once a rapid gravity or pressure filter reaches a breakthrough condition there is no means of stopping the breakthrough other than taking the filter out of service and backwashing.

A treatment plant can be considered as consisting of a succession of defence lines, and a conventional process sequence may be sedimentation, filtration and disinfection, or alternatively storage, followed by rapid gravity filtration, slow sand filtration and disinfection. A great deal can be done to reduce capital costs and it is perfectly reasonable to increase the flow rating through one of the stages (more sensibly the first) but to increase the ratings through both principal stages in circumstances overseas, where for example, it may be difficult to obtain the disinfection agent, is surely bad design and should be avoided.

It is also not often appreciated that the capital cost of a water treatment plant usually forms only a relatively small proportion (possibly 10 to 20%) of a complete new water supply system. It therefore seems illogical to reduce costs to a level which may severely prejudice the quality of water distributed to consumers, when there are usually many other ways in a new scheme where at least an equivalent amount of money can be saved without incurring possible health risks.

To meet the needs of Appropriate Technology, there is no simple formula and each case needs to be considered separately and on its own merits. Whilst a relaxation of some physical and chemical standards which do not affect public health may be acceptable, it is absolutely necessary to ensure a high level of bacterial purity. It should also be borne in mind there is likely to be a rejection of any new plant if the quality of water is inferior to what consumers have been accustomed to drinking. *Neither is the best solution necessarily the cheapest solution*, as for example, slow sand filters in preference to rapid gravity filters, or horizontal sedimentation tanks in preference to sludge blanket tanks and this can be something of a contradiction in terms of Appropriate Technology. In those cases where, because of shortage of money, calculated design risks have to be taken, then it would be appropriate for the designer to inform the Authority or the funding agency in clear terms as to the risks involved.

A great deal can still be learnt by studying some of the designs which were used forty or fifty years ago in countries like India and Malaysia. There are still many working examples of horizontal flow sedimentation tanks with and without intermediate trays, and with and without bottom sludge scrapers; similarly, there are examples of rapid gravity filters used as roughing filters followed by slow sand filters. Simplicity of maintenance and operation were the chief requisites then and this still applies today in many parts of the world. There is therefore likely to be a return to these techniques in preference to using advanced treatment technology; sedimentation tanks to be horizontal, chemical mixing to be hydraulic, chemical dosing by gravity, rapid gravity filters to be simple, uncomplicated designs, possibly making use of the declining rate principle or with a simple inlet control system. The greater use of slow sand filters, either in conjunction with rapid gravity filters or preceded by plain settlement, will probably be favoured.

Some may consider this to be a negative approach in avoiding the use of modern technology but in those areas of the world where labour for maintenance and operation is unskilled and where water treatment chemicals are not readily available, it is undoubtedly the correct attitude to follow. There are already too many examples in remote corners of the world where plant, of sophisticated design incorporating complex equipment was specified by, or sold to, unsuspecting clients, now stands idle for the absence of knowledge as to how to repair it, or because of the difficulty of obtaining spare parts. Under the heading of 'Appropriate Technology', at least such errors should not be repeated.

INFLUENCE OF CONTINENTAL TECHNOLOGY

Entry to the Common Market and the greater involvement of consulting engineers overseas in the last few years has provided wider opportunities to exchange views and work with engineers and contractors from

Continental countries.

Probably the greatest impact on traditional designs in this country over the past few years has been in the more widespread use of a French design of clarifier and a different approach to the design of rapid gravity filters. The report on Recent Developments related to Clarification (5) presented at the IWSA Congress in 1974 gave a comprehensive review of recent clarification tanks although strangely, the report omitted to mention the pulsing type of clarifier. Of French design, the tank is a flat bottomed clarifier which uses a centrally placed vacuum fan to provide an irregular distribution of the feed water and so create an expansion and contraction of the sludge blanket - the pulse. After some initial misgivings, the tank has been well received in the U.K., and there are now a number of units in operation treating raw waters with suspended solids up to about 300 mg/l. The high rate version with inclined plates positioned within the sludge blanket is likely to receive more attention in the future, especially for direct river abstraction schemes.

Both French and German practice in filtration is very different to traditional British practice. Sand media is coarser with an effective size generally not less than 0.95 mm and with a slightly deeper bed depth of about 1 metre for conventional applications. In some plants, it is not uncommon to find coarse media bed depths of sand media 1.5 m or even 2 m in depth with sand gradings up to 2 mm effective size. When up-rating filters, the use of a deep coarse sand media bed is favoured in preference to removing part of the media and capping with anthracite, as is the general practice in the U.K. Water depth over the media can vary from about 400 mm to 1.5 m whilst filter underdrains invariably consist of false floor slabs with sand tight nozzles. Cleansing is usually simultaneous air and water with air at about 16 mm/sec and water at 4 mm/sec followed by a water only rinse period at a fast rate of 4 mm/sec or a slow rate of 2 mm/sec, depending on the application. In many German plants, this sequence is preceded by a separate air scour for about one minute duration with a tendency to use higher air and water rates. Designs vary as to the method of removing wash water but generally a medium level system is preferred centrally positioned in the filter with a cill level of about 500 mm over the sand media. To reduce costs, inlet isolation is frequently performed with simple non return flap or bellows type valves in place of butterfly valves or penstocks and some designs also omit the washout valve; similarly, on cost grounds, flangeless butterfly valves are used in place of the traditional double flanged type of valve, and conventional downstream filter control is sometimes replaced by weir or butterfly valve inlet control.

Initial scepticism in this country of coarse media and a wash system using simultaneous air plus water appears to have been largely replaced by a somewhat puzzled acceptance that following sedimentation a coarse media filter of 0.95 mm effective size can give equally good quality results as a 0.65 mm effective size media filter, which is the traditional size of sand used in the U.K. There is still resistance to reducing water depths below about 2 m because of potential negative head conditions arising with a shallow water depth and this practice is unlikely to be accepted by many.

Although there are few working examples in the potable treatment field in the U. K., there seems to be a greater awareness and interest in considering some of the processes which have been in common use in Continental countries for many years. These include ozone for disinfection; granular activated carbon filters for taste and odour control or for use in place of conventional sand filters; flotation for eutrophic waters; and, different clarifiers such as the sand seeded type and the multi tray horizontal design. One Continental practice which is unlikely to receive favour is the tendency to apply a higher coagulant dosing rate than would be considered necessary in the U. K.

It is not intended to suggest that the flow of expertise in water treatment has been in one direction only; Britain has made, and continues to make, a considerable contribution in both know how and hardware and our standards are as high as anywhere in the world. What is suggested however, is that the technology and experience of Continental countries is now more accessible to us and indirectly therefore to those with whom we work overseas, thus making available a wider choice of plant and designs than ever before. This is bound to stimulate development in this country which is a desiraole trend.

PILOT PLANTS

There has always been disagreement among water treatment specialists as to whether pilot plants are necessary, desirable or even capable of producing results which will be repeated in a full scale plant. Like many other situations which occur in water treatment it very much depends on circumstances, but on balance, the evidence suggests it is advisable to undertake a pilot plant investigation if the design and construction programme permit in order to achieve the most cost effective solution. This is particularly so for schemes involving direct river abstraction where raw water quality variations are likely to be far greater than for a ground water or an impounded source.

Desirably, a pilot plant should operate for a period of at least three years in order to cover as many variations in raw water quality as possible. This is seldom achieved in practice because of the time factor but unless the plant can be operated for a twelve month period in a seasonal climate, the results must necessarily be treated with some reserve.

Staffing can be a great problem for pilot plant work as operation, at least in the early days, needs to be on a 24 hour basis. When a routine has been established and sufficient information has been collected on the behaviour of the plant it is probably acceptable (and may be economically necessary) to reduce operation to one shift working.

If possible, the plant should be designed with two streams to enable comparative results to be obtained using different processes or different forms of chemical treatment and dosing rates. For reasons of cost, a single stream will usually need to suffice, and it is then desirable to repeat tests under the same conditions at intervals.

The sizing of individual process units requires careful consideration. Dimensional similarity becomes important in scaling up results from pilot plant to full scale and this is particularly so for processes concerned with mixing, flocculation and sedimentation. As one of the objectives of a pilot plant will be to examine maximum ratings, an increase in throughput of 33% and preferably 50% should be provided over the nominal design rating and this excess capacity can exacerbate the problem of dimensional dissimilarity.

A hopper bottomed vertical flow sludge blanket type of tank either square or circular in plan is probably the simplest high rate sedimentation tank to operate and will usually provide sufficient information to predict the performance of any type of sludge blanket tank. If preferred, horizontal tanks can also be used with equally good results, but it is more difficult to design a satisfactory sludge recirculation type of tank on a pilot plant scale.

Economies can be made in sizing pilot filter units as it is possible to obtain a representative behaviour pattern during filtration with a pilot filter of say 200 mm diameter having a total depth equal to a full scale unit. Several filters can be arranged to operate in parallel and design parameters can be varied to include single or multi media beds, media size, media depth, water depth and both constant and declining rate flow control can be compared.

A quite natural mistake which is sometimes made is to try to obtain too much information in too short a time by changing variables simultaneously. For example, chemical dose rates may be changed at the same time as sedimentation rates to meet a change in raw water quality condition. This can produce very misleading results as it then becomes impossible to identify which parameter change has given the desired result. It is usually better to concentrate on one variable at a time, even though a series of tests will then take appreciably longer.

It is recognised there are obvious difficulties in designing and operating pilot plants, but it is perhaps the only way in which a designer can attempt to optimise those parameters which can significantly affect the costs of a full scale plant, such as chemical treatment, sedimentation tank overflow rates, and filtration rates. Whilst laboratory tests can identify the most effective chemical treatment for a particular sample of water it is unlikely that the time of sampling will happen to coincide with the most difficult conditions for treatment. In these circumstances, tests in the laboratory can only go so far in predicting maximum overflow and filtration rates. Indeed, for a process such as flotation which is relatively new in potable treatment, for the treatment of sludge from sedimentation tanks, and for some direct filter applications, there is really no substitute to pilot plant work. Also, it is sometimes an advantage to continue operating the pilot plant after commissioning the main works to determine the most effective mode of operation.

As the concern for higher water quality standards increases, particularly in the identification and removal of complex organics and heavy metals, pilot plants or experimental stages are likely to be required more frequently to test removal by new or modified processes. It is after all a logical transition from a research stage where theoretical considerations often predominate to full scale plant design.

AUTOMATION IN WATER TREATMENT

Although in the past few years there have been a number of significant developments in water treatment instrumentation which affect process monitoring and control there have been no recent dramatic changes.

Improvements which have been made are notably in the wider use and acceptance of solid state systems and printed card circuits for filter control sequencers; there are also much simpler systems available now for filter outlet controllers. Data logging and computer technology generally, plus the use of remote television viewing, have all made their contribution in surveillance and monitoring plant performance but it would appear there is yet no likelihood of a breakthrough in complete process control over quality variables (6). One wonders if there may be wider scope for the us of a mathematical statistical approach to the automatic control of coagulant and chemical dosing.

The development of instruments and control systems for water treatment is no doubt influenced by commercial considerations as both initial demand and repeat orders are limited. As a result, advancement in automation has lagged behind other industries despite the fact that the needs are less demanding and are normally limited to the measurement and correction by minor adjustments of a number of variables in a normally continuous process.

There seems little doubt that in this country emphasis will continue to be placed on designing automatic unmanned treatment plants, unmanned in the sense that continuous supervision is unnecessary although daily visits may still be needed for batching chemicals, changing charts, lubrication and similar activities. This is a logical trend in view of the high cost of labour plus the fact that commercial servicing and availability of spare parts for equipment is generally good and the water Authorities themselves are able to call upon skilled personnel for maintenance.

Overseas, in the less developed countries, the position is different.

One school of thought supports the idea that because the operating and maintenance personnel are in many cases unskilled then a high degree of automation is warranted in order to limit human errors. Conversely, others hold the view that automatic operation should be minimal if not eliminated altogether, and that maximum use should be made of indigenous labour and skills for manual operation. There are obviously many factors to be taken into account and, not least, is the availability of local servicing facilities whether these be within the Authority itself or from a commercial supplier. If facilities are not available then the answer must surely be to exclude such automatic equipment, at least until such time as servicing and spare parts become locally available. It is generally straightforward to make provision for automation at a later date, as for example in filter backwashing systems, and this is probably the most sensible approach when in doubt.

TRENDS IN UNIT PROCESSES

The subject is vast and as recent clarification and filtration developments were reported by Gomella (5) and Ray (7) at the IWSA Congress 1974, comment is restricted to those processes where very recent changes have occurred and to where new development is either probable or desirable.

Bankside Storage

In the case of natural rivers exhibiting eutrophic tendencies, it is extremely difficult, if not impossible, to predict the nature and extent of algae growth for bankside storage designed for retention periods of up to 7 days. Location, shape, size and depth of the reservoir can influence the type and extent of algae development and unfortunately, it is unlikely that pilot studies before construction can produce a realistic assessment on account of scale effect.

In such cases, treatment plant designs will have to provide for greater flexibility and may need to allow space and hydraulic head for additional stages of treatment such as microstraining, roughing filters or flotation for excessive algae removal.

Chemical Mixing

Despite the considerable research work which has been undertaken in recent years, there is still a dearth of information on chemical mixing techniques and their effects on flocculation. The application of the velocity gradient concept (8) to earlier classical theory has enabled mixing requirements to be approached on a more scientific basis, but because of the high energy input there is still a need to assess the relative merits and cost effectiveness of mixing devices such as in-line and static mixers, hydraulic jumps, recirculating pump, paddle and turbine agitators.

Sedimentation Tanks

Sludge blanket and solids recirculation tanks. One of the disadvantages of many earlier designs of sludge blanket tank was the complexity of structure which made construction costs very high and sometimes resulted in quite unpredictable hydraulic flow patterns within the tank. There is now a strong trend towards the development of flat bottomed clarifiers as they are generally simpler and cheaper to construct and have the advantage that they promote stable hydraulic conditions; the optimisation of current designs will probably result in reduced water depths and a lowering of construction costs.

There is a continual striving for higher upflow rates accomplished by either modifying existing tank designs or providing entirely new design concepts. As an example of the former, the basic design of the French pulsing type of clarifier has been modified to accept new developments as they have occurred; inclined tube modules can be installed in the clear water zone to increase throughput; and, the most recent variation includes the provision of parallel inclined plates partly installed within the sludge blanket zone to give a degree of sludge recirculation between the sloping plates. In modifying the tank, the original design concepts have been retained and there are working examples of rise rates 12 m/h and above.

A gravimetric device developed by a U.K. contractor for the extraction of sludge is an example of a device to enable flow rates to be increased through existing tank designs by stabilising the sludge blanket at higher operating rates, providing a direct and positive means for sludge extraction and affording better protection against variable raw water conditions. Hopefully, it will be relatively cheap to instal as the device could be of great assistance in the uprating of many types of conventional sludge blanket sedimentation tanks both in the U.K. and overseas.

New high rate designs are generally looked upon with some apprehension, but there appears to be considerable promise for a design making use of lamellar plate racks with a concurrent flow pattern; that is, the influent stream and the sludge are made to flow in the same direction. It is claimed that this type of tank is suitable for treating both low and high turbidity waters at rise rates of up to 12 m/h and that it is possible to obtain a sludge concentration of about three times that achieved in a separate sludge thickener.

Another relatively new high rate clarifier is the design which provides for the injection of very fine sand together with a polyelectrolyte to give a concentration of about 4,000 mg/l in the raw water which has been previously dosed with a coagulant. A proportion of sand and sludge mixture is maintained in continuous circulation through a mixing tank and through the sedimentation tank to provide seeding of the incoming water. Very good results have been obtained with this type of tank on an acidic highly coloured stored water and rise rates of 6 m/h have been achieved. Wear on pumping equipment and hydrocyclones for sand separation does not appear to be excessive.

Horizontal tanks. The multi-tier horizontal flow sedimentation tank with up to four storeys and parallel flow operation appears to work well on certain river waters on the Continent at rates of up to about 4.8 m/h. This type of design is an interesting extension of the traditional horizontal tank and could possibly find far wider application in less developed countries overseas for waters with suspended solids up to about 200 mg/l; above this solids level, sludge extraction would most certainly be a formidable problem.

Flotation tanks. Whilst flotation must necessarily be placed in the category of new concepts, the process has been in use for many years in the treatment of industrial waters and wastes. For potable supplies, it is not anticipated there will be a widespread adoption of the process in favour of other proven sedimentation techniques and its use will probably be restricted to those applications such as the treatment of waters which are naturally eutrophic or in "peak lopping" at otherwise conventional treatment plants to overcome seasonal algae blooms. The claims of the process to compete on more equal terms with conventional high rate clarifiers will most likely improve when the mechanical plant associated with flotation units is improved; although chemical treatment is critical for success, progress on the process side appears to have outstripped mechanical and hydraulic development.

Filtration

Rapid gravity downflow filtration. As with sedimentation processes, there is a continuing endeavour to achieve higher rates of filtration often coupled with the desire for very large individual filter units; the use of dual and multi-layer beds together with more efficient coagulation and the wider use of pre-filter polyelectrolytes has played an important part in permitting filtration rates to be increased by two or threefold compared with rates obtained from 0.65 mm effective size sand filters.

With anthracite sand filter beds it is necessary to increase back wash rates for periodic re-grading of the media, and for countries with hot climates having water temperatures of 30°C or more, the standard wash rate has to be increased by 70% or more to compensate for the temperature effect on water viscosity. It has become evident that filter underdrain systems and particularly pipe lateral designs, whilst perfectly suitable for single media sand beds and low rates of back wash, have not been able to satisfy the more critical hydraulic conditions imposed by the higher backwash rates needed for anthracite sand filters and the larger filter units. A complete reappraisal of traditional filter designs is necessary as it is believed there will be a demand in the future for even greater backwash rates for direct filter applications and for the high water temperature conditions experienced in some overseas countries. A more scientific approach to design is needed, with an intelligent use of mathematical analysis and the maximum use of scale models in order to optimise wash water flow distribution; the reappraisal needs to include the whole system including pumps, pipelines, valves and conduits in addition to the underdrain systems. The type of design incorporating a false floor underdrain is probably not so susceptible to irregular distribution of wash water as a pipe lateral system, and providing there is no large difference in cost, will probably be used to a greater extent in the future. An ideal filter design would be one which could operate under normal operating conditions with moderately low rates of air and water, applied separately or simultaneously, but designed hydraulically and structurally to accept at least double the rates when a filter becomes clogged in depth without losing the media or disturbing any bottom gravel layers.

Until a great deal more is known about the transmission of viral disease, rapid gravity filter rates will probably be restricted to a maximum of about 12.6 m/h for impounded sources having a reasonable measure of protection and about 7.2 m/h for polluted sources of water.

One school of thought contends that instead of using an anthracite sand filter bed to achieve higher filtration rates, equally good results can be obtained in respect of length of filter run, turbidity and head loss by increasing the sand depth in a coarse sand filter by about 30%; whilst this is probably a cheaper approach than using anthracite, particularly in countries where the material has to be imported, it is unlikely that such a filter design can achieve equivalent results for all types of applications.

The importance attached to obtaining high quality and correctly graded filter media is increasing with the wider use of rapid gravity filters for applications such as direct single stage treatment. Ives (9) has discussed the possibility of a standard specification for filter media and any progress towards this aim will be welcomed by designers. On cost grounds alone, it seems unlikely that media such as garnet or ilmenite will take the place of sand or anthracite in the short term future.

There is also a clear need for a standard method to be devised to assess the efficiency of a backwashing system as visual inspection or head loss on re-start seldom give a true indication. A method which has been used with some success is to compare the volumetric sludge content of grab samples of sand at various depths before and after application of a wash.

Direct filtration. Single stage filtration with sand media filters has long been practised in the U.K. for the treatment of low turbidity impounded sources using either a flocculation stage or a micro-floc technique; the development of anthracite sand and multi-media filters has extended the application of this method of treatment. The performance of a granular media filter depend on the interaction of many factors and the sensitivity of filters to inaccurate chemical dosing of coagulant or filter aid together with the amount of colloidal matter in the raw water are of particular importance to the success of direct filter applications. Where the quality of raw water varies, it is generally necessary to adjust the amount of coagulant applied and there is a risk of incorrect dosing which can quickly affect filter performance. In such circumstances, the close monitoring of filter turbidity and loss of head is essential in order to predict filter run termination. Quality deterioration of an individual filter usually occurs suddenly and if unchecked will quickly rise to a level approaching the influent quality. If a low cost efficient method could be designed to monitor turbidity at various depths in a filter and be representative of conditions throughout the media it would enable quality breakthrough to be predicted more accurately; there would then be a far greater degree of confidence for the use of direct filter installations where variable raw water conditions can occur. For direct filter applications, an efficient back wash system is of paramount importance.

Declining rate filtration. The use of a declining rate system of control for rapid gravity filters deserves consideration where it is essential to avoid mechanical or electro-pneumatic flow control devices and in those cases where a works has more than four filters; however, claims to complete simplicity of design, longer filter runs and better effluent quality need to be treated with reserve.

Slow sand filtration. In order to cheapen the cost of slow sand filter installations efforts continue to be made to obtain increased filtration rates without loss of quality and tests in Switzerland (10) and at Walton, England (11) have achieved promising results at rates of up to 15 m/d. In the Swiss tests, the use of a dual bed of sand and activated carbon extended the operating life of a filter by a factor of five, and at Walton, in addition to hydraulic up-rating, promising results were obtained with pre-filtration ozone to reduce the organic load on the filters.

It has been proposed (12) that slow sand filtration can be used following chemical coagulation but as slow sand filtration is essentially a biological process and susceptible to floc carry-over, it would be of interest to know if others have achieved success with this form of treatment.

Granular activated carbon

With greater emphasis being placed on removing organic carbon from polluted sources the use of activated carbon in conjunction with conventional treatment processes will become more evident. Powdered carbon is now in common use in the U.K., but the high cost of replacement material together with the absence of strategically placed regeneration equipment, continues to act as a constraint to the wider use of granular activated carbon.

Considerable success has been reported in the United States and on the Continent at installations where the sand in rapid gravity filters has been replaced with activated carbon either partially or completely, but it is believed that most Authorities in the U.K. will prefer to retain the safeguard of a separate sand media stage and to use granular activated carbon units as adsorbing and polishing filters, particularly when treating water from polluted sources.

Disinfection

Dyachkov (13) has recently confirmed the overwhelming preference throughout the world of chlorine but the greater exploitation of raw water sources more polluted than hitherto is stimulating the use of other known disinfectants such as ozone and chlorine dioxide, particularly the former. If the capital and operating costs of ozone can be effectively reduced, it will undoubtedly be used more extensively in the future, either alone or in conjunction with chlorine, because of the more powerful germicidal effect on many micro-organisms.

Desalination

Throughout the world, a total distillation capacity of about 2250 Mld has either been installed or is planned with the majority of plants using the multi-stage flash process (MSF); other distillation processes used on a smaller scale are multiple-effect distillation using vertical, enhanced surface heat exchange tubing (VTE) and vapour compression evaporators (VCE). The principal interest now is in the development of hybrid units using the best features of each process and further development will probably be directed towards plants having higher operating temperatures, the reduction of corrosion and erosion, the use of more cost effective materials, and, the greater use of chemicals for combating corrosion. As distilling plants are energy intensive in operation, the recent four fold increase in fuel costs will influence development and may result in the wider use of alternative desalination processes such as reverse osmosis, electrodialysis or freezing. With adequate pre-treatment, reverse osmosis is particularly suitable for brackish waters and there have been encouraging results for two stage series treatment of sea water. A wider application of reverse osmosis would be available if membranes could be developed for high temperatures water conditions of 40°C and more which occur in many countries in the Middle East; also, as standby plant to conventional treatment works in areas stricken with periodic drought.

Sludge treatment and coagulant recovery

There is no doubt that in many parts of the world with more stringent discharge conditions appearing, greater attention will need to be paid to the improvement of techniques for the treatment and disposal of sludges. The high cost of a sludge treatment scheme which may include mechanical equipment plus chemical and land useage is a strong restraining influence. Pilot plant work is essential to accurately predict the behaviour of a sludge to different forms of treatment in order to obtain the most cost effective scheme; but if pilot work cannot be done before inception of a new treatment plant, it seems reasonable to require the treatment plant contractor to participate in sludge studies during the plant commissioning stages.

Systems which offer a high percentage recovery of the coagulant, either with separate settling and thickening stages operated on a batch basis or using continuous sludge extraction from a sedimentation stage are attractive costwise, but their use will probably be confined to those treatment installations where the concentration of contaminants in the raw water is not critical.

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REFERENCES

1. World Health Statistics Report, 1973, Vol. 26, No. 11.

2. Berg, G., 1975, Literature Review, Microbiology-detection, occurrence, and removal of viruses. Journal WPCF, 47, 6, 1587

3. Draft Directive on Water Quality Criteria for Drinking Water, 1974, EEC Bulletin, Vol. 18, C214, 2.

4. Gerba, C. P., Wallis, C and Melnick, J. L., 1975, Viruses in Water: The Problem, some Solutions. Environmental Science and Technology, 9, 13, 157.

5. Gomella, C., 1974, General Report on Recent Advances in Methods of Clarification, IWSA Congress, Brighton, England.

6. Melbourne, J. D., and Butcher, R. A. F., 1975, Control and Instrumentation Used in the Operation of Water Treatment Plant, WRC Conference.

7. Ray, W. J. F., 1974, Recent Advances in Methods of Filtration, IWSA Congress, Brighton, England.

8. Camp, T. R., and Stein, P. C., 1943, Velocity Gradients and Hydraulic Work in Fluid Motion, J. Boston Soc. Civil Engineers, 30: 219.

9. Ives, K. J., 1975, Specifications for Granular Filter Media, Thunderbird Enterprises, London.

10. Schalekamp, M., 1975, The Effectiveness of Rapidly Operated Slow Sand Filters, Proc. 95th. Ann. Conf. AWWA.

11. Windle Taylor, E., 1973, 45th Report of Metropolitan Water Board for 1971-1973, London, England.

12. Ambrõsio, A. J. R., and Silva, M. F., 1976, Basic Criteria for Water Purification Plants of Small Capacity, IWSA Congress, Amsterdam, Holland.

13. Dyachkov, A.V., 1976, Recent Advances in Water Disinfection, IWSA Congress, Amsterdam, Holland.

DISCUSSION

Author's Introduction

MR. F.W. CROWLEY, in introducing his paper, said that in preparing it he had tried to follow the directions given to keep to the theme of the symposium, to give the paper an international flavour, and to be a little provocative. This necessarily meant that the paper tended to generalize rather than to discuss detailed aspects of design.

The design of a new water treatment works required consideration of many diverse but essential matters, any of which could exert a fundamental influence on layout, character, and cost, whilst others might even effect the choice of process unit selection. Parameters such as hydraulics, headloss, staged construction, flow measurement, chemical handling, together with operational, environmental, and visual aspects were some of the factors which had to be considered. They constituted the basis of good design and would continue to require the same careful examination irrespective of future changes which might occur in water treatment practice and the development of unit processes.

The need to exploit sources of water which were more difficult to treat than those drawn on in the past - as for example, rivers subject to excessive pollution, or brackish ground water or sea water - was likely to create a greater demand for pilot plant work. This was particularly so for many countries overseas, and there would probably be scope in the future for the type of co-operative effort which recently occurred for a pilot plant installation in Bombay, India, which was an example where pilot plant results were used to optimize a number of design features in the full-scale plant. The consulting engineers were responsible for co-ordination, preparing the design and test programme and placing orders for offshore equipment; a treatment plant contractor received the equipment into store, arranged for packing and despatch to Bombay, and then erected and commissioned the plant on site; the client and user, who was the Bombay Municipal Corporation, arranged fabrication of the large water storage vessels and provided all the electrics, transport and subordinate operating staff for the plant. Finally, the Water Research Centre, at Medmenham, gave some helpful advice at the design stage, and provided the services of a chemical engineer to supervise the tests in Bombay. As a measure of the successful co-operation between all the parties involved, water actually flowed through the plant just 12 weeks after the decision was given to proceed with the scheme.

Verbal Discussion

MR. E.C. REED (Thames Water Authority), in opening the discussion, said that the author had brought into focus the needs of the developing countries on the one hand, and on the other the influence of continental technology upon developments in the treatment of water for potable supplies.

Public water supplies in Great Britain remained the envy of the world, and the Thames Authority, with the Consultancy Service established earlier in the year, aimed to encourage the export of the undoubted expertise which existed in this country. Thus, operating experience and experience of river basin management could be added to the design and manufacturing know-how offered by consultants and the manufacturing industry.

Concerning slow sand filtration, this plant needed little sophisticated equipment, was easy to operate and control, and was simple to maintain and virtually fail safe. The system used cheap materials and had in the past been labour intensive, requiring relatively unskilled attendance. Whilst not necessarily labour intensive now, they could of course be operated in a labour intensive manner if appropriate. In many respects they were ideally suited to the socio-economic environment of the developing countries. Their main disadvantages, as claimed by some, in requiring a relatively large area of land, and having a minor reduced efficiency at low temperatures, would not apply in many of these countries. It was his experience that careful design could produce economical use of land; the Coppermills works in East London compared well, in terms of output per hectare, with other forms of treatment works.

The performance of the system was generally excellent. Indeed, recent work on the scientific side had served to confirm and quantify a number of additional important performance characteristics of slow sand filters. For example, whilst rapid gravity filtration alone would not remove virus, it was now known that high removal rates of virus particles were achieved in slow sand beds at filtration rates in excess of the orthodox rate of 0.2m/hr.

Work continued in this field and the following figures and tables showed:-

(a) the reduction in virus particles achieved by slow sand filtration compared with temperature, showing consistent removal of over 95% (Fig. 1),

(b) the effect of bed thickness and rate of filtration, again showing over 90% removal at rates up to 1½ times orthodox (Fig. 2),

(c) some more general biological results in graphical and tabular form showing how the effectiveness of slow sand filtration in the removal of virus particles paralleled its proven efficiency against bacteria (Fig. 3 and Table I).

Concerning Mr. Crowley's comments on bankside storage, good engineering design and sound operating practice could go a long way towards reducing the problems of eutrophication in reservoirs. Furthermore, raw water storage has an excellent first-line of defence against pathogenic bacteria and enteroviruses. Additionally, and importantly in relation to lowland river sources, storage allowed biodegradation of pollutants of industrial or natural origin. Many highly toxic chemicals were readily biodegradable.

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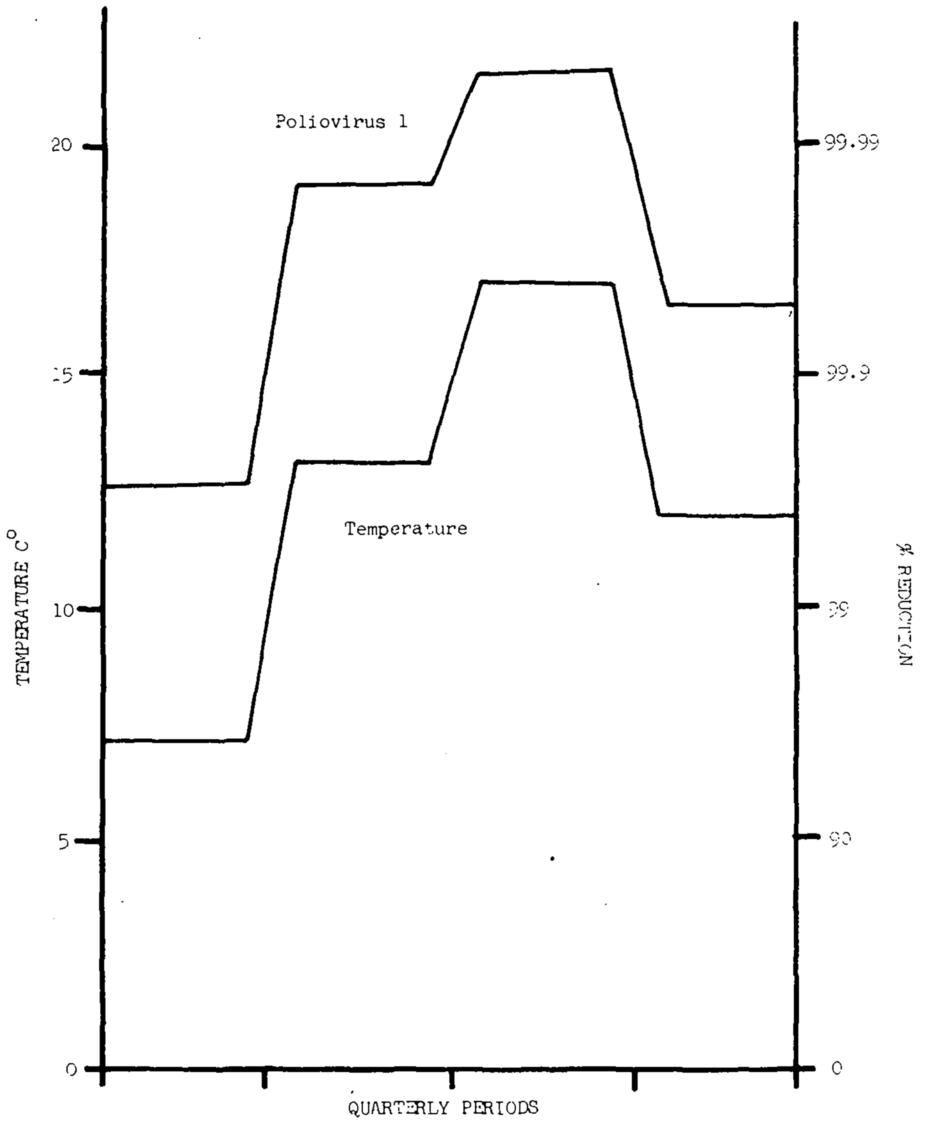

Fig. 1. Slow sand filtration. The percentage reduction of attenuated poliovirus 1 by slow sand filtration compared with temperature. Results averaged over quarterly periods. Flow rate 4.8 m/d

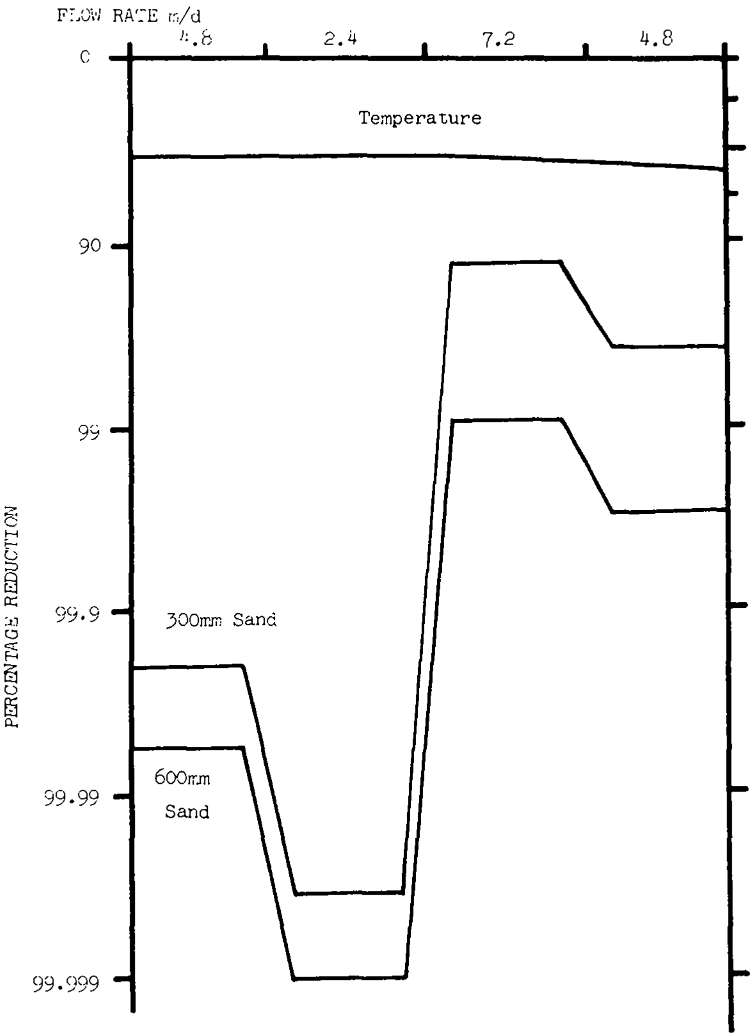

Fig. 2. Slow sand filtration. Effect of bed thickness and rate of filtration on the percentage reduction of attenuated poliovirus. Results averaged over quarterly periods

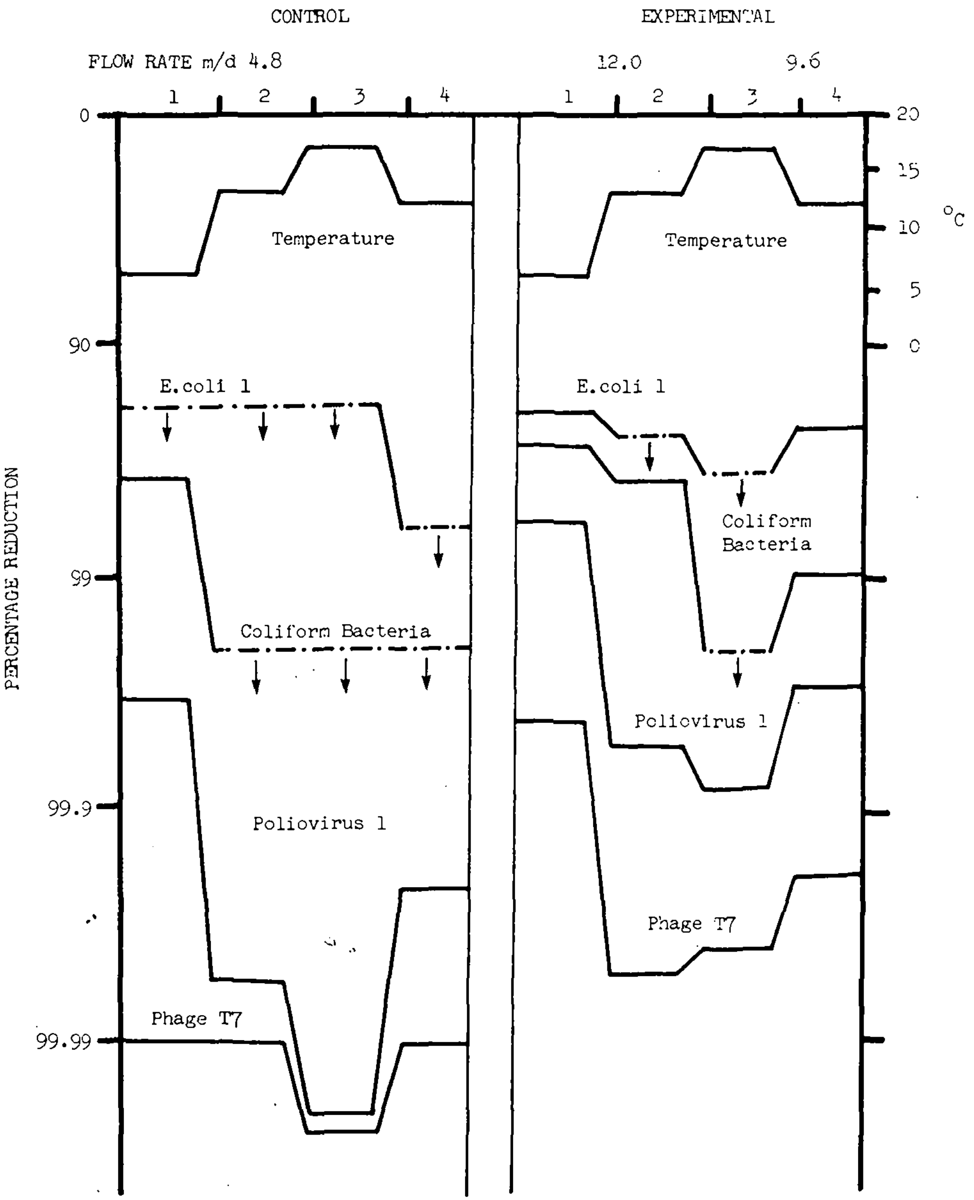

Fig. 3. Slow sand filtration - biological results

TABLE I - The weekly average percent reduction in viruses and bacteria by slow sand filtration

Date	Temp. Range ^oC	Filter No.	Flow Rate metres/d	Percentage Reduction				
				Poliovirus 1	Bacteriophage	E. coli	Coliform Bacteria	37^oC Colony Count
19-25 Nov.	11-11	1	9.6	99.30	99.87	95.1	98.1	90
		2	4.8	99.86	99.97	99.2	99.7	97
26-30 Nov.	10-11	1	9.6	99.60	99.85	98.8	98.1	95
		2	9.6	99.50	99.42	97.1	98.2	92
3-9 Dec.	10-10	1	9.6	99.91	99.99	99.6	99.6	60
		2	9.6	99.82	99.95	97.5	96.8	79
10-16 Dec.	10-9	1	9.6	99.89	99.99	99.3	99.5	90
		2	9.6	99.91	99.96	99.9	99.2	93

Filter No. 1 was running constantly at 9.6 m/d. The flow rate of filter No. 2 was doubled from 4.8 to 9.6 m/d.

TABLE II - Polynuclear aromatic hydrocarbons - range of results, January to October 1976

Nanograms per Litre (ng/l)

	River Lee at Chingford	Coppermills		Supply water
		Inlet to primaries	Primary filtrate	
Fluoranthene	20 - 80	10 - 40	10 - 30	< 5 - 40
*Benzo (a) Pyrene	5 - 40	3 - 20	2 - 10	< 1 - 5
*Indeno (1,2,3 - cd) Pyrene	4 - 30	3 - 20	2 - 15	< 1 - 10
Benzo (g.h.i) Perylene	5 - 40	3 - 20	2 - 20	< 1 - 5
*Benzo (b) Fluoranthene	30	< 2	< 2	< 2
Benzo (k) Fluoranthene	20	< 2	< 2	< 2
Total of six above P.A.H.+				
September	240	50	56	40
October	79	55	42	40

* Carcinogenic + WHO limit for drinking water - 200 ng/l NB. 1ng = 10^{-9}g.

By way of illustration of the combined effects of bankside storage and sand filtration, Table II showed preliminary results of recent work carried out in the Thames area on the combined reduction by these processes of polynuclear aromatic hydrocarbons. This was a group of highly toxic chemicals, some of which were carcinogenic, derived from a wide range of fuel-consuming and chemical industries. Substantial reduction was achieved during storage and blending, and again in the slow sand filters, but the effect of rapid gravity primary filtration was not so noticeable.

In cases of accidental spillage, the aim was to avoid polluted water entering the storage reservoir by closure of the intake. However, if there was delay in recognizing pollution, bankside storage acted as a valuable buffer. Similarly, the recurring problem of high nitrate levels from surface-derived sources might be managed. After the recent drought, the Thames Authority took steps to fill its storage reservoirs at a rapid rate once the rains came, before the seasonal rise in nitrate levels. This was successful and the Authority was now in the secure position of having in store good quantities of water of an acceptable nitrate level.

Acknowledgments: The detailed analytical results contained in this contribution were derived from work carried out in the Scientific Services Directorate of the Thames Water Authority (Director: Mr. H. Fish).

Reference: "The removal of viruses by slow sand filtration", by S.F.B. Poynter and J.S. Slade : to be published.

MR. R.V. ASH (South West Water Authority) said that having applied both the second and third methods of project execution described by the author (p. 1), he had some apprehensions about the standards of mechanical and electrical plant and equipment design. Also, being sensitive about the inevitable extra costs which developed with these alternatives, he admitted to a preference for the first method. The "in house" designer could have the advantage of a closer contact with those responsible for managing the works, the operators and the maintenance teams, such that a feed-back on performance could be more readily achieved. This feed-back was not so readily available to the consultant or the package plant designer.

In the application of methods (ii) and (iii) (p. 2), he found it necessary to prepare specifications covering more than just the expected performance of the works but to include the standards of design, quality of materials, manufacture and installation of plant and equipment to be provided and workmanship in construction.

Depending on circumstances, it was occasionally more expedient to undertake a turnkey contract of method (ii), particularly if it was necessary to complete a works within a limited time scale and the "in house" design team was heavily committed. It was also an advantage, in these days of tight financial controls, to know the full extent of capital commitment for a project (within the bounds of price indices) at a relatively early stage, and this was possible with a turnkey contract.

His own Authority recently chose to undertake such a contract for the foregoing reasons. In appraising the tenders, it was evident that only a few organizations were experienced in undertaking such contracts.

The accepted tender for this contract was, in fact, for a high rated pulsating clarifier of French design, to be constructed at the site of an existing treatment works. The Authority already had two pulsator clarifiers. It was worthy of note that the upward flow rates of the pulsators were about 2 to 4 times those of conventional clarifiers of comparable size; the super pulsator, which incorporated lamellar inclined plates, was capable of upward flow rates of about 4 to 8 times. The rates of change of flows which could be accommodated by the pulsator were impressive, but he understood the super pulsator would be capable of a rate of change which was a substantial improvement over conventional clarifiers. These smaller tanks with their rectangular arrangement could also be more easily fitted in the site with room available for further extension if required. In addition, a process having no moving parts built within tanks and principal items of plant contained in adjacent houses, making access for maintenance easy, had merits. All too often a designer failed to consider that plant and equipment must be easily accessible and maintainable in safety. He hoped that the new Health and Safety at Work Act would bring an awareness of these and other factors to the designer.

MR. P.F. BULLOCK (Anglian Water Authority) said that the three principal methods of project execution which were generally used were considered by the author. The setting up of the ten regional water authorities had created ten great repositories of engineering and scientific design and operating experience. If the authorities fully exploited this new resource it was probable that there would be a greater proportion of future projects for which the client would specify the exact nature of the treatment processes to be adopted.

The increasing stringency of drinking water standards was having a marked effect on design. The industry had come to terms with high nitrates and high or low fluorides, and was learning to live with the sodium content of its finished product. It was not yet known which would be the next parameter to become fashionably significant but, whatever it was, it lent weight to the author's plea for greater flexibility in the design of works. Adequate space for expansion and alternative points through the plant for the dosing of chemicals could generally be provided fairly easily, but generosity with hydraulic head required more careful thought because it constituted a permanent and increasing revenue expense through wasted power. The designer might serve his clients' interests better by making provision for repumping, should additional treatment processes ever be required.

The author's philosophy of appropriate technology for developing countries was equally appropriate for this country, particularly having regard to the high cost of providing a higher quality product that was needed by the users. This approach was linked with the benefits of simplicity in design and operation and with the author's comments on the use of automation in water treatment. There were considerable dangers in adopting too sophisticated an approach which required highly skilled personnel for plant maintenance, especially when the community appeared to be particularly vulnerable to the whims of small groups of individuals who found themselves in positions of industrial power.

Managers of distribution systems containing accumulations of eggs, worms, crustaceae, and algae which had passed through conventional treatment plants apparently unharmed perhaps greeted the advent of flotation with more enthusiasm than the author. When there was a heavy algal bloom in the raw water even 95% removal in a conventional plant left a great deal of undesirable material to enter the system. First results from the operation of the pilot flotation plant at the Ardleigh Reservoir Committee's works suggested that the process would have much to offer in overcoming the problems caused by heavy algal blooms.

In this situation the output of the conventional sedimentation tanks had to be reduced to 60 % of their normal throughput if even acceptable final water was to be produced. The provision of flotation as a process additional to, or as a replacement for, conventional sedimentation was tempting and, if it could be inserted between sedimentation and filtration, the possibility of combining flotation and filtration in the same tank was worthy of serious investigation.

Finally, becuase of the relatively rapid changes in water treatment technology, would the author comment on our "build to last for ever" philosophy compared with a more industrial approach to the design of plants with built-in obsolescence?

MR. W.J. CARLYLE (Binnie and Partners) thanked the author for introducing an international theme. He had very properly drawn attention to the need for wide acceptance of reasonable standards for water quality. There was considerable divergence of opinion on the acceptance level of water turbidity and he himself advocated acceptance of 0.5 FTU as reasonable, as it was perhaps the most important of the standard parameters. He had hoped to hear from the Symposium about the future refinements of the sort of developments which had led to the confident acceptance of clarifier ratings up by more than 100% and filter ratings up by say 50% whilst still maintaining efficiency. However, Mr. McLellan, in opening the event, had led off by explaining the change in emphasis from quantity in the 1960's to the present preoccupation with quality in the refined sense of the word, and the discussions had so far concentrated on this aspect. The potential for up-rating plants was such that it must be within reach of the authorities to meet much of their future demand increase by improving existing works. This could change the market position of the manufacturing industry, who had done much in the past to develop new ideas in water treatment. Like consulting engineers, much of their future would lie abroad, in the developing countries. It seemed beautifully logical that they should take the ideas developed by such as Dr. Palin and sell them in the competetive world market. This certainly seemed to have happened in the case of distribution of inlet water to flat-bottomed clarifiers, and it was to be hoped that UK manufacturers might indeed take more notice of the successful development of suspended floor filters at Newcastle. It would be wrong to assume, as speakers had done, that our standards were the envy of the world. There were a lot of rather poor plants in the UK, and a lot of seemingly good ideas marketed by industry as essential had been shown to be virtually useless. What we did have was a high degree of conscientiousness at all levels of plant operation which kept the product at its generally excellent level. He envied the French for the ideas they had formulated and the techniques they had developed, and not everything the Americans did was wrong! Consulting engineers had little opportunity for pure development work. They were expected to specify plant that would do the job at full-scale when completed in say 4 to 5 years from inception. To do this they had to have teams of plant designers and water treatment scientists, many of them drawn from the manufacturing industry and from water authorities. That they were being entrusted with engineering plants for cities such as Tehran - Istanbul - Bombay - Ankara - Hong Kong demonstrated the high regard in which the British Water industry was held, and they would continue to draw on development work of the water authorities to back this up.

The role of the consulting engineer in development should be a positive one. The author had demonstrated the pattern that might be followed to choose the best buy for a new plant to be built by contract. The evaluation process for a major plant was a formidable task. In the case of the tenders for the first new plant for Ankara (4 stages each 550 TCMD) it took place in London and engaged ten of his staff and three Turkish engineers for a period of three months covering a complete design check on all aspects of the proposals including essential civil works design check. This was a wonderful opportunity to examine an international bid. West European consortia were most competent and competetive. The lessons to be learnt were the divergence of opinion on the rating standards imposed by us and the considerable influence of civil works costs. The evaluation of plant performance in comparative present cost terms was most difficult, as was the acceptance of ideas sound in principle, tested at small scale, and proposed to be extended enormously at plant scale.

MR. R.J. SLATER (Mid Kent Water Company) questioned the author's forecast that there would be no widespread adoption of the flotation process, except for specific types of water.

Flotation was a technique which had been in limited use in both sewage and water fields for a number of years. Both pilot and full-scale experience had demonstrated the exceptional efficiency of flotation for algal removal and in view of the ever increasing quantities of stored eutrophic waters and the recommendations for bankside storage, he asked whether it was not logical to predict a large potential for its application?

Obviously, consideration would have to be given to the type of material to be removed, but surely flotation merited serious consideration where low density impurities, such as algae or organic matter, were concerned, whereas sedimentation or possibly lamella separation might show advantages where dense inorganic materials had to be dealt with?

Flotation was relatively compact compared with conventional sedimentation tanks, and costs appeared to be competitive for medium rate sedimentation. The increasing emphasis that was placed on working conditions and security (both deliberate interference and vandalism) provided the incentive for small compact solution which the Scandinavians appeared to have adopted for small to medium sized plants very successfully and apparently with good mechanical reliability. Taste removal was one aspect of flotation which seemed to have received little attention.

In sedimentation the algal cells in the sludge blanket were retained for possibly up to several days, i.e. long enough for some cells to break down and release their intracellular materials with consequent taste problems. In flotation the trapped algae were removed in minutes rather than days, and only the extracellular products were likely to need further attention. Pilot plant tests carried out by the Mid Kent Water Company certainly suggested that highly palatable waters could be produced from waters with high algal loadings.

Zooplankton removal was rarely mentioned in literature, yet this was a matter which could be of considerable importance with eutrophic waters with high potential productivity. These animals could be regarded as small particles of about the same density of water, but able to resist coagulation because of their size and power to swim.

In a sedimentation system they could swim freely in all parts of the system including the blanket and were not selectively removed. In flotation they behaved somewhat like floc particles and collected air bubbles and so they were rapidly floated off before they reached the filters. This was particularly valuable, because once on the filters they could penetrate them by the swimming actions.

The unique combination of features which could be obtained from the flotation process afforded a great potential for the treatment of some specialized classes of water and he predicted an increasing application in the UK. The Mid Kent Water Company hoped to have a medium sized plant in commission before the Summer of 1979.

MR. A.D. EDWARDS (Degremont Laing) endorsed the author's introductory comment that the method of project execution would influence future development. This was important because the different methods brought the thinking and knowledge of all sections of the industry into the design where it really mattered.

A development of the last few years had been the introduction of a greater contribution from the contractor through the package or turnkey project. This trend would continue. However, he disagreed with the author's description of the merits of the scheme which made the project sound a poor alternative to others. The package concept was now well proven in this country through the many large plants constructed.

The advantage of the package deal was the shorter design and construction period, which could be as much as half of a conventional contract. This was possible through the overlapping of the design and construction and the overlapping of the mechanical and civil elements. This saving could be commuted into a cost saving, if it was considered that over 30% of the total cost of a project was related to time. The economics of design and construction had changed in recent years as interest rates had risen, making the funding of the whole project a major cost. The amount of money to be borrowed and thus the interest to be paid rose rapidly towards the end of the project through the cost of mechanical plant and on-site construction. If the time savings occurred in this period, as they did in the package deal, there would be a significant reduction in the funding costs. This argument was set out and quantified in a paper to be published in the January 77 edition of the Journal of the Insitution of Public Health Engineers.

The three drawbacks referred to in the author's paper were, firstly that there was insufficient time to study the alternative bids and that the bidding prices might be difficult to compare. In the package deal there was ample time as the process was shorter than a conventional contract. Secondly, it was essential for the contractor that the client understood the bid and the contractor understood the client's requirements, because as the design developed changes would occur and unlike a conventional contract where claims and variations followed and the client paid, in a package deal the contractor paid because he was carrying out the design. The author felt that there might be substantial claims. Claims could arise of course, but experience had shown that there were fewer claims and variations than in the conventional contract.

The third draw back was the need for harmony between the plant and civil contractors. This was not a problem when the contractors were responsible and experienced in this method of contracting. The single management could organize the works on a sound basis of commonsense rather than seek to avoid contractural interfaces. The three methods, client design, consultant design, and turnkey, were all well proved and should be thrown into the melting pot together. The resulting competition between them would result in new ideas and real enterprise.

MR. J.F. WALLWORK (Sunderland and South Shields Water Company) said that the success of any system of water treatment works automation depended ultimately on the accuracy of the sensors used for monitoring treatment parameters. Assuming that these sensors were continuous measurement, in-line instruments in feed-forward or feed-back closed loop control systems, what manufacturing developments did the author see in their accuracy and reliability?

The use of in-line mixers for the distribution of treatment chemicals in coagulation processes had been mentioned. These mixers were of particular importance in the treatment of "thin", upland waters, where it was sometimes necessary to dose chemicals directly into raw water pipelines immediately upstream of pressure filters and hence with minimal head losses. What, therefore, were the trends in the development of "in-pipeline" mixers for this type of duty?

It was likely that many water treatment works (and especially those associated with continuous river abstraction schemes) would undergo a change in their rapid gravity filter media at some stage from sand to e.g. anthracite/ sand, granular activated carbon/sand or granular activated carbon only. What relevant features would the author therefore recommend in the design of new rapid gravity filters?

The Central Electricity Generating Board had developed a new piece of plant known as the "Capenhurst ozonizer", which was said to use applied energy more efficiently than existing ozonization units. Could the author comment on its potential application in water disinfection?

Written Discussion

MR. D.A. BURROUGHES (British Water and Effluent Treatment Plant Association) wrote that two previous speakers had raised matters concerning health and safety. BWETPA had held two seminars in 1975 on the Health and Safety at Work Act. Discussions on Safety Codes of Practice had been sought with the water authorities through the National Water Council, but although a first meeting had been held the wheels were grinding somewhat slowly. The Association was keen to establish good practice, and not to have safety measures a subject for risk-taking on tenders.

BRIGADIER C.C. PARKMAN (Ward, Ashcroft and Parkman) wrote that he agreed with the author's assessment of the merits of various methods of treatment works project execution. Given the excellent liaison which had been fostered between experienced consultants and water authority staff, there was no time penalty produced by calling for plant tenders first and then designing works for a civil contract around the selected process.

This procedure avoided the need for successive refinements, and their associated recriminations and contract extensions, and allowed the operating staff to participate in the detail of the design from the very outset.

The success of any project depended on the correct amount of money being allocated for proper investigation at the design stage. Any tendency to cut costs on this most important stage would be wrong.

Author's Reply to Discussion

MR. F.W. CROWLEY, in reply to the discussion, thanked Mr. Reed for his detailed contribution, particularly the information relating to the removal of viruses by slow sand filtration. There was a need in many of the developing countries to have treatment plants which were both simple to construct and to operate. The virtues of slow sand filtration were well known and whilst not wishing to decry anything which had been said by Mr. Reed, they were unlikely to be the least cost method of treatment for all raw water sources. Apart from the cost of slow sand filters themselves, possibly preceded by a rapid gravity filtration stage, one would need to take some account in cost estimating for any bankside storage requirements where storage was necessary as a pre-requisite for treatment by slow sand filters.

There were also obvious restraints on the use of slow sand filters, as for example where the raw water source exhibited high colours or other characteristics requiring treatment by chemical coagulation. The author knew of several examples overseas where slow sand filtration had been used as a second-stage of treatment preceded by a chemical coagulant stage, with disastrous results. In such cases the choice of slow sand filtration in the treatment cycle was well meaning, but incorrect.

Both Mr. Ash and Mr. Edwards had commented on the methods commonly used for project execution of water treatment plants. Whilst agreeing with both that it was sometimes expedient to make use of a turnkey type of contract (method (ii) in the paper) it was a misconception to assume that this method would automatically result in savings of time and money, as was suggested by Mr. Edwards. Similarly, a turnkey type of contract did not permit the authority or his consultant to retain the close control throughout all stages of design and execution which were inherent with other methods referred to in the paper. The choice of method was particularly relevant to work in the less developed countries where there was a very natural desire to make the maximum use of indiginous resources and to favour a turnkey approach. Without adequate safeguards, however, difficulties could arise in a turnkey contract with a single contractor taking the lead where an off shore treatment plant contractor and a local civil contractor might work together for the first time. A joint-venture-type of collaboration might be a more appropriate requirement in this situation.

In referring to different methods of contract execution his aim had been to draw attention to what he believed to be the greater opportunity to take advantage of new developments in process or plant design, by using separate plant and civil contracts.

He agreed with Brigadier Parkman that thorough and searching investigations at the design stage (and also at the tender adjudication stage) was extremely important and could help to reduce the number of claims during later stages of a contract.

He thanked Mr. Slater for his contribution on the flotation technique and regretted he had not yet had the opportunity to visit the installations referred to in Scandinavia. He shared Mr. Slater's enthusiasm for the adoption of the flotation process for the treatment of eutrophic waters, but did not necessarily agree that the technique would be more widely used in the future for waters containing low density impurities and in particular where high rate sedimentation alternatives were proven methods of treatment. In trying to evaluate the treatment alternatives for such waters, it would be necessary to take into account the very much higher power input required for air injection and water circulation, the sensitivity to correct chemical conditioning (because of short retention), and the cost of any sludge removal equipment. He suggested that in the final analysis it was unlikely there would be any great cost difference with other proven methods of treatment. In these circumstances the reason for selecting flotation could well be attributable to efficiency of algae removal or possibly taste improvement. Without such a reason, there would surely be some difficulty in advancing claims for flotation now that lamellar designs had been demonstrated to operate successfully with both low and high density impurity waters at rise rates well in excess of 20 m/hr.

A considerable challenge existed for the flotation process and the author welcomed a situation where there now existed at least three alternative solutions for the clarification stage of a water treatment process whereas previously the choice was limited to variations on the same theme.

Clearly, there was ample scope for the use of flotation in the special circumstances of heavy algal blooms referred to by Mr. Bullock, and he had intended to imply an obvious use for the process in referring to peak lopping in the paper.

Both Mr. Bullock and Mr. Carlyle had referred to the increasing stringency of drinking water standards in relation to design and he believed there had long been a need for clearer directives on final water quality standards in preference to the current practise of relying on local judgement for formulating standards. Presumably, the EEC Directive would accelerate response to the problem of standards.

Mr. Bullock had also raised the interesting question of permanency in design and construction of potable treatment plants compared with the short-term approach frequently adopted in the industrial sector. He himself believed it was highly desirable to provide for flexibility in hydraulic design, chemical treatment and where possible, in the treatment cycle itself. If this resulted in higher initial costs the investment was probably well worthwhile and was particularly important for direct river abstraction schemes where raw water quality variations were pronounced and for stored eutrophic waters.

He believed construction standards generally used in this country were about right and any reduction in standards would be false economy. Whilst standards of treatment and water quality in the industrial sector were frequently very high, they did not, in general, have to maintain a public relations front and could therefore cut back on initial construction costs.

The answers to Mr. Wallwork's four specific questions were:-

(1) With the current sensitivity to water quality, significant advances had been made in water quality monitoring equipment with single and multiple sensing and recording devices, but it was probably fair to say that few of these developments had any real value in solving the problems normally encountered in water treatment where the need was for both quick detection and response to sudden changes in raw water quality parameters. The reason

was probably one of commercial supply and demand. Computer-stored statistical information on raw water quality could go some way towards meeting the objectives, but there was at present no real substitute for laboratory analytical and flocculation tests for treatment determination. The WRC had a research programme on this topic which might provide some useful guidelines for the future.

In all other areas of instrumentation and control normally required for a water treatment plant such as flow, level, pressure, chemical handling and data collection, there was no logical reason why standards and application should be in any way inferior to other industries.

(2) Pressure filters were an obvious application for in-line mixers but maintenance could be a problem if a valved bypass arrangement was not provided. A variable-speed drive might also be necessary with a fluctuating flow or sensitive chemical conditioning. For the future, static mixers might find wider application in the water industry, but there continued to be a great need for applied research on all forms of chemical mixing. At the moment the solution chosen for main stream mixing was usually one of personal preference.

(3) A rapid gravity filter had yet to be designed which could meet the hydraulic and structural demands of using any combination of media with variations of size density and depth together with any of the systems normally used for back-washing. In any case, the conditions encountered in a two-stage process would not generally justify the cost of such a filter. In practise, however, a very desirable feature, particularly for a single-stage direct filtration installation, was the ability to apply a more vigorous cleansing agitation when a filter became severely clogged. For example, if a filter had a basic design for separate air and separate water application then it should be designed additionally to accommodate the simultaneous application of air and water when the need arose.

Similarly, a filter with water wash only should include the ability to apply an air scour if and when necessary. In all cases the design should provide for the application of at least a 50 % increase over normal flow rates or air and water.

(4) It was understood that following prototype plant trials extending over several years the Capenhurst ozonizer was now being considered for large-scale ozone production. The principal claim of the unit was the use of high power densities in the electric discharge and efficient electrode cooling had reduced ozonizer bulk to about one-tenth of conventional mains frequency units. It appeared the unit represented a considerable breakthrough in ozone production technology, and it would be interesting to see if it resulted in a wider acceptance of ozone as a disinfectant.

3(b) DESIGN ASPECTS: SEWAGE

A.D.Maskell, B.Sc.(Eng.), F.I.C.E., F.I.P.H.E., M.Inst.W.P.C. *
D.M.Robinson, M.I.C.E., F.I.P.H.E., A.M.Inst.W.P.C. +

SYNOPSIS

In this paper the introduction of new processes into Sewage Treatment Works design is discussed and specific processes are examined. An attempt is made to identify new treatment processes likely to be accepted for general use both in the short and long term.

INTRODUCTION

Just over four years ago a one day Conference entitled "Advances in Sewage Treatment" was held at the Institution of Civil Engineers. In his opening address the then Under Secretary of State at the Department of the Environment reminded the Conference that "for many years Britain has led the world in the introduction of new processes and methods .... Yet if the design principles and treatment methods first introduced in Britain are now accepted universally, it must be recognised that here as in many fields a price has been paid for being first." He went on to say that "as I see the future, the basis of sewage treatment is likely to continue to be the physical and biological systems already common; but new methods of a physical and chemical nature will be increasingly applied where higher standards are needed. Works will have to be increasingly compact, attractive in appearance and odourless." (1)

In a similar vein a well known ex-minister is recorded as stating that "I go around the country opening sewage works built at massive expense to replace old works built around 1880. The new ones are almost exact replicas of the old ones, fundamentally using the same techniques and methods and I find it surprising that a much better and cheaper solution for the problems of sewage disposal has not been developed ...." (2)

These introductory statements are useful reminders of an informed appraisal of the design scene in 1972 and it is appropriate in 1976 to consider what progress has been made in utilising new design techniques over the last few years and to consider to what extent new techniques will be put into service in the years ahead.

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Howard Humphreys & Sons, Consulting Engineers.

In general the replacement of an existing treatment method will depend not so much on the availability or development of new techniques but more on the outcome of the economic and practical appraisals necessary to justify any decision to effect a change. For example in a negative mode soaring fuel costs have made thermal treatment processes of all kinds less attractive than they were four years ago and also compelled designers to reappraise processes which are power intensive. On the other hand rising land costs and environmental considerations of amenity, noise and odour have increasingly influenced engineering decisions.

Developing this theme it is encouraging to note that despite the economic climate of recent years it has still been possible for successive governments to implement those recommendations of the Jeger Report stating that "Government funds should be made available to -

1. finance full-scale trials at sewage works of proven laboratory scale projects

2. underwrite the costs of full-scale plants at sewage works including newly designed processes: and the results of such work should be well publicised." (3)

Numerous small, medium and large experimental projects were financed by Central Government prior to the April 1974 Re-organisation of Local Government and this initiative has been maintained by the W.R.C. and the Water Authorities. (4), (5).

In step with public funded research it is encouraging to note that the sewage treatment manufacturing industry has continued to research and develop new techniques, new processes and the application of new materials to conventional uses. As an example, one might mention the extensive use of plastic materials to replace metals, a change which has continued despite the increased cost of oil from whence many plastics are derived.

IMPLEMENTING NEW DESIGNS

Why

The designer of a sewage treatment unit or a pumping station is generally aware of the operational limitations that his selection of equipment or his layout of plant will impose on the performance of that unit. Experience and a feed-back of any operational difficulties will identify for him those areas where a new design approach or a new technique is required. Efficient grit, grease and rag removal, instrumentation, correct flow splitting, further mechanical and electrical safeguards and process control are among the many operational features that designers would wish to see improved. There will always be a requirement for operators to identify problem areas and to communicate their operating experiences to designers so that newly designed works leaving the drawing board incorporate known desirable modifications.

When

The introduction of a new unit to a conventional treatment process stream is only justified after a full economic appraisal of all the factors involved. Land costs, labour charges, material and power costs and the effect of unit operational and maintenance expenses all contribute to an evaluation of the total process. A mathematical model technique to determine the optimum arrangement and sizing of various units continues to be developed by

C.I.R.I.A. (6) using the Total Annual Cash Flow principle and in due course it will be possible to check the benefits of a new process by this method. Meanwhile both the designer and the operator will require reliable evidence of costings and associated performance parameters of a new process from the innovator before allowing themselves to become process guinea-pigs. The decision to use new equipment is made with more confidence when independent corroboration is available of the developer's reported operational results. New designs will be used where operational advantages are demonstrable; where real economies can be effected without a reduction in performance or where environmental improvements result.

How

Sewage treatment necessitates substantial capital and operational expenditure and the publication of experimental results for new processes accompanied by realistic costings constitutes a pre-requisite for their adoption. In practice this means laboratory trials followed by pilot plant studies spread over several years before the construction of a full-scale plant is contemplated.

In this context those elements of sewage treatment plant that absorb the lion's share of capital and operating costs will come under closest scrutiny. These elements are the biological treatment processes, the tertiary treatment of effluents and, most important, sludge dewatering. For confirmation of this, reference should be made to C.I.R.I.A. Report No. 54 where the relative cost of treatment stages are highlighted albeit the comparison is made for a steady flow condition. (7)

It is unlikely that a revolution in sewage treatment will occur in the next decade but there is likely to be some variation of the traditional theme. *Possible variations are illustrated in Figure 1.*

NEW DESIGN APPLICATIONS

Reception

By tradition the reception or preliminary treatment of crude sewage is aimed at reducing the gross solids whether organic or inorganic to a size which will minimise difficulties in subsequent treatment processes. The conventional method of screening is likely to continue for years to come but opinions concerning screening disposal will change. Until the advent of the screenings press the designer was unable to offer the operator a satisfactory means of disposal apart from returning the macerated screenings to the flow with its inherent stringing problem. The screenings press is not the cure for all ills but it does produce an end product which can be effectively disposed of by burying, bagging or incineration and is likely to come into general use on larger works.

Fine screening with the hydrosieve and cup screen have gained popularity in recent years and could reduce the retention time or even ultimately displace the sedimentation tank in the conventional plant. Further study work is necessary on the practicalities of handling fine screenings.

Stormwater Treatment

There are no new developments in the field of Stormwater Treatment but designers of new works will take note of the recommendations set out in the final report of the Technical Committee on Storm Overflows and the Disposal of

<u>*POSSIBLE MODIFICATIONS TO SEWAGE TREATMENT PROCESSES*</u>

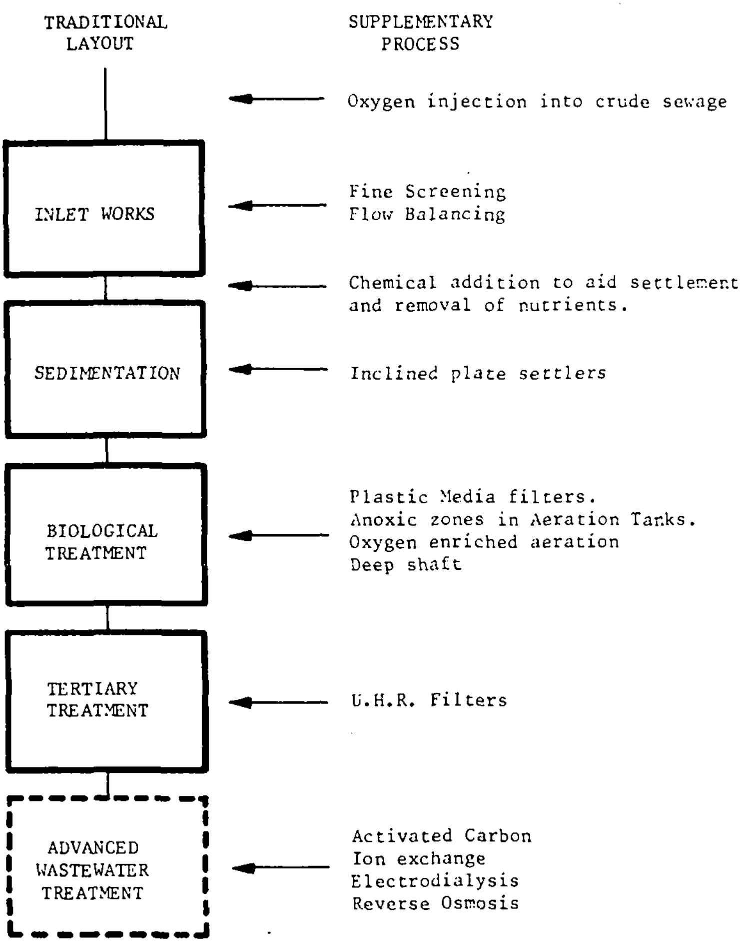

Figure 1.

Storm Sewage, for the sizing of Stormwater Tanks. (8)

Flow Balancing

Flow balancing in various forms has been introduced at some Sewage Treatment Works in the U.K. but no positive evidence exists to indicate that significant improvements occur with such installations.

It is hoped that this situation will improve when the results are available of the long-term large scale study which is to be undertaken by the W.R.C. to determine the effects on biological filters under steady and fluctuating flow.

With a totally pumped inlet flow a system of peak lopping and return pumping effectively reduces the instantaneous values of hydraulic and pollution load but there is evidence that the total oxygen demand of an effluent over a flow balancing cycle will not show much change. (9)

The above comments do not apply to overloaded works where hydraulic balancing utilising empty storm tank capacity can offer considerable improvement.

The economies of flow balancing appear to be in the reduction of capital expenditure on pipework and unit size by restricting flow to full treatment to say twice dry weather flow. Balancing tanks will require some careful attention to detail by the designer to cope with settleable solids, odour and septicity but costs should not be excessive once acceptable design parameters are defined by further research work.

Mechanisation and Automation

Mechanisation and automation has been used to a limited extent on the Sewage Works for many years but stringent effluent standards, high energy and labour costs are demanding a tighter control of works operation. The degree to which metering, data logging and process control is undertaken is debatable from the operational and economic aspects but even so we now have three computerised or semi-computerised Sewage Treatment Works in operation in the U.K. (10) Benefits of computer control include lower power costs, a better understanding of plant operation and potential, improved unit performance and most efficient use of personnel, but to-date no overall financial advantage has been shown by the system. The full potential of computer control will be realised when the necessary sophisticated instrumentation is available. By designing equipment that is readily extensible, additional programmes can be incorporated as new reliable systems are marketed.

It is likely that large and medium sized works will become increasingly automated and that smaller works will become increasingly mechanised.

Sedimentation

(i) Chemically Aided Settlement. Controlled and monitored work is now being done at the A.W.T. plants at Stevenage, Coleshill and Daveyhulme on the use of chemicals as an aid to sedimentation. (11) The high cost of chemicals and the subsequent cost of dewatering large quantities of sludge sometimes with low filterability, is likely to deter the designer from adopting such methods in isolation for conventional treatment. However, it is likely that circumstances will arise when chemical settlement may be economic such as:-

(a) Uprating existing sewage treatment plants which are overloaded, either hydraulically or biologically.

(b) Treatment of storm sewage to a required standard as an alternative to enlarging existing primary or biological facilities.

(c) Increasing the efficiency of primary treatment to obtain a specified standard for discharge of effluent into estuarial or coastal waters, which could not otherwise be achieved with ordinary primary sedimentation.

(d) Pretreatment of sewage ahead of Advanced Wastewater Treatment Units which will benefit from the process.

(e) The removal of specific pollutants.

(ii) Inclined Tube Settlement. Inclined plate or tube settlement has been successfully used for some time for the separation of oil and water and only comparatively recently has it been applied to the sewage industry. The efficiency of a horizontal flow sedimentation tank is a function of the surface area and not the depth and therefore by the use of inclined plates, a larger effective surface area can be installed in the volume occupied by a conventional tank. The effective throughput of any particular tank can be increased by 2 to 5 times with inclined tubes provided that the influent temperature does not exceed the temperature of the tank contents by $1^{o}C$ and that the tubes are regularly cleaned.(12, 13)

In theory, inclined tubes have an application to all forms of sedimentation but in practice they are most suited to a Humus Tank application. It is difficult to foresee a general adoption of inclined tube settlers on sewage treatment works.

(iii) Flotation. Sedimentation is the traditional method of solid removal but in recent years the alternative process of sludge flotation by both air and electrolytic techniques has aroused interest.

Flotation has been used for sludge thickening of activated sludge in Municipal treatment plants but the process is also established as a liquid/solids separator in the protein recovery industry. The process operates at higher throughput rates than sedimentation and also produces more concentrated sludges.

Much research work is still required into air/solids ratio, the float blanket depth and the flux applied to the flotation unit but there is no doubt that the process will make considerable inroads into the industrial sector and may ultimately replace final settling and humus tanks in Sewage Treatment.

Biological Treatment

(i) Plastic Filter Media/Rotating Disc. The performance of a unit volume of filter is directly proportional to the surface area of the media that can support aerobic growth of attached micro-organisms. Whilst having as large a surface area as possible, the media must possess sufficient void space to allow humus solids to pass freely through the media carried by the liquor undergoing treatment. Plastic filter media and the rotating disc are both able to offer high surface area coupled with voidage up to 95% making them substantially more efficient than conventional trickling filter mineral media particularly in high rate applications. At present the high cost of the media is not offset by the saving in constructional costs and the substitution only becomes economic in special cases such as pretreatment of trade wastes, or uprating overloaded plant on restricted sites.

(ii) Deep Shaft. One of the most exciting and original biological treatment processes to be developed in recent years is the I.C.I. deep shaft. The results of preliminary full-scale experimental work reports oxygen transfer rates in excess of ten times that of conventional aeration with less than half the equivalent volume. Constructional problems in shaft sinking may well deter possible applications of the deep shaft and despite the saving in land area the high cost of sinking a 50/100 m. deep shaft will tend to limit the application of the system to population equivalents in excess of 50,000. (14)

(iii) Pure Oxygen Treatment. The degree of purification effected by an aerobic biological treatment process is related to the rate at which dissolved oxygen in the plant is utilised by the micro-organisms and ipso facto by the amount of dissolved oxygen in the waste water.

Several techniques have been developed recently to make more efficient use of the oxygen in the activated sludge process, the best known one being the use of pure oxygen instead of air in an enclosed tank. (15) The economics of pure oxygen treatment against conventional aeration are marginal depending upon particular circumstances but there are two major factors that tend to off-set the advantage of the reduced physical size of treatment tank required. They are:-

(a) The dependence on a continuous supply of oxygen from either an external source or site generated oxygen from a high cost complex unit requiring highly skilled staff for operation and maintenance.

(b) The difficulty in producing a nitrified effluent without the introduction of a second stage conventional aeration unit.

Investigations are currently being undertaken to determine the beneficial effect on sewage treatment by injecting pure oxygen into a side stream of settled sewage prior to aeration and into sewage rising mains. Initial results from the latter method indicate that it is likely to be economic as a means of avoiding problems of septicity and at the same time reducing the biological load imposed on the treatment works. (16)

Accepting the obvious benefits of oxygen assisted treatment the emphasis in the next few years is likely to swing in favour of injection into rising mains.

(iv) *Nitrification. In order to improve or protect our river water quality* it is becoming increasingly necessary for the Water Authorities to set effluent standards with an ammonia limit.

Low B.O.D. loadings on filter beds, two stage filtration and aeration with 9 to 12 hours retention are methods by which the designer can achieve a nitrified effluent but with a significant increase in the cost of the treatment plant.

It is likely that regional rather than local considerations and the location of potable water abstraction points will dictate the imposition or withholding of ammoniacal nitrogen standards on medium to large sewage treatment works.

(v) Denitrification. Substantial discharges of nitrified sewage effluent into a watercourse can result in high concentrations of nitrate particularly during dry periods. Although unacceptable levels have not yet been reached in the U.K., situations have developed where concentrations of nitrate in drinking water abstracted from a river are close to the recommended maximum concentration of the World Health Organisation. (17)

The Water Research Centre at Stevenage has obtained denitrification using methanol as a source of organic carbon in submerged biological filters but the results of full scale test at Rye Meads Sewage Treatment Works utilising anoxic zones are much more encouraging. The existing plant has been modified to produce zones where stirring occurs without aeration, and by controlling the sludge recycle rates, nitrate levels have been reduced by at least 40 per cent without additional operating cost. However, on a new installation there would be a 10% increase in capital cost of the aeration tank. (18) Further experimental work is required but aeration plant with anoxic zones are likely to be constructed in the next few years in specific locations.

The alternative use of the flooded biological anaerobic filter is more likely to progress as and when the supplemental carbon source which at present is methanol is replaced by, for example, settled sewage. (19)

Phosphate Removal

Sewage effluent is the main source of phosphorous in watercourses which as a result suffer from eutophication. The concentration of phosphate in sewage is a function of detergent usage and the average concentration in sewage in the U.K. is approximately 10 to 12 mg/l (as P). (20) Some removal can take place in conventional treatment plant by biological activity or in special methods of treatment such as ion exchange reverse osmosis and other demineralisation treatments where phosphorous removal is not the prime objective.

Phosphate can be removed by chemical precipitation by iron compounds or lime either in primary sedimentation tanks or in the tertiary treatment plant. Phosphate removal is being used quite extensively in the United States for inland waterway discharges but the application of Phosphate limits to sewage effluents in the U.K. is unlikely to be necessary or economic for many years in all but isolated instances.

Tertiary Treatment

Tertiary treatment processes are designed to "polish" a good secondary effluent by removing suspended solids. Well established processes such as slow sand filters, upflow and downflow rapid filters and microstrainers have all been succesfully operated world-wide.

The development of the multimedia or Ultra High Rate (U.H.R.) filter after a long period of extensive experimental work is likely to replace the above mentioned processes as a very efficient, cost effective method for water recovery and re-use. The principle of the U.H.R.F. is the use of several layers of different media to form the complete bed. The size and density of the selected materials is such that after backwashing they remain in their pre-selected location and maintain their large to small size grading.

Many applications of U.H.R. filtration are operating throughout the world on industrial installations and it has been demonstrated that removal of over 80% in suspended solids and substantial reduction in B.O.D. have been achieved from sewage effluents without the use of coagulating chemicals.

Disinfection

Chlorine is established as the practical disinfectant in the water industry. It has been used quite extensively with sewage effluents but its efficiency can be greatly reduced when ammonia is present and it can convert certain pollutants into undesirable compounds. These factors have encouraged investigations into other forms of disinfection and in particular ozone. The classical method of disinfection with ozone is by chemical oxidation but with proper application ozone can be used to produce a frothing operation that will also remove suspended solids and dissolved organics by a physical flotation process. This two fold process does not require any additional ozone above that required for disinfection. (21)

A future additional application for ozone is the removal of colour from sewage effluents where discharge into recreational waters could be objectionable.

Overseas Applications

Evidence is available to show that in countries with significantly different diets, the per capita S.S. and B.O.D. load in domestic sewage does not differ greatly from developed countries.

Conventional treatment processes and accepted U.K. design parameters have been successfully adapted for overseas projects where these are appropriate although due to temperature differences a change in oxygen transfer rate in tropic climates occurs. The waste stabilisation pond in its several forms is perhaps the only system for sewage treatment which is unique to tropic climates. Sunlight, high temperatures, low cost but high land usage and unskilled maintenance are all factors that make ponds eminently suitable for the developing countries of the 3rd World. There is no universally accepted method of design, the parameters changing almost from Continent to Continent. Some idea of the variations can be gauged from Table 1 which gives pond sizes calculated by the different methods for a population of 50,000 at 100 l/day and 50 gm/day B.O.D. per capita.

TABLE 1 - Comparison of results given by different design methods for Waste Stabilisation Ponds

Method	BOD Loading Rate (kg/ha/day)	Area (ha)	Retention (days)
Load/Unit Area	250	10	25.0
Empirical Equation	105	28.6	71.5
African Typical	182	13.8	34.4
Indian Average	336	7.4	18.6
Solar Radiation	254	9.8	24.6
Thirumurthi	304	8.2	20.6
McGarry & Pescod	405	6.2	15.4

Advanced Waste Treatment

The inability of the conventional biological treatment methods to consistently produce the high quality effluent that may increasingly be required in the future for watercourse discharge or a secondary water supply system has stimulated interest in the following liquid treatment methods hitherto not usually associated with Sewage Treatment.

(i) Activated Carbon. Activated carbon is used in water treatment for colour removal and control of taste and odour. Its application to sewage purification is at present mainly limited to projects in the U.S.A. but considerable research work is being undertaken by the W.R.C.

Recent improvements in the absorptive capacity and regeneration capabilities of activated carbon have made its use a more economic proposition. Performance figures from research studies indicate that it should be possible to remove 75 per cent of the residual C.O.D. and organic carbon content, 60 per cent of the B.O.D. and practically all the anionic detergent from "polished" secondary effluents. (22)

(ii) Ion Exchange. The ion exchange method is capable of producing a high quality water from a sewage effluent but some form of pretreatment may be necessary as the system is subject to blockage by organic matter. Problems are likely to occur in satisfactorily disposing of the waste waters from the system which will contain substances removed from the raw water and the electrolyte.

(iii) Electrodialysis. Electrodialysis is accepted as a means of treating brackish water but has to date been little used for sewage treatment due to its inability to remove organic matter and colloidal organisms. However, the technique is capable of reclaiming water from sewage effluent if used in conjunction with some form of pretreatment such as Activated Carbon.

(iv) Reverse Osmosis. Reverse osmosis is a relatively new process and considerable development is still required particularly on the membrane structure to make it an economic proposition for general applications. Reverse osmosis will remove soluble organic and inorganic substances and all solid matter including bacteria and to-date has been used on a variety of trade effluent plant. Treatment of sewage effluent by reverse osmosis generally requires pretreatment of the tertiary effluent by activated carbon to reduce fouling of the membrane.

(v) Costs of A.W.T. The substantial capital and operating costs associated with A.W.T. processes lead us to believe that only the Activated Carbon process will be generally developed for sewage treatment.

Sludge Treatment

The method of sludge treatment adopted by a designer is likely to be determined by the ultimate means of disposal. Optimum solutions are required which marry the level of mechanical dewatering with the disposal method whether it be wet sludge to land, dried sludge to land, incineration or tipping.

(i) Conditioning. Sewage sludges are generally difficult to dewater due to the complex structure of the particles and the colloidal nature of much of the material present. These properties tend to produce a material which does not allow much inter-particle contact and hence is difficult to dewater by mechanical means. This can be overcome by heat treatment or chemical treatment of the sludge.

Heat treatment is unlikely to attract attention in the near future due to the high energy costs but may be used in isolated instances where destruction of pathogenic bacteria and virus is considered essential.

Chemical conditioning with lime and copperas has been traditionally used in the past but their use is on the decline with the availability of new conditioners such as Aluminium Chlorohydrate and polyelectrolytes which are easier to handle and can be mixed in-line.

The chemical conditioner represents a high percentage of the overall cost of operating a sludge dewatering plant and there is a requirement to produce modulating control of the chemical input related to variations in percentage solids.

(ii) Sludge Dewatering. New chemical conditioners have enabled manufacturers to produce a new breed of sludge dewatering equipment in the form of belt filters and centrifuges. Filter presses are still favoured in some quarters but all forms of mechanical dewatering requires energy and chemicals plus additional processes to make the product suitable for land use or disposal by incineration.

The digestor process has stood the test of time, maybe a little precariously during some periods, but with improved control on trade effluent discharges and a better understanding of the digestion process, it has a promising future. Already the Water Authorities, with their increased resources are considering the purchase and control of farm land for liquid sludge disposal following digestion.

Odour Control

Odour from Sewage Purification Works has always been a problem and increasingly so as the town development encroached on the site of the once isolated sewage farm. By careful attention to design many areas of nuisance can be eliminated but inevitably some still remain.

Effective means of measurement of odour has always been the screen behind which the accused has hidden and even today the most sensitive gas chromotograph can only measure down to a billionth of a gram whereas the nose can detect levels that are ten times weaker than this.

Methods of measurement are being developed in various U.S. cities, the forerunners being Los Angeles and San Francisco. The Los Angeles method is to establish odour units - one odour unit being the concentration of odour in 1 cu. ft. of air such that the mixture is at the threshold of sensory perception. The San Francisco method is to establish permissible emission concentrations for specific odourous substances.

If legislation is introduced on the basis of either of these methods of measurement then considerable reappraisal of sewage treatment design will have to be undertaken. An indication of the problem can be gauged by the fact that the present level of odour concentration at Los Angeles Sewage Plant is 10,000 odour units and attempts are to be made to establish control techniques to 150 odour units.

Methods of odour control are well proven such as masking, incineration, chemical oxidation by wet scrubbing, activated carbon and gas phase oxidation but all systems are costly and subject to problems of operation or dangerous gas emissions.

Trade Waste Treatment

Trade waste treatment in U.K. has progressed very slowly mainly because the local authorities and latterly the Water Authorities have not, until recently, had the backing of legislation to support their consent requirements. Trade effluent agreements often have been concluded only after protracted (23) negotiations and conditions tempered to allow for social or local situations. It is time that facilities were established for a nationally accepted method of trade effluent charges with provision for grants to Industrialists who opted for on-site treatment.

Trade effluents contain organic matter which is biodegradable, organic matter which is non-biodegradable or toxic metals and inorganic substances,and as such the methods of treatment vary considerably.

High rate biological filtration is now a well established method of treatment for biodegradable wastes either on a partial treatment or full treatment basis. It is reasonably economic in terms of capital cost and land usage and for certain processes can provide water for recycling. Recent research into anaerobic digestion of organic wastes indicates significant saving in energy compared with aerobic processes although additional treatment is required if the effluent is to be discharged in a watercourse due to the appreciable amount of fine suspended matter.

Role of the Manufacturer

A great deal of research is sponsored or directly undertaken by equipment manufacturers and they are naturally anxious to see an early return from their investment by progressing the process to the manufacturing stage. The pay-off on research investment is always uncertain and there is often a hiatus between the development of the full-scale unit and the first sale. A method often used to bridge this gap is the sale or return procedure related to satisfactory performance.

Another method of introducing new plant or techniques is to acquire the licence to manufacture locally an established process in common use in other areas of the world. This procedure has the advantage that operating experience is available to establish overall confidence in the performance of the plant providing this can be related to the characteristics of the local raw material to be treated.

PERFORMANCE

Operating Results

The operational and teething troubles that occur with new process plant are invariably passed on to the designer when the plant is first commissioned. As the plant operator gains experience and develops resourcefulness in keeping the equipment operational so the designer proportionately hears less and less of plant performance at first hand. The dissemination of operational results is often carried out by the supplier and is frequently used as an aid to further sales.

When an overseas application for equipment is under consideration the designer requires plant performance data since by specifying the type of equipment, he will be required in due course to justify his choice and, indeed, often to provide a performance bond for the satisfactory operation of the total installation. It might be politic in such a situation to carry out pilot plant trials in the overseas location but often time is of the essence and the installing authority cannot wait while the experiment is set up and sufficient indigenous results are made available.

ECONOMICS

The benefits of plant standardisation apply particularly to large authorities and once new equipment is demonstrating a benefit it follows that extended use should be encouraged and designs rationalised. Standardisation of plant will keep down operator training costs and also minimise the capital investment in spares to be stocked.

Among the benefits that the operator might expect from the designer's efforts in the next few years one would include an improved level of treatment. Another approach would be to concentrate on providing a more consistent level of treatment throughout the day or alternatively the facility to vary the degree of treatment so that it is in balance with the seasonal quality of the receiving water.

MATERIALS AND METHODS

New materials that become available to industry on a commercial scale may alter the economics of a process if investment capital can be saved without sacrificing the existing reliability of the process. Manufacturers continue to show movement towards lighter constructions and lower costs made possible by the availability of aluminium alloys, tubular constructions and plastic components.

This rethink approach is also being extended into the civil engineering sector where the designer is examining the benefits of alternative methods of construction such as steel or timber tanks, reinforced concrete tanks formed by diaphragm wall piling or the use of soil anchors to keep down tank wall thickness. It is possible that we may see more of the 'above ground' type of construction that is common in the U.S. taking the general form of the oil tank farm installation.

If we are to use these new materials and techniques we must, however, be certain that they will be technically, environmentally, aesthetically and economically acceptable.

PLANNING MATTERS

The location or extension of a treatment works is governed by the normal planning procedures that apply to all development in the U.K. Increasingly environmental legislation adds to the problems of the designer by requiring that structures are built below ground, are covered, are sound-proofed, do not cause aerial nuisance and emit no dust or smoke. The man in the street would paraphrase the regulations by saying - "We must have a Works but don't build it here."

Overseas the designer needs to avoid the temptation to reproduce the conventional orthodox U.K. design since water quality requirements will vary widely. An acceptance of local architectural styles and shapes is essential to successfully harmonise with existing development in such situations. Construction techniques will favour certain methods of treatment and the availability of local materials and the facilities for the maintenance of mechanical and electrical plant will also influence design considerations.

CONCLUSION

The national experience of the acute water shortage of 1976 is bound to affect our future water planning policy. Increasingly there will be a demand to recycle water for re-use and the designer will be faced, in the long term, with more stringent effluent standards aimed at the removal of pollutants, nutrients, bacteria and trace chemicals or he may be called upon to respond to a new policy to produce a second quality water for non-potable use. These policy decisions will be dictated partly by economics, partly by environmental balance but undoubtedly they will be responses to public demand to safeguard the environment probably accompanied by an acceptance of a broader regional approach.

In the short term quality standards of effluent are unlikely to change dramatically and indeed the funds are not available for major national advances in quality levels. Efforts are more likely to be directed to up-rating existing sub-standard installations to an accepted local norm where this will be environmentally beneficial to the watercourse and the community and will also show a cost benefit.

REFERENCES

1. Institution of Civil Engineers. 1972. Conference Proceedings. Advances in Waste Treatment.

2. Banks, N.B., 1973. Surveyor. CXL11 (4239), 32.

3. Ministry of Housing and Local Government/Welsh Office. 1970 "Taken for Granted" Report of the working party on sewage disposal.

4. Water Research Centre. 1975/76. Annual Report.

5. Department of the Environment. 1975. Register of Research.

6. C.I.R.I.A. 1973 "Cost-effective sewage treatment - the creation of an optimising model. Report 46."

7. C.I.R.I.A. 1975 "Cost-effective sewage treatment - an assessment of the prototype model. Report 54."

8. Ministry of Housing and Local Government, 1970 "Technical Committee on storm overflows and the disposal of storm sewage. Final Report."

9. Maskell, A.D., and Lumbers, J.P., 1974. I.A.W.P.R. Workshop *Instrumentation and Control Proceedings*, 291.

10. Drake, R.A. and Crossley, A.M., 1975. Instrumentation and Control in Wastewater Treatment : Three case studies of U.K. works. W.R.C.Conference.

11. Banks, N.B., 1975. Water Pollution Control : 74(3), 312.

12. Water Research Centre. 1975. Notes on Water Pollution No. 68.

13. White, M.J.D., 1976. Water Pollution Control : 75 (1), 21

14. Hines, D.A. and others. 1975. "The I.C.I. deep shaft aeration process for effluent treatment." Instn. Chem. Engs. Symposium Series No. 41.

15. Boon, A.G. and others, 1976. Water Pollution Control : 75 (2) 206

16. Boon, A.G. and others, 1976. "Use of oxygen to treat sewage in a rising main." South Western branch meeting, I.W.P.C.

17. World Health Organisation. 1970. "European standards for drinking water."

18. Cooper, P.F. and others. 1976. "Modification of the conventional activated sludge process at an existing sewage works to achieve effluent denitrification." Met. and Southern Branch Meeting, I.W.P.C.

19. Water Research Centre. 1974. Notes on Water Pollution No. 66.

20. Water Research Centre. 1970. Notes on Water Pollution No. 49.

21. Nebel, C. and others. 1976. Wat. and Sewage Works : 123 (5), 82.

22. Bayley, R.W., 1972. Water Pollution Control : 71 (1), 45.

23. Control of Pollution Act, 1974.

DISCUSSION

Authors' Introduction

The authors, in introducing the paper, said that the paper discussed design possibilities in certain areas of sewage treatment which might be introduced in the foreseeable future. Any advance in design techniques required a parallel advance in the designer's knowledge of design parameters and process relationships associated with each stage of sewage treatment. In this connection the work being carried out by the CIRIA research programme into the production of an optimization model for sewage treatment design had highlighted for designers the need for them to improve their understanding of the process relationships involved in sewage treatment.

By far the most expensive element of sewage treatment was the biological stage, and efforts should be concentrated over the next few years to minimize both capital and operating costs concerned with this element of sewage treatment. Several methods of reducing investment in biological treatment were discussed in the paper and one of the most promising was likely to be the use of pure oxygen.

Another area of high cost was in the sludge dewatering process and one might be tempted to say that the less water required in the finished product then the higher the cost of the process plant required to achieve this. The designer did not necessarily have a free choice in this area, since it would be a matter for the instructing authority to determine whether a dry sludge or a wet sludge should be produced. This decision would in turn be governed by the ultimate method of disposal selected for the sludge. Some employing authorities would continue with their traditional disposal methods of barging to sea, others would continue to brave environmental censure by disposing of sludge to land, while others would take a bolder course and embark upon a campaign for the production and marketing of an organic-based fertilizer. The ultimate solution for the disposal of sludge had always been the production of an innocuous fertilizer, suitably packaged.

In the paper some mention was made of physical chemical treatment of sewage and also advanced wastewater treatment. From the experimental work carried out in the UK, it was as yet too early to say whether these methods of treatment would be in general use in a few years' time. We must await the publication of the results of the experimental work now being carried out at Stevenage, Davyhulme, and Coleshill before opening the flood gates to these new techniques.

Turning to the application of new designs to developing countries, it was always difficult for the designer to know quite how much innovation to permit. He had to balance the possible savings that optimization and mechanization could bring in capital costs against the dislocation that the failure of sophisticated equipment could bring to the total process if the necessary spare parts and specialist maintenance expertise were not readily to hand.

Environmental aspects of design were touched upon in the paper, such as noise, odour control, landscaping, and planning concepts. It was particularly important that the construction of buildings and plant should be in harmony with the general environment and local architecture both in the UK and overseas.

Besides considering new techniques and new treatment processes that might be in general use, it was appropriate to mention a new approach to the design of sewage treatment works incorporating the use of new materials, new methods of construction, and indeed a move away from the traditional use of concrete monoliths.

The authors presented a number of slides (not reproduced) illustrating aspects of the paper and finally commented that Peter Walker would be a little disappointed if he visited a sewage works in the next decade. As a layman, he would still see the old physical and biological systems which had been used for the past 50 years. However, to the initiated, that works would be the culmination of the efforts and collaboration of the reseacher, the operator, the statistician, and the designer to produce an efficient economic plant utilizing new techniques where these showed a benefit for the community and the environment.

Verbal Discussion

DR. D.E. WRIGHT (Sir William Halcrow and Partners), in opening the discussion, said that although concern had properly been expressed in recent years on "environmental" issues, professional engineers still had a primary obligation and responsibility to their clients and to the community whose waste they treated to see that resources were wisely allocated and well spent. It should be the hallmark of the professional engineer working in the water field (as in any other) that he based his selection of a particular waste water treatment scheme on a rational examination of the economics of the alternatives, taking account of capital, operating, and maintenance costs. He endorsed the authors' statement (p.2) that "...the replacement of an existing treatment method will depend not so much on the availability or development of new techniques but more on the outcome of the economic and practical appraisals necessary to justify any decision to effect a change".

As the pros and cons of new individual processes were debated, it must not be forgotten that to work effectively each process had to be linked with others into an *interdependant* sequence. This led naturally to a consideration of the role of the CIRIA sewage treatment optimization model, which was mentioned on pp. 2 and 3 of the paper. The basic rationale behind the construction of the CIRIA prototype mathematical model was that the complexities of sewage treatment, in particular the interaction between various stages and the effects of the feedback of waste and surplus sludges and liquors from the sludge treatment stream, were such as effectively removed the possibility of a designer having the time to evaluate more than a few alternatives if he relied solely on manual methods of calculation. When developed, the CIRIA model would enable a designer to obtain a better estimate of the particular combination of processes, and for that combination the capacities of each process stage which produced the required degree of purification at minimum total annual cash flow, i.e. with greatest economy of resources. The advent of such a design aid was as important to the future design of works, as the introduction of new individual processes.

The authors' firm was one of ten organizations invited by CIRIA to use the prototype model in a design situation in predevelopment trials, and it would be interesting to have their views on the potential usefulness of the model as a future aid to design.

On page 2 the authors reminded their readers of the need for operators to communicate problems to designers so that newly designed works incorporated lessons learnt from operating experience. Although this had traditionally been seen as a particular problem for the independent consulting engineer in his relations with a client, he suspected that unless care was taken similar problems of communication would not be completely unknown in the water authorities.

On p. 11 the authors made the "schoolmasterly" comment that sludge digestion had a promising future; it would be helpful to have their elaboration.

On p. 12, the authors raised the important problem of the hiatus that could occur between the development of a new process and its use, due to the uncertainties over performance and operating cost. Although this was a particular problem to manufacturers, it also existed when new technology was incorporated in civil engineering works. It would be interesting to make a detailed study of the delays that had occurred to the introduction of new techniques because of the financial consequences of failure and whether the water authority structure had lèad to an improvement in this respect.

He welcomed the emphasis in the paper to overseas work and said that it was of great importance to British consultants. The general concepts embodied in the phrase "appropriate technology" were ones that were much to the fore and simplicity of process technology, robustness of design, reliability in operation and ease of maintenance were the chief requirements of works to be built in the developing countries. These qualities most emphatically did *not* mean second best. It was perhaps a paradox that there was a place for advanced design methodology when evolving design solutions which themselves embodied essentially simple technology.

MR. J.M. HASELDINE (John Taylor & Sons), referring to the second paragraph of the introduction (p. 1), said that because the basic sewage treatment processes in use today were established 50 years ago or more, it did not mèan that they were not still the best and that they might not remain the best for the next 2000 years.

It was unlikely that within the present state of knowledge anyone would come up with a cheap and easy answer to the problems of sewage treatment. The processes at present used would be with us for a long time, although this did not mean, however, that each process and the equipment used for it would not be refined and improved. Manufacturers were constantly producing new ideas for the design of equipment and more and more processes were becoming mechanized and automated.

Innovation in the design of sewage treatment processes normally always resulted in unforeseen difficulties and it was a bold man who decided to install on a large scale completely new and unproven equipment.

The authors were conscious of this and recommended laboratory experiments followed by pilot plant studies spread over several years before the construction of a full-scale plant was contemplated. This was certainly necessary for some new types of processes, but it was very time-consuming since it was unlikely that any full-scale plant would be in operation in much less than three or four years after completion of pilot scale plant experiments.

The authors had referred to the high cost of fuel, which made thermal treatment process of all kinds less attractive than they were some years ago. This might be one reason for these processes being unattractive, but generally the processes themselves had normally always proved to be unsatisfactory due to the difficulties of maintaining the plant in working order. There were a number of monuments to enthusiastic plant suppliers and optimistic designers which were at present lying idle or being demolished due to the enormous costs of maintaining the equipment.

On new design applications, the authors referred to screening processes. These would appear to work well, provided there was not too much faecal matter in the screenings. If comparatively fine screens were installed at the inlet of a works where the sewage entered by gravity without having been pumped anywhere on the sewerage system, then the amount of faecal matter that was intercepted by a fine screen could cause serious problems.

Under the heading of flow balancing, the authors' comments were related mostly to quantity but, of course, any form of balancing would also balance the quality. This aspect must not be overlooked at a sewage works, since on most systems there was always the possibility of some shock load arriving at the sewage works which, if it were not allowed to mix quietly in a *primary sedimentation tank, could well affect the biological treatment process.* This matter should not be overlooked if works were ever designed using inclined tube settlement where retention times would be so much less than normal. Variations in flow were not appreciated by those who criticized the conservation of the sewage engineer.

Under the heading of biological treatment the authors referred to the deep shaft process, which might well be a thing of the future. But shafts were expensive to construct. The idea of the deep shaft was simple, since it enabled the sewage to be subjected to high pressures without involving anything much in the way of power costs. He wondered whether anyone had tried subjecting sludge to high pressures to see whether this helped with the conditioning. If it did, then a deep shaft design would probably be the best way of obtaining high pressures.

His own view on the activated sludge process using pure oxygen was that the complications involved in producing the pure oxygen were too great for a sewage treatment works, and he could not see that its development would get much further.

In their conclusions the authors said that funds were not available for major national advances in quality levels. Whilst he appreciated the important aims of environmentalists and abhorred any gross pollution of the environment, there was no need in this country for major national advances in quality levels. There were some works that were substandard and these should be improved. But under normal circumstances the present Royal Commission standard worked well and had stood the test of time. He hoped that we were not ever going to be in a position of spending vast sums of national resources in setting and achieving standards which were unnecessarily stringent.

MR. G.E. EDEN (Water Research Centre) commented on the authors' reference to the Jeger Committee's recommendation that Government funds should be made available to finance full-scale trials of new processes. Prior to reorganization the DOE had provided a considerable degree of support, but this was no longer forthcoming. Some water authorities had invested capital in novel processes (such as the Unox process at Palmersford by the Wessex

Water Authority), but there was now no central co-ordination. The WRC, though able to provide technical support, did not have the financial resources to supply capital, and he felt that the DOE might reconsider their position when the economic situation improved.

Flow balancing had been referred to by several speakers. Traditional methods of sewage treatment were tolerant of changes of flow and composition, and it was only under extreme conditions that failures occurred. To deal with peaks of flow and concentration by transferring them to periods of lower loading was to reduce to some extent the margin of safety which was inherent in traditional processes. There were other methods of dealing with peak loads (by processes having low capital but high running costs such as flotation, oxygen injection, and chemical treatment) and these should certainly be considered as alternatives to flow balancing.

MR. A. MURRAY (Laporte Industries) said that experience on chemical flocculation of sewage, using aluminium sulphate or ferric sulphate, was that costs were on average 2.0 to 4.0p per 1000 gal. Additional sludge weight was 5 - 10%, and these sludges had been easier to dewater, no doubt due to the lower amount of secondary sludge.

The fact that injection of pure oxygen into a main could prevent septicity was accepted - the injection of hydrogen peroxide would have a similar effect. The improved BOD of the primary tank effluent would probably only apply when compared against a septic sewage. It was likely that a more cost effective BOD reduction would be obtained with chemical flocculation.

In the comment on phosphate removal, only iron compounds and lime were mentioned. In Scandinavia some 85% of the plants used aluminium sulphate.

Regarding disinfection of sewage effluents, he believed that chlorine dioxide had a number of advantages over chlorine, due to it not reacting with ammonia which was present in most sewage discharges.

A new chemical not mentioned in the comments on sludge conditioning was poly aluminium chloride. This product was particularly effective on mixed raw primary and surplus activated sludges.

Many odour problems in the U.S.A. were currently being overcome by the addition of hydrogen peroxide to sewers, sludges, and in wet scrubbing systems.

DR. P.E. HALE (GKN Birwelco Ltd) said that the Jeger report had been quoted in the paper and he thought it a pity that this publication had not made specific emphasis on the publicizing of the results of work on existing plants. Perhaps there was an over-emphasis on the development of new techniques when a scientific appraisal of the existing processes to develop these and optimize their efficiency could lead to benefits equal in magnitude to those accruing from new processes which might, or might not, prove to be beneficial to the industry.

Many of these new designs might not prove to be economic in the foreseeable future. However, the desirability of a tertiary treatment facility for sewage was acknowledged by the authors when they concluded that there would be an increasing demand for re-use.

The ultra high rate filtration process that had previously been proved on industrial applications had now been satisfactorily demonstrated as a cost effective unit on sewage effluent, and this was one of the "new" unit processes that would have a significant impact on the water industry.

As a contractor, his own firm had been actively engaged in the research and development of a high rate filter specifically for the T T. of sewage. Each sewage had different characteristics and every sewage works effluent had its own "fingerprint", so the intensive pilot plant tests carried out in different parts of the country had not covered all the various permutations of effluent quality. However, the result of the work carried out was a deep bed filter supported on a suspended "nozzle plate" floor in either steel or RC shells.

General removal rates of 65-80% SS with corresponding BOD removal had been demonstrated at surface loadings some 5-6 times greater than for conventional filtration, with acceptable filter runs.

With the recent commissioning of the GKN filters at the Ash Vale tertiary treatment plant of the Thames Water Authority a new and exciting possibility in this field was opened up. The results of the tests at this plant could not be given as they were incomplete, and it would pre-empt the publication of a near future paper on the subject. But the results so far achieved confirmed the order of magnitude greater than conventional expectations indicated earlier. Tests were to be done to confirm the levels of phosphate removal and how the removal efficiency of SS could be improved by the addition of alum as a coagulant.

Finally, he asked if the authors had any information on nitrate removal by the injection of hydrogen peroxide into deep bed filters. Also, could the authors put figures to their section on phosphate removal during T T. as carried out in the U.S.A.?

MR. W.J.F. RAY (Thames Water Authority) considered recent developments and modifications to the unit processes laid out in Fig. 1, p. 4. Dealing firstly with inlet works, he referred to a screenings washing and dewatering plant at present being installed at the Basingstoke sewage treatment works which should not only eliminate the perennial rag problems from the rest of the process, but at the same time produce rags free from faecal material and in an acceptable form for disposal.

At the East Hyde sewage treatment works, at Luton, trials were in progress to assess the effect of adding low lime doses upstream of the sedimentation tanks not only reducing the lime dose required for sludge pressing later, but improving primary sedimentation and reducing the load on the biological process. The similarity with late 19th Century practice would not be lost on the historically minded.

He referred to the CIRIA report No. 58 which, *inter alia*, dealt with the use of plastic media at the outside edge of percolating filters in order to reduce wall cracking due to temperature effects.

The "deep shaft" process was an interesting new method of sewage treatment, although he had reservations as to whether a completely watertight shaft would be economic in locations where the strata was pervious. Protection of the aquifer was essential, where subject to potable water abstraction.

There was considerable potential for using pure oxygen, especially for uprating works on restricted sites and for trade waste treatment; pilot plant trials had been carried out by the Thames Water Authority.

With increasing reuse of water from rivers there was a requirement not only for nitrification but also denitrification. Thames Water Authority research and development work in conjunction with WRC at Rye Meads, Lee Bridge, and Luton was most encouraging. Cooling towers, associated with electricity generating stations, had considerable potential in improving river quality; recent work had shown that high rates of nitrification could be achieved.

Substantial denitrification was being achieved in the Carrousel method of sewage treatment and he hoped that a report on this work would soon be published. It was desirable to achieve denitrification by natural means rather than by adding further chemicals, such as Methanol, if at all possible.

Written Discussion

MR. P.A. BANKS (John Taylor & Sons) wrote that on p.6, para. (i), the authors stated that the performance of a unit volume of biological filter was directly proportional to the surface area of the media that could support aerobic growth of attached micro-organisms, provided that the voids were adequate for the passage of humus solids.

Experience gained from two years of operating pilot-scale filters at the Anglian Water Authority's Cliff Quay sewage treatment works in Ipswich * suggested that the specific surface (the total surface area per unit volume of medium) was not so critical. As the authors had implied, it was the amount of biological activity that could be supported that was important and this was not just a function of surface area or even specific surface but also of other factors. Important among these were flow distribution over the filter bed and the degree of lateral distribution within the media.

MR. D.A. BURROUGHES (British Water and Effluent Treatment Plant Association) asked the authors to comment on the possible trend towards more trade effluent plants to remove toxic substances at the factory, particularly where metals recovery and water recycling was possible. This could abate certain problems at the sewage treatment works, although drought-inspired water saving measures might be working in the opposite direction towards strengthening sewages albeit with more tractable components.

It might also pay water authorities to adjust their charges to give industry an incentive to remove toxic metals themselves to improve the opportunity of selling non-toxic sludge to farmers.

* 1976, *Water Pollution Control*, vol. 75, no. 1, p. 40, "Studies of high rate biological treatment of Ipswich sewage on pilot filters using plastics media".

MR. C. MARTIN (L.G. Mouchel & Partners) disagreed with the authors over the benefits to be obtained from balancing flows and loads to a sewage treatment works. He wanted to dispose of the notion of the use of storm tanks as balancing tanks. If the design of storm tanks had been correctly carried out for the loads reaching the works, there would not be any spare capacity for use for flow balancing. This use would imply that some or all of the tanks would be full at some time. If a storm occurred when they were in this condition, then following the first assumption, there would not be adequate capacity for the storm. If it was argued that there would be adequate capacity, then clearly they must have been over-designed in the first instance.

His firm had recently completed the design of a works where the provision of flow balancing had reduced the peak hydraulic load through the works to 2 x DWF, and this had produced considerable savings in cost. The question had been carefully considered of whether or not to remove sludge from the balancing tanks; in the event, it had been decided not to remove it. The sludge was scoured from the tanks back to the main flow by the use of sparge pipes which were fed by the washwater return from the tertiary treatment plant. This was a special case and the question of sludge removal must always be considered individually.

Throughout the Symposium there had been no mention of one of the main advantages to be gained from automation or the mechanization of manual operations. A major problem of a sewage treatment plant was the low rates of pay that were available to operators because they were carrying out menial and unskilled tasks. The use of mechanization and automation could reduce the amount of low quality and unpleasant tasks which had to be undertaken and which attracted only low pay. The use of more sophisticated procedures required higher skills, attracted higher pay, but from fewer people, and this must surely be a desired aim. A different approach was required in overseas installations, where there might not be the necessary infrastructure to support the maintenance of sophisticated equipment.

He questioned the value of de-nitrification as a sewage treatment process. The total risks of high nitrate levels were not yet established, and whatever action was taken at the sewage treatment plant, there could still be a substantial contribution from run-off from agricultural land. Since at any time only part of the total river flow was taken for water supply, it would seem to be more appropriate and economical to include de-nitrification as a water treatment process.

He had been dismayed to hear a contributor say that a new classification of river quality was being considered combining BOD, suspended solids, and ammonia levels, and that the requirement for effluent discharge would be that a river would not be down-graded in classification. Why was it necessarily the case that to down-grade a river from one arbitrary class to another was automatically to be regarded as a bad thing?

Finally, he agreed with the authors over the necessity to publish experimental results, be they good or bad. In the past the sewage industry had been an open industry where the exchange of information had been full and easy. It was true that bad results gave a more favourable indication than good ones. He was concerned that with the increasing public relations consciousness of water authorities, there was an increasing tendency to not publish bad results for fear that this might diminish the expert image of the authority.

MR. N.J. NICOLSON (Thames Water Authority) wrote to question the statement (p.8) on denitrification that "... on a new installation there would be a 10% increase in capital cost of the aeration tank", attributed to Cooper *et al.* Although there might prove to be a need to install larger aeration tanks on the grounds that the aerobic part of the tank needed to be the same size whether anoxic zones were present or not, the full-scale work at Rye Meads showed no significant difference between denitrifying and conventional units run in parallel. This might have been due to spare capacity in the units; it might, in part, be due to the removal in the anoxic zone of a significant amount of BOD, thereby reducing to some extent the load for the remainder of the unit. If the 10% factor was proved it might be necessary to reconsider the use of the methanol process when smaller retention times could be possible. Another factor would be the time of year when denitrification was needed; if this did not coincide with mid-winter, when maximum retention time was needed for nitrification, then existing tanks might be sufficiently large even when up to design load. Until the question had been resolved, the claim was not proven.

Authors' Reply to Discussion

The authors, in reply to Dr. Wright, accepted that the use of the CIRIA mathematical model was likely to produce the greatest economy of resources. Their experience in using the model was that it was an exciting exercise and with further development and refinement it would provide a useful tool for the design engineer.

Elaborating on the promising future for sludge digestion, the energy crisis had changed the economics of power generation from sludge gas in that this was now possible for smaller communities than hitherto while at the same time producing a stabilized sludge suitable for direct land application.

While agreeing with Mr. Haseldine's general views on the introduction of new plant the authors believed that the operation of sophisticated thermal treatment units was often outside the range of experience available at a sewage treatment works and could account for recent process failures and abandonments in addition to the increased cost of fuel.

Fine screening was a process that needed careful consideration both in location and operation including adjustable screen sizes, variable washwater rates and cleaning cycles but, nevertheless, it had great potential particularly on a pumped system.

So far as effluent standards raised by both Mr. Haseldine and Mr. Martin were concerned, the pollution level that the river could accept while maintaining plant and fish life was the guideline to be adopted when fixing discharge standards for that works.

In reply to comments by Mr. Eden and other speakers, flow balancing required further research work in order to determine quality benefits. In considering other suggested treatment methods for dealing with peak loads, these would require economic justification.

The authors apologized to Mr. Murray for omitting to mention Aluminium Sulphate as a useful flocculent, and drew attention to the work now going on at Stevenage, Coleshill, and Davyhulme on physical chemical treatment. The results of this work would answer many questions on sludge quantity production and dewatering.

Hydrogen peroxide was an alternative to pure oxygen injection into rising mains, and there were advantages in using the latter, particularly in long mains.

The authors were interested to hear from Dr. Hale of high rate filter developments and awaited the published results of the Ash Vale experimental work. They had no information to contribute on nitrate removal by the injection of hydrogen peroxide, but could give average figures for phosphate removal for activated carbon treated effluent at the Pomona experimental plant as follows:-

Ion exchange	-	P04	Reduced from 8.8 to 0.1 mg/l
Reverse Osmosis	-	"	Reduced from 10.9 to 0.2 mg/l
Electrodialysis	-	"	Reduced from 10.1 to 7.8 mg/l

The authors welcomed Mr. Ray's comments, and looked forward to the publication of the denitrification results from the Ash Vale Carrousel unit, which they understood to be running under diurnal variation conditions.

Concerning Mr. Burroughes' view, it was desirable to encourage water reuse for industrial processes and the removal of toxic materials at source. The authors too hoped that some initiative could be taken by the water authorities to encourage such action.

In reply to Mr. Martin, it was believed that when considering the balancing of flows and pollution loads the designers should be seeking an optimized solution. The economics of denitrification might well be such that this process was best effected as a water treatment stage but there were also ecological factors in the river which must be considered in a cost-benefit comparison.

The point that Mr. Nicolson raised regarding the cost of providing an anoxic zone for denitrification was interesting and the publication of results from full scale works specifically designed for denitrification would be informative.