

Manuals of British Practice
in Water Pollution Control

Unit Processes

PRIMARY
SEDIMENTATION

The Institute of
Water Pollution Control
Ledson House, 53 London Road,
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1980

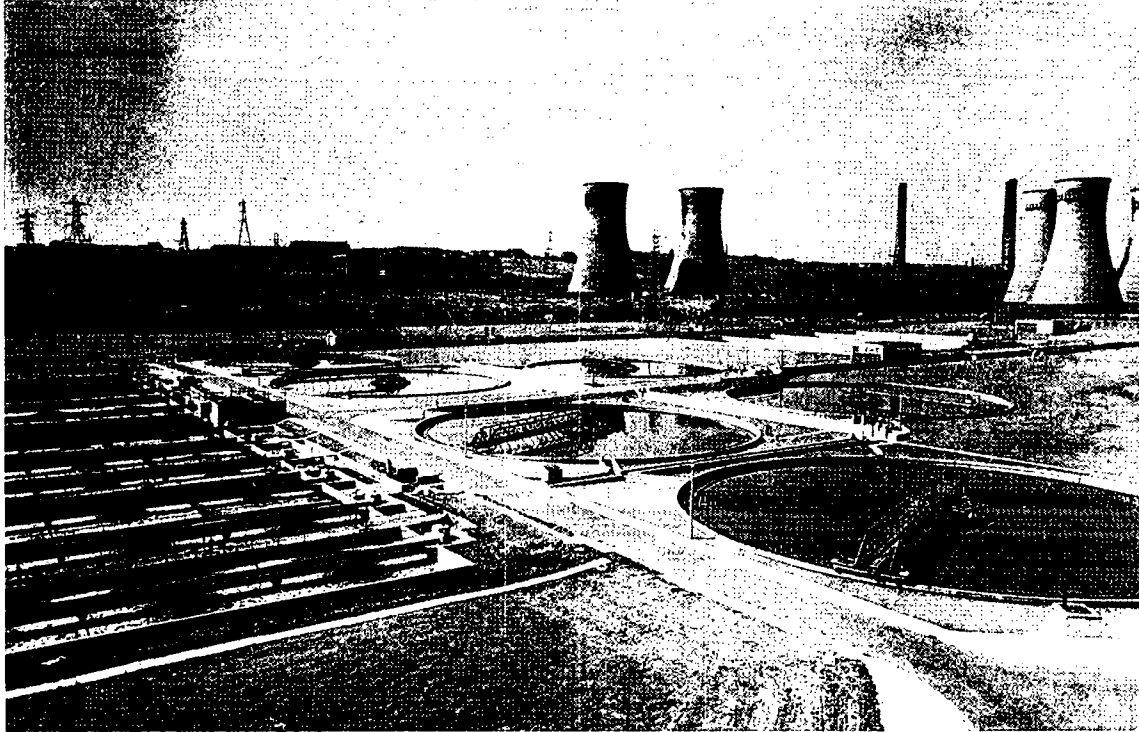
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Primary sedimentation tanks at the Ringley Fold works of the North West Water Authority

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in Water Pollution Control**

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PRIMARY SEDIMENTATION

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THE INSTITUTE OF WATER POLLUTION CONTROL

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P R E F A C E

In 1970 the Council of the Institute of Water Pollution Control discussed the question of the publication of definitive manuals on the subject of British Practice in Water Pollution Control and concluded that such publications would be generally welcomed.

The Institute's publication An Introduction to Sewage Treatment will continue to serve as a general guide to the layman interested in the subject, whilst the manuals will, it is hoped, cover the subject in sufficient depth to become accepted as a reference source both to those already actively engaged in this particular field as well as to students seeking authoritative guidance when preparing for professional qualifications.

Throughout the manuals of unit processes of waste-water treatment it will be seen that there is often a variety of equipment available for any particular purpose, and different modes of operation are described. Wherever possible, an indication will be given of circumstances which favour the use of any particular type of equipment or method of operation which past experience has shown to be advantageous. The variable nature of sewages and sludges means, however, that such an indication can usually only be given with qualifications.

Every effort has been made to ensure that the information given is as up-to-date as is practicable and, where possible, future trends and likely innovations are discussed.

The preparation of this Manual has included a lot of work on the part of a number of persons, and the Sub-Committee of the Institute's Publication Committee which has been responsible for its production wish to thank those members of the Council of the Institute who have made comments and suggestions for its improvement, and especially do they wish to thank the staff of the Water Research Centre, Stevenage Laboratory.

This Manual was first printed in 1973 and has been reviewed by the current Sub-Committee; except for Section 5.1 only minor amendments have been made to the original version.

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1. Sedimentation: General Considerations

1.1 Purpose

Sewage is complex and contains polluting matter in many forms. In addition to the dissolved impurities, it contains a heterogeneous dispersion of numerous substances, both organic and inorganic, in colloidal, pseudo-colloidal and simple suspension. Gross solid material and most of the insoluble inorganic matter are removed by the preliminary processes of screening and grit removal but the remaining suspended matter, which is mainly organic and highly polluting, passes forward in the body of the liquid.

The purpose of sedimentation is to separate the sewage into two main components, sludge and settled sewage, which by being treated separately are normally dealt with more efficiently and economically. Generally up to 50 per cent of the total polluting load in the sewage is removed by sedimentation. The secondary, or biological, treatment of sewage results in the production of further organic solid materials (secondary sludges) which are more difficult than primary sludge to dewater, consequently any process that can reduce or minimize the production of secondary biological sludge is to be favoured.

Primary sedimentation is the process by which the velocity of the sewage is reduced below the point at which it can transport the suspended matter, so that much of this settles and can be removed as sludge.

Basically, the purpose of sedimentation is to remove the maximum amount of polluting matter, in the form of readily settleable solids, from the sewage as quickly and as economically as possible. However, this has beneficial side effects, which include:

- (a) flocculation of the finely dispersed solids and adsorption of colloidal and pseudo-colloidal matter on to the solids,
- (b) equalization of the strength of the sewage prior to further treatment, and
- (c) the provision of time to enable possible beneficial biological changes to take place in the sewage¹.

1.2 Mechanism

The settling velocity of particles of suspended matter depends on their size, shape and density. According to Stokes' Law, which holds for fine granular particles, their rate of settlement varies:

- (a) as the square of the diameter of the particle,
- (b) as the difference in density between the particle and that of the fluid in which it is suspended, and
- (c) inversely as the viscosity of the fluid, which is dependent on its temperature.

Hazen² investigated the settlement of larger particles using quartz sand with a specific gravity of 2.65 and the grains ranging in diameter from 0.1 to 1 mm. He found that with such particles fluid friction rather than viscosity controls the rate of settlement. There is therefore a transition stage during which the viscosity becomes less important and the importance of fluid friction increases. With granular particles this occurs as the diameter of the particle reaches about 0.9 mm.

However, Hazen's investigation was carried out with granular particles settling under quiescent conditions. In sewage treatment the conditions are vastly different. The particles vary widely in size, shape and density, they are flocculent in character and the sewage is moving. Also the sewage is subject to currents caused by:

- (a) dissipation of energy at the inlet,
- (b) differences of density and temperature between the sewage entering the tank and its contents (particularly when the incoming sewage contains a high concentration of suspended solids),
- (c) wind effects,
- (d) short-circuiting, and
- (e) upward draw at the outlet.

Consequently there are considerable limitations on the application of Stokes' Law and the results of Hazen's investigation to the settlement of suspended matter in sewage.

The factors mentioned in the previous paragraph tend to affect settlement adversely, but there are others which assist settlement. Owing to the various currents the flocculent particles in sewage are continuously impinging on one another and as they settle at different velocities, with particles settling

at a faster rate overtaking those falling at a slower rate, an opportunity is afforded for them to coalesce and form larger particles the rate of settlement of which is even faster.

As particles settle, liquid is displaced and settlement is then impeded. The stage is next reached when the downward movement of the particles starts to impede the upward flow of displaced liquid through the void channels until, eventually, the throttling effect equals the effect of gravity and the particles come to rest.

The size, shape and density of the particles of suspended matter in sewage, and therefore the efficiency of settlement, depend on a number of factors, such as:

- (a) the system of sewerage,
- (b) the age of the sewage, and
- (c) the degree of fragmentation before settlement, due to pumping and preliminary treatment.

Also, Stones¹ has shown that biological changes take place during the passage of sewage through a sedimentation tank, reducing its oxygen demand quite independently of the reduction due to the removal of suspended matter.

The settlement of sewage is therefore very complex and for this reason it is not yet possible to design sedimentation tanks on a purely theoretical basis.

1.3 Application

Once the gross solids and grit have been removed from sewage, sedimentation is generally considered to be the cheapest way of removing impurity present as suspended matter.

Solid matter not removed during sedimentation adds to the load on the biological treatment plant and increases the amount of secondary sludge to be dealt with. It has been suggested that with an activated-sludge plant a well settled sewage may not contain sufficient solid particles to act as nuclei for the flocs of activated sludge but on a works producing such a sewage it has been shown that this fear is unfounded³. With a biological filter plant an increase in the solids content of the settled sewage will increase the possibility of the filters becoming blocked.

Secondary sludges are much more voluminous and more difficult to

dewater than primary sludge and an increase in the amount relative to that of the primary sludge will increase the difficulty of treating the sludge as a whole. Also secondary sludges are often returned to the incoming sewage for settlement along with the sewage solids and the greater the amount returned the greater will be the load on the primary tanks.

It is therefore advisable that in the treatment of sewage, provision should be made for removing solids by sedimentation to the greatest reasonable extent.

1.4 Factors Affecting Sedimentation

1.4.1 Composition of sewage

The sedimentation of domestic sewage is affected by the concentration and character of the solids present in the sewage and by its content of synthetic detergents. Experiments carried out by the Water Pollution Research Laboratory⁴ showed that the amount of sludge produced was largely controlled by the hardness of the water supply; with a soft water the amount of sludge which settled in a given time was reduced, but with a hard water the addition of packaged detergent resulted in the formation of a considerably increased volume of sludge. It was found that the additional solid matter contained calcium and phosphate, together with flocculated organic matter derived from the sewage, and it was concluded that the increased volume of sludge was due to the "builders" present in the synthetic detergent.

1.4.2 Preliminary treatment

Sewerage system. With a separate system of sewerage less solid matter will be diverted to the watercourse in wet weather than with a combined system and the load on the sedimentation tanks will be greater; also if the sewers have been laid to slack falls they will not be cleansed in wet weather. Sewers should be laid to such a fall that the velocity is self-cleansing, at least during the daily period of peak flow in dry weather, otherwise the sewage will be stale and may even be turning septic by the time it enters the sedimentation tanks. Deposits of grit and septic sludge will be scoured out and discharged to the works when rainfall causes the flow to increase after a period of dry weather.

Pumping. The turbulence created during pumping, especially when the pumps are small, tends to disintegrate settleable solids and renders the sewage less amenable to sedimentation.

Screening. If screening is inefficient, or the screenings are disintegrated and returned to the sewage, or the sewage passes through comminutors, shredded rag will collect on underwater steelwork of scrapers or tend to "ball up" and cause blockages at tank inlets and in sludge pipelines, whilst the amount of scum to be dealt with could be increased.

Grit removal. If grit removal is inefficient, and this may occur particularly at high flows, grit will be deposited in slack areas on the floors of tanks, in the mitres of sludge hoppers, or in sludge pipelines where it may cause a blockage. If it collects in the central hopper of a radial-flow or upward-flow tank the manual work involved in removal is dirty, arduous and time-consuming.

1.4.3 Secondary sludges

When biological-filter sludge or surplus activated sludge is returned to the primary sedimentation tanks an additional load is imposed on them, depending on the rate of return and solids content of the secondary sludge and the rate of flow and solids content of the sewage during the period of return.

It has been demonstrated⁵ that when secondary sludge is returned continuously to primary tanks the concentration of suspended solids (SS) in the sewage may be increased by 50 to 100 mg/l, or roughly 10 to 20 per cent of the initial concentration in the crude sewage. When secondary sludges are returned intermittently the increase in the solids concentration over short periods is much higher. Thus, sludge from biological filters is often allowed to accumulate in horizontal-flow secondary tanks for periods of 24 h or longer and when it is eventually returned to the works inlet the concentration of SS in the sewage may be increased by as much as 2000 mg/l. Townend⁶ estimated that the return of surplus activated sludge to primary sedimentation tanks at the Mogden Works increased the concentration of SS in the crude sewage by about 120 mg/l.

Tests carried out by the Water Pollution Research Laboratory⁵ showed that "the introduction of secondary sludges is likely to increase the concentration of solids in the settled sewage but that this increase will probably be fairly small".

Experiences with the return of surplus activated sludge have varied. At the Mogden Works, Lockett⁷ found that sludge rose to the surface of the primary tanks when the concentration of nitrate N in the sewage after admixture with surplus activated sludge was about 5 mg/l but that no difficulty was experi-

enced when the concentration was 3 mg/l. At the Maple Lodge works⁸ the return of surplus activated sludge from a plant which was producing a highly nitrified effluent was discontinued after it was found that denitrifying bacteria in the sludge were multiplying in the primary tanks and causing denitrification to take place in the secondary settlement tanks; when the practice was discontinued denitrification ceased. At Oxford⁹ the practice was discontinued when it was found that some of the activated sludge was passing through the primary tanks and back to the aeration plant.

At the Hogsmill Valley works³, after it was found that activated sludge was passing through the primary tanks the practice was adopted of returning the surplus sludge at a steady rate throughout the night when the flow of sewage was low and then withdrawing mixed sludge from the primary tanks early the next morning before the activated sludge had had time to turn septic. When, for a period, the surplus activated sludge was dealt with separately¹⁰ there was no improvement in the quality of the settled sewage and difficulty was experienced with movement and withdrawal of the heavier sludge.

One great advantage of returning secondary sludge to the primary tanks is the reduction in volume which occurs. At the Mogden works⁶, 4090 m³/d of surplus activated sludge was returned but the volume of mixed sludge withdrawn from the primary tanks averaged only 2045 m³/d. At the Hogsmill Valley works¹⁰ an average of 445 m³/d of surplus activated sludge was returned but the volume of mixed sludge withdrawn from the primary tanks averaged only 327 m³/d, the activated sludge constituting 26·8 per cent of this on dry solids.

1.4.4 Works liquors

Works liquors which are often returned to the primary tanks include the contents of storm tanks and of other tanks on the works when they are being emptied, liquor separated from digested sludge in secondary digestion tanks, storage tanks or lagoons, liquor originating from sludge conditioning or dewatering processes, and wash water from tertiary treatment plants.

Such liquors are usually returned during the working day when the load on the primary tanks is at a maximum, and as they are often pumped by automatically-operated pumps, the return is intermittent.

The SS content of sludge liquors may vary widely, depending on the method used for conditioning or dewatering and its efficiency. Liquor separated from digested sludge may cause septicity in the primary tanks,

and gassing may still be occurring which will hinder the settlement of solids. Traces of chemicals from the coagulation of sludge may assist sedimentation.

The effect of works liquors on the efficiency of primary sedimentation tanks therefore depends on many factors, including the source of the liquor and the efficiency of the conditioning or dewatering process, the period over which the liquor is returned and the manner in which it is returned.

1.4.5 Industrial waste waters

Industrial wastes vary widely in composition and character, and their effect on primary sedimentation will depend on local circumstances, such as the degree of pretreatment of the waste before discharge into the public sewer, the efficiency of control over its discharge, and the degree of dilution with sewage and other industrial wastes prior to sedimentation.

The following constituents and characteristics of industrial wastes may affect primary sedimentation:

High rates of flow. Significant variations in rate of flow due to the intermittent discharge of large volumes of industrial waste, e.g. from the periodic emptying of vats, may cause a temporary reduction in sedimentation efficiency, depending on the size of the drainage area and of the sewage works.

High temperature. The discharge of a substantial volume of hot waste in contravention of the Public Health Act 1936 may raise the temperature of the sewage. The reduction in viscosity which ensues will improve sedimentation, but any improvement may be offset by the adverse effect of density currents set up in the tank as a result of the difference in temperature between the incoming sewage and that in the tank. A higher temperature will encourage bacterial activity and difficulty may be experienced due to rising sludge caused by the liberation of gas.

Suspended solids. High concentrations of inorganic solids, e.g. from collieries and clay workings, can cause overloading of the grit removal plant at high flows and increase the proportion of grit in the sludge, thereby increasing the density of the sludge and making collection and removal difficult. High concentrations of organic matter will increase the amount of sludge to be dealt with and if readily putrescible, e.g. from slaughterhouses and the food industry, may cause septicity, rising sludge and odour nuisance. Fibrous solids will increase the bulk of the sludge, and the possibility of blockages in pipelines and heat exchangers and the formation of scum.

Colloidal matter. Wastes containing an excessive amount of colloidal matter, such as from tanning, fellmongering, food processing, wool washing and laundering, do not readily respond to sedimentation and may cause difficulty at a small works, especially when there are seasonal flushes, e.g. as from canneries. Blood and residues from poultry processing plants may also cause trouble. The lactose in dairy wastes may ferment to form lactic acid on standing, giving rise to the coagulation of fats and proteins in the primary tanks and adding to the amount of sludge to be handled.

Metals. Wastes from plating and other metal working industries, especially those containing aluminium and iron salts, can flocculate colloidal matter and thereby increase sedimentation efficiency. However, the amount of sludge is increased, due partly to their content of inorganic matter but more so because such chemically-flocculated and precipitated sludges may consolidate much more slowly than those which are less colloidal. Also, because of their toxicity, biological changes which take place during passage of sewage through the sedimentation tanks may be inhibited.

Ether extractable material. Industrial wastes containing fats or emulsified oils, e.g. from meat processing, oil refining, soap making, wool scouring and tanning, and even from large numbers of restaurants and canteens, can coat walls of sedimentation tanks with a fatty deposit which, if not removed, decomposes to form lower fatty acids having an unpleasant odour. The deposit imposes an excessive load on tank cleaning equipment and the amount of scum will be increased, with increasing possibility of blockages of scum draw-offs, pipelines and pumps. The grease content of the sludge will also be increased.

pH value. When an industrial waste causes the pH value of the sewage to rise above 10, e.g. due to the presence of lime or alkaline salts, hydrolysis of urea to ammonia is inhibited. A low pH may have adverse effects, including metal salts passing into solution and being carried forward to the biological treatment plant.

1.5 Sedimentation Tanks

Sedimentation tanks are normally designed to operate on a continuous flow basis and are either rectangular or circular in plan, with hoppers or a trough for the collection of sludge and power-driven scraper devices to move the sludge gently across the floor to the outlet. Facilities are usually provided for collecting and removing scum and floating debris.

1.5.1 Distribution of flow

When there are a number of tanks, equal distribution of the sewage to each tank at all rates of flow is difficult to achieve, particularly if the site area and head are restricted.

Unfortunately cut-waters tend to collect rag and paper, and unless regularly attended to the division of flow soon becomes unequal. Also, the velocity of the sewage during distribution must be self-cleansing, otherwise deposition of solids will occur.

Even if the flow is equally divided the solids load might not be so. When partial settlement has already taken place the concentration of solids near the floor will be greater than near the surface, and if the flow changes direction solids will tend to be carried to the outside of the bend by centrifugal force. Consequently, before division takes place there should be some degree of mixing, and there should be a minimum length of channel upstream of the cut-water to ensure a uniform flow.

Horizontal-flow tanks may be fed from pipes or channels; radial-flow and upward-flow tanks are fed by pipes.

When distribution is to be effected by channels the flow may be divided so that each tank is fed by a separate channel in which there is a penstock to control the flow and a measuring device, the penstock being adjusted to give equal distribution as shown by the flow indicator with which each channel is provided. The use of a flume or a magnetic flow meter for this purpose involves little loss of head and it is self-cleansing.

Where space is limited, a tapering feed channel, common to all the tanks, may be used, with each tank fed through penstocks as shown in Fig. 1. The channel is designed to give a constant velocity throughout its length, and it will be noted that the channel ends at the last penstock, thereby avoiding having a "dead" end in which grit and scum may collect. At Sheffield¹¹, for example, a transverse feed channel serving eight horizontal-flow tanks is 4.25 m wide at the inlet end and tapers to 0.6 m wide, with each tank being fed by two 0.6 m square electrically-actuated penstocks designed to function as remote-controlled submerged orifices of variable cross-section.

However, disadvantages of this method of distribution are the possibility of solids being deposited in the feed channel with scum being trapped at its end, and that a greater proportion of the solids will enter the first tank than the others.

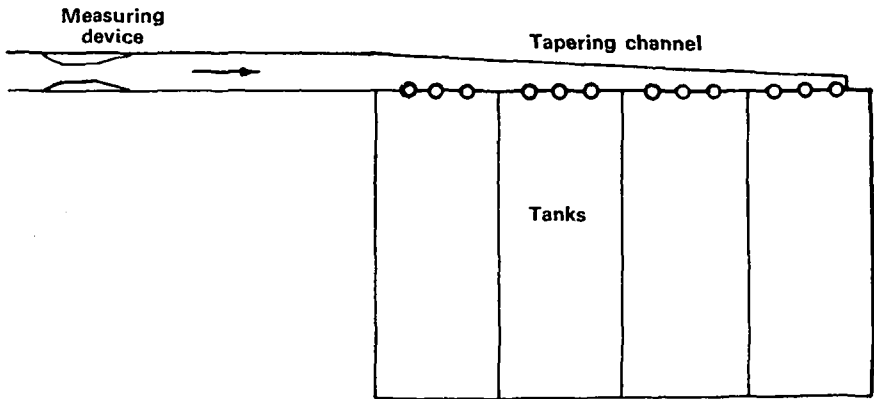


Fig. 1. Tapering channel feeding series of horizontal-flow tanks.

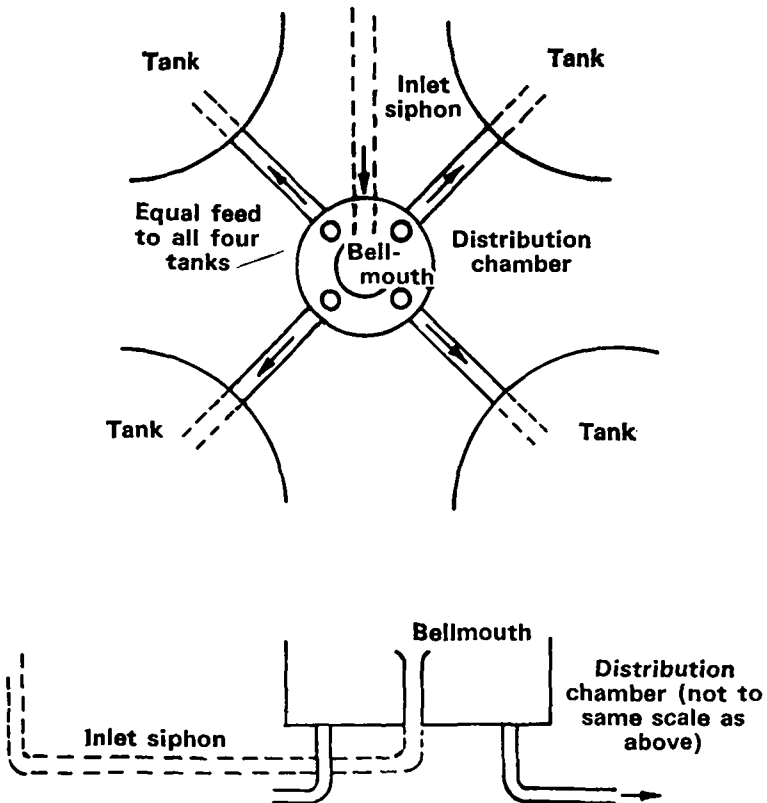


Fig. 2. Distribution chamber serving four radial-flow tanks.

Radial-flow or upward-flow tanks may be arranged symmetrically round a flow distribution chamber. One method is to discharge the sewage through a vertical pipe with a bellmouth into a circular chamber as shown in Fig. 2. The feed pipes to the four tanks leave the chamber at floor level, and being equal in all respects (with all the tanks at the same level), equal distribution is achieved without the use of cut-waters.

A layout likely to give poor distribution is shown in Fig. 3 where, although the feed arrangement to the individual tanks is equal in all respects, because of the directional velocity of the sewage discharging into the distribution chamber, two of the tanks are likely to receive a greater proportion of the sewage, and the solids, than the other two tanks.

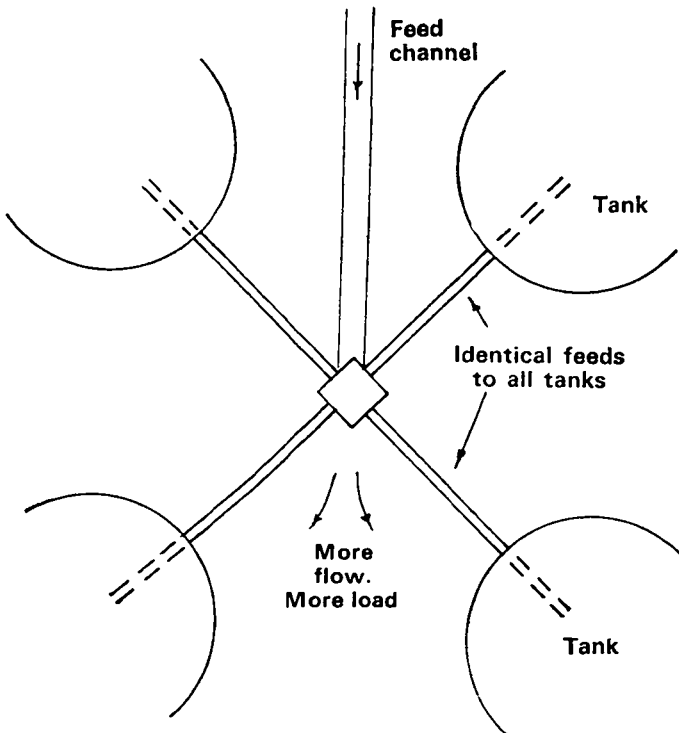


Fig. 3. Example of bad design of distribution chamber.

If the feed pipes are unavoidably unequal in length or size, a conical distribution chamber with weirs and partitions as shown in Fig. 4 may be used, the lengths of the individual weirs being proportional to the required flow.

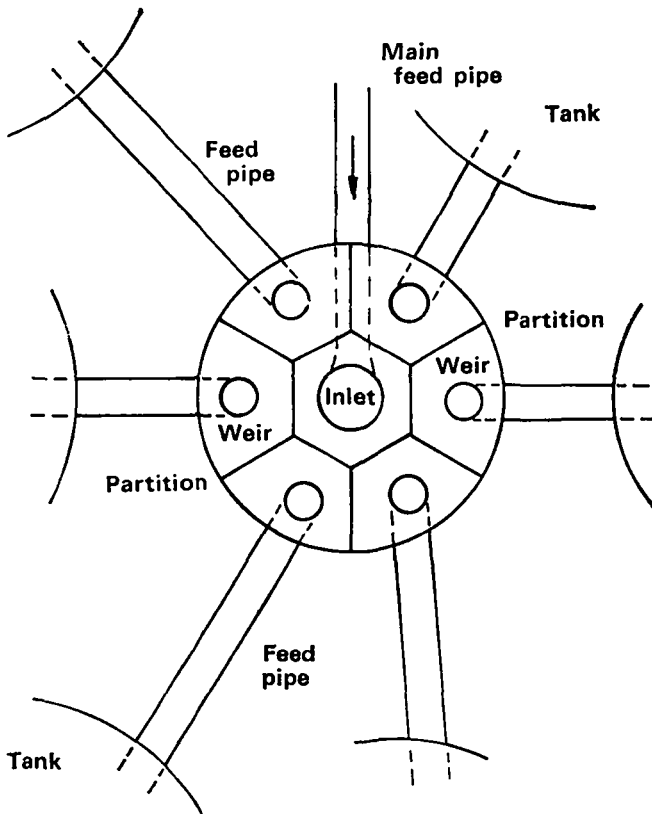


Fig. 4. Distribution chamber designed to provide equal distribution to tanks of equal capacity but with varying lengths of feed pipe and located at various levels.

With a small works, when the throat width of the flumes would be less than, say, 0.1 m and the diurnal variations in flow are large, a distribution chamber with weirs or weir penstocks may have to be used, although this arrangement suffers from the disadvantage that solids are likely to be deposited upstream of the weirs.

Whether channels with flumes or weirs are used for distributing the flow, the channel or weir must be sufficiently high above the outlet weirs of the tanks to give a free discharge at all rates of flow.

1.5.2 Number

The number of tanks should be such that one may be taken out of service without interrupting or greatly affecting the sedimentation process. Con-

sequently, even with a small works there should be at least two tanks. With a large works the number will depend on structural considerations, operating conditions and the facilities available for removing and dealing with the sludge. In the case of circular tanks the larger the number the greater the total length of the overflow weirs and the smaller the overflow rate. With upward-flow tanks, since there is an economic limit to their size, the number will depend upon the volume of sewage to be treated, with a minimum of two tanks.

1.5.3 Types

Horizontal-flow tanks. These are rectangular in plan, with the floor sloping towards a sludge draw-off at the inlet end. Although termed "horizontal-flow" tanks, the sewage usually enters at a lower level than the sill of the outlet weir and during passage through the tank the flow is affected by eddies and currents, although its general direction is from one end of the tank to the other, with the heavier solids being deposited at the inlet end and progressively lighter solids being deposited as the sewage flows from the inlet to the outlet.

Radial-flow tanks. These are circular in plan, with the floor sloping to a central sump. The inlet is at the centre and since the level at which the sewage enters the body of the tank is usually much lower than that of the peripheral weir, the flow has an upward as well as a radial component. Also, during its passage from the central inlet to the peripheral outlet the velocity of the sewage is constantly decreasing, reaching a minimum at the outlet weir. This destruction of velocity renders the sewage susceptible to eddy currents.

Upward-flow tanks. These may be square or circular in plan and are basically an inverted pyramid or cone, with the floor sloping sharply to a central sump. The inlet is at the centre and the direction of movement of the sewage when it enters the body of the tank is downward. The sewage then flows radially outward and upward towards a peripheral outlet weir. As the distance below the surface of the zone in which the direction of flow changes from downward to outward and upward is relatively great compared with the horizontal distance from the central stilling box to the peripheral outlet weir, the direction of flow in the tank, although partly radial, is mainly upward, hence the term "upward-flow" tank. With this type of tank, movement of the sewage is against the motion of the falling particles of solid matter. Consequently a greater opportunity is afforded for particles to impinge on one another and coalesce to form larger particles with consequent increased efficiency of settlement and a higher quality effluent.

1.5.4 Sludge collection and withdrawal

Tanks may also be classified according to the method used for sludge collection and withdrawal, as shown in Table 1.

TABLE 1. CLASSIFICATION OF PRIMARY SEDIMENTATION TANKS ACCORDING TO THE METHOD USED FOR SLUDGE COLLECTION AND WITHDRAWAL

| Tank | Method used for sludge collection and withdrawal |
|---|---|
| Horizontal-flow tanks | Manual collection, removal by emptying tank. |
| Horizontal-flow tanks modified for cleaning by power-driven squeegee or rope-hauled scraper | Mechanical collection, removal by emptying tank. |
| Upward-flow tanks | Collection by settlement in deep hopper, withdrawal by pressure due to a differential head. |
| Horizontal-flow tanks designed for mechanical collection Radial-flow tanks } | Mechanical collection, withdrawal by pressure due to a differential head. |

Mechanical collection, now normally used, has the following advantages:

- (a) with sludge being withdrawn more frequently than with manual desludging, less space is required for storing sludge, and as the sludge is withdrawn without the tank having to be taken out of service, the capacity required for settlement is reduced;
- (b) less manpower is required for the desludging operation;
- (c) the frequency and time of desludging can be keyed to the requirements of other works operations such as the feeding of digestion tanks;
- (d) with a horizontal-flow tank the operation of the scraper can be regulated to sweep that portion of the tank floor on which the bulk of the solids are deposited more frequently than other portions of the floor;
- (e) since the sludge stays in the tank for a shorter period of time there is less tendency for it to turn septic, and as it is withdrawn under water the possibility of odour nuisance is reduced;
- (f) the desludging operation can be automatically controlled.

The disadvantages of mechanical collection are:

- (a) the cost of the desludging equipment, and
- (b) the cost of maintaining the equipment.

When primary sedimentation tanks are desludged mechanically it is advisable to empty them at least once a year (see 5.4.).

Sludge pipelines. Owing to their liability to blockage, pipelines conveying primary sludge by gravity should be as short as possible, be of ample size and have a minimum number of bends. They should be at least 200 mm and preferably 250 mm in diameter and should have sufficient fall to promote a self-cleansing velocity of at least 1.2 m/s. Manholes, which should be provided at each change of direction, should have a shaft which is not less than 1 m wide and the opening should have a minimum diameter of 0.6 m. When calculating friction losses in sludge pipelines account should be taken of the fact that such losses are 3 to 4 times those for water.

1.5.5 Design criteria

Maximum rate of flow. The design criteria for primary sedimentation tanks are based on the maximum flow to receive treatment. The method of calculating the maximum *sewage* flow is given in the manual on *Preliminary Processes*, and to this must be added the maximum rate of return of secondary sludge and works liquors, which should always be added to the sewage downstream of the device for diverting storm-sewage.

Surface loading. This is expressed in terms of the maximum rate of flow to be treated per day in m³ per m² of tank surface, i.e.

$$\text{Surface loading (m}^3\text{/m}^2\text{ d)} = \frac{\text{Maximum flow (m}^3\text{/d)}}{\text{Tank surface area (m}^2\text{)}}$$

Hazen² showed mathematically that surface loading is the most important factor for design purposes. Consider a particle of suspended matter entering a tank and falling downwards at a certain rate; whether or not the particle will fall to the bottom of the tank before reaching the outlet will depend on two factors, viz. the distance through which it has to fall (the depth of the tank) and the length of time it stays in the tank (the retention period). If the depth of the tank were doubled the period of retention would be doubled but so also would the distance through which the particle has to fall. If, on the other hand, the depth were halved the period of retention would also be halved. In both cases the chances of the particle falling to the floor before reaching the end of the tank would be unaltered. If, however, the period of retention were increased by increasing the surface area, i.e. increasing the length or width of a rectangular tank or the diameter of a circular tank, the time available for the particle to fall to the floor would be longer and the possibility of this happening would therefore be increased.

Retention period. For design purposes, the nominal retention period is based on the maximum rate of flow to be treated in m^3/d and is given in hours, i.e.

$$\text{Retention period (h)} = \frac{\text{Total capacity of tanks (m}^3\text{)}}{\text{Maximum rate of flow (m}^3/\text{d)}} \times 24$$

A sedimentation tank may be regarded as having four zones:

- (1) an inlet zone in which the kinetic energy of the incoming sewage is dissipated;
- (2) the settling zone in which settlement takes place;
- (3) the outlet zone, in which the effluent is collected before discharge and in which disturbance may take place due to upward draw to the outlet weir, and
- (4) the sludge storage zone.

The settling zone represents the effective capacity of the tank and any reduction in the sizes of the other three zones due to a more efficient inlet, a reduction in the upward draw at the outlet or more frequent withdrawal of sludge enables the retention period to be reduced.

The period of retention should be long enough to enable the required degree of settlement, flocculation and beneficial biological changes to take place, but anything beyond this will involve unnecessary capital expenditure and could lead to the sewage turning septic before it leaves the tank, with adverse effects on subsequent treatment and the possibility of odour nuisance.

Results of tests carried out by the Water Pollution Research Laboratory⁵ on the settling properties of suspended solids in samples of crude sewage from four sewage-treatment works (Fig. 5) indicated that in each case "virtually all the settleable material had been deposited within 2 h. The concentration of very slowly settling material after 2 h was greater the higher the initial concentration of suspended solids". A nominal retention period of 2 h at maximum flow is now commonly used as a basis for the design of primary sedimentation tanks which are desludged mechanically so that little storage space is needed for sludge. However, a longer retention period is justified where the sewage has a higher SS content than usual or the solids settle less readily, or where the sewage has a high content of industrial waste which would otherwise cause shock loads on the biological treatment process.

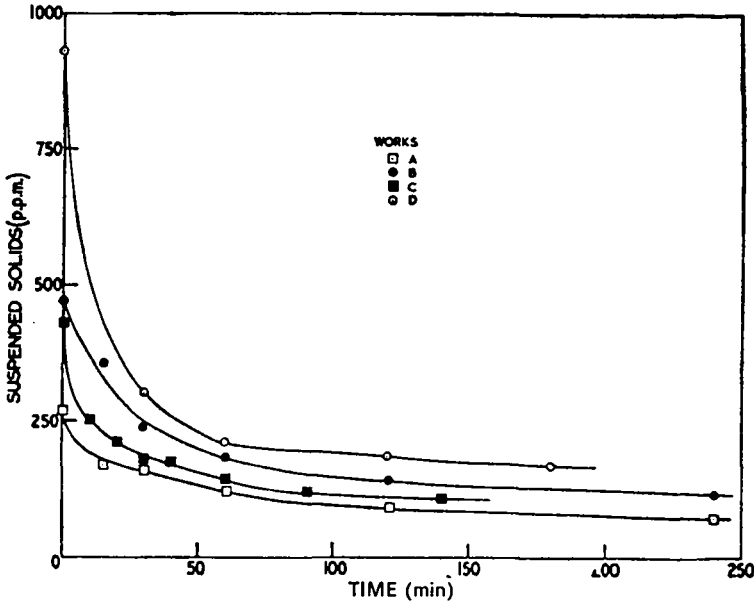


Fig. 5. Settling properties of suspended solids in samples of crude sewage from four sewage-treatment works.

Weir overflow rate. This is expressed in terms of the maximum rate of flow to be treated in m^3/d per metre total length of the outlet weirs, i.e.

$$\text{Weir overflow rate (m}^3/\text{m d)} = \frac{\text{Maximum flow (m}^3/\text{d)}}{\text{Total length of outlet weirs (m)}}$$

If the maximum rate of flow over a weir is less than $100 m^3/m d$, problems may occur because of surface tension and at low velocities the flow will not be self-cleansing. For methods of increasing the weir overflow rate see 3.4.2.

If the weir overflow rate exceeds $450 m^3/m d$ at maximum flow the velocity of the sewage as it approaches the weir will be excessive and sludge may be scoured out of the tank and scum drawn under the scum baffle. However, Table 3 shows that, in practice, reasonable efficiencies may be obtained at higher rates than this.

Upward velocity. In an upward-flow tank the particles of solid matter will be falling against an upward flow of sewage, and consequently their rate of travel will be retarded. With the particles falling at a rate varying from 3 to 6 m/h and the upward velocity of the sewage at maximum flow being, say,

1.2 m/h there will be a considerable difference between the two velocities, and at lower flows the difference will be even greater.

1.5.6 Design

The main purpose of a sedimentation tank is to remove settleable solids from sewage. The tank should be designed with the following general principles in mind:

- (a) the inlet should dissipate the kinetic energy of the incoming sewage with a minimum of turbulence and as quickly as possible, so that the "inlet zone" of the tank occupies as little space as possible;
- (b) the zone in which settlement takes place should be free from short-circuiting and stagnant areas;
- (c) the outlet should be such that effluent is withdrawn with a minimum of disturbance to the contents of the tank;
- (d) the facilities for collecting and withdrawing settled sludge should be such that the sludge is moved or moves to the necessary hopper or trough as quickly as possible and with a minimum of disturbance and that, as withdrawn it contains a maximum concentration of solids;
- (e) the design should provide for efficient collection and withdrawal of scum so that the surface of the tank is kept free from floating matter;
- (f) the design should be simple, consistent with achieving the above objectives.

Finally, the hydraulic design of channels, pipelines and treatment plant downstream of the sedimentation tank should be such that there is a free discharge over the outlet weir at all rates of flow.

1.5.7 Performance

In practice, the performance of primary sedimentation tanks is usually assessed in terms of the percentage reduction in suspended solids. However, the method used for their determination¹³ measures solids which are too small to settle in a sedimentation tank during the nominal retention period. On the other hand, flocculation may enable some of these solids to settle (see 8.3). When assessing performance using the SS determination, the concentration remaining in the settled sewage should also be stated because it is easier to achieve a particular percentage removal when the sewage contains

a high concentration of solids than when the concentration is low. The concentration of SS remaining in the sewage is the important factor from the point of view of subsequent treatment.

The purpose of a sedimentation tank is to remove settleable solids rather than suspended solids. Therefore, when comparing efficiencies of sedimentation tanks a truer measure is obtained by comparing the settleable solids actually removed with the solids removed from the same sewage during quiescent settlement for a period equal to the nominal retention period in the

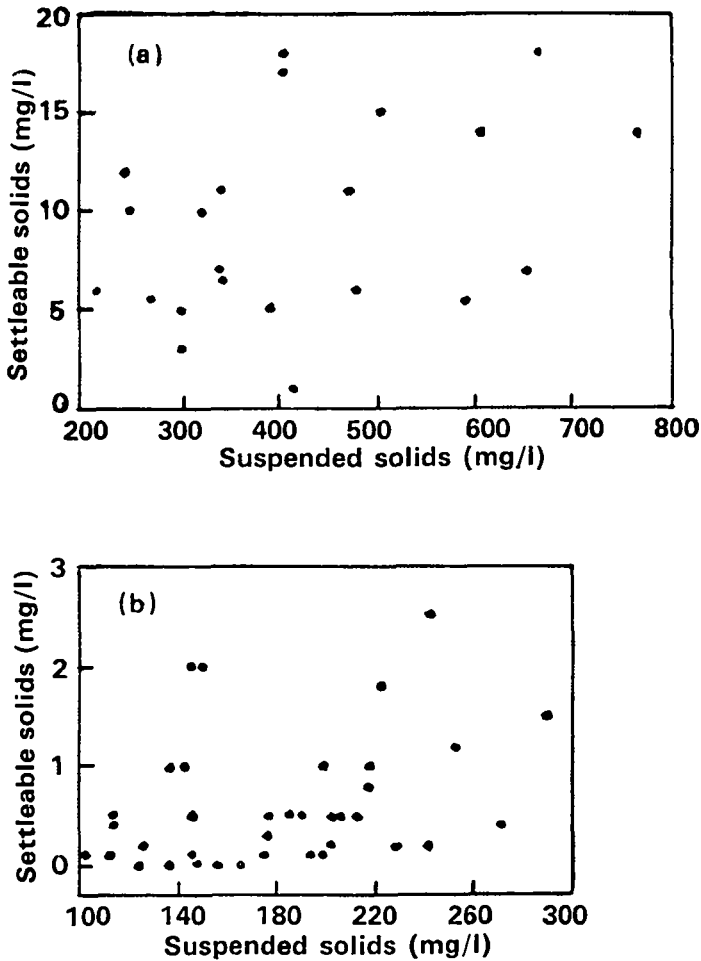


Fig. 6. Relation between settleable solids and suspended solids in (a) crude sewage and (b) settled sewage.

sedimentation tank or, as is usual in experimental work, during a period of 2 h. In experiments with the settlement of domestic sewage, Tebbutt¹² found that there was no relationship between its content of settleable solids and the SS concentration. His results are shown in Fig. 6. Other parameters for assessing tank performance include permanganate value¹⁴, BOD and COD.

1.5.8 Relative costs

Capital costs of different types of primary tank and of tanks of various sizes constructed between 1956 and 1960, also costs of mechanical equipment, have been given by Calvert¹⁵, who emphasized the tremendous range in unit costs. In general, the unit cost varied with the type of tank and its size and was governed to a large extent by site conditions.

In 1969 Bradley and Isaac¹⁶ published the results of a survey of costs of sewage treatment as at June 1967, which included graphs showing the relation between total capacity and capital cost per unit volume treated for different types of primary tank. These form the basis of Table 2, which shows that when the total capacity is 500 m³, upward-flow tanks are cheaper in capital cost than either horizontal-flow tanks or radial-flow tanks—and this probably holds true for tanks of smaller capacity. When the total capacity exceeds 500 m³ there is little difference between the capital cost of horizontal-flow tanks and that of radial-flow tanks, and site conditions may be the deciding factor.

TABLE 2. COMPARATIVE CAPITAL COSTS AT JUNE 1967 OF DIFFERENT TYPES OF PRIMARY SEDIMENTATION TANK *

| Total capacity (m ³) | Total capital cost (£/m ³) | | |
|----------------------------------|--|-------------------|-------------------|
| | Horizontal-flow tanks | Radial-flow tanks | Upward-flow tanks |
| 200 | | | 38 |
| 300 | | | 29 |
| 400 | | | 24 |
| 500 | 30 | 29 | 20 |
| 1000 | 27 | 24 | |
| 1500 | 24 | 22 | |
| 1750 | 23 | 21 | |
| 2000 | 22 | 20 | |

* Based on graphs in "The Cost of Sewage Treatment", by R. M. Bradley and P. C. G. Isaac. *Wat. Pollut. Control*, **68**, 1969, (4), 368-402.

2. Horizontal-Flow Tanks

2.1 Arrangement

Figure 7 shows diagrammatically the main features of a manually-desludged horizontal-flow tank.

2.2 Application

For many years, horizontal-flow tanks were the type most often used for primary sedimentation, but with the development of lighter scraping mechanisms and the introduction of the concept of frequent withdrawal of sludge, radial-flow tanks came into use as an alternative.

Horizontal-flow tanks are economical in the use of land and, with the shorter feed pipes, less head is required. With a series of tanks, one division wall serves two units and one scraper can be made to serve more than one tank, also the feed and effluent channels are common to all the tanks and the sludge pipelines are shorter, more readily accessible and less liable to blockage. Another factor in favour of horizontal-flow tanks is that an operating gallery can be incorporated in the design, housing the various services and permitting the withdrawal of sludge to be supervised under cover.

2.3 Design Criteria

2.3.1 Surface loading

This is usually about $30 \text{ m}^3/\text{m}^2 \text{ d}$ at maximum flow but may be as high as $45 \text{ m}^3/\text{m}^2 \text{ d}$ if the design maximum exceeds 3 DWF.

2.3.2 Retention period

If the tanks are desludged mechanically the retention period should be at least 2 h, based on the maximum sewage flow plus returned liquors.

If the tanks are desludged manually, appropriate provision must be made for storing sludge and for ensuring that the increased rate of flow caused by the withdrawal of one tank from service for desludging will not result in an unacceptable increase in the concentration of solids in the effluent from the other tanks.

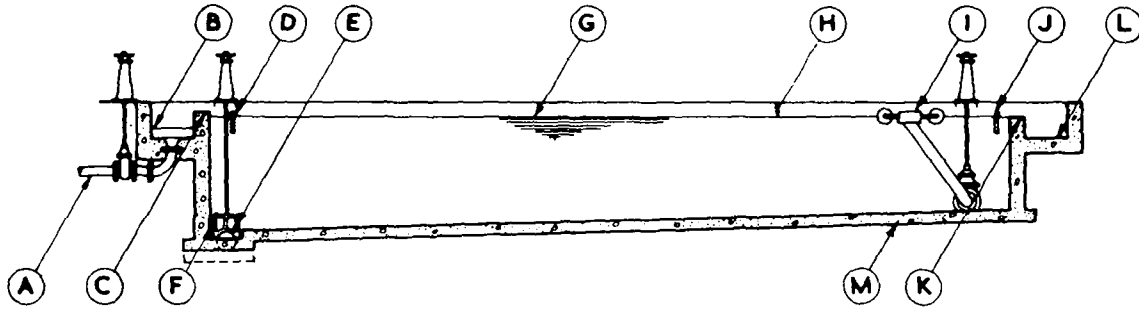


Fig. 7. Main features of a manually-desludged horizontal-flow primary tank.

A, Feed pipe; B, feed channel; C, inlet weir; D, baffle plate; E, sludge channel; F, sludge penstock; G, top water level; H, freeboard; I, floating-arm supernatant water draw-off; J, scum baffle; K, outlet weir; L, effluent channel; M, floor.

2.3.3 Dimensions

Depth. Given the surface loading and the retention period, the depth may be calculated. However, to avoid scouring of deposited sludge and so that sludge disturbed by the motion of the scraper may not rise into the stream of sewage passing through the tank, with small tanks the depth from water level should not be less than 1.5 m at the outlet end. Large tanks may be up to 3 m deep at the outlet end. The coping should be at least 0.3 m above water level to prevent sewage and scum from being blown over it by high winds.

Length and width. The total area of the tank surface may be calculated from the maximum rate of flow and the surface loading. The length is much more important than the width. Holroyd¹⁷ found that the settling velocity of flocs falling in glass cylinders full of sewage ranged from 0.83 to 1.67 mm/s, and horizontal velocities of sewage flowing through rectangular tanks of 0.005–0.015 m/s have been given by different authors. With a velocity of 0.01 m/s the sewage would travel a distance of 72 m in 2 h and flocs settling at, say, 0.83 mm/s would reach the floor of a tank 3 m deep about half way along its length. However, as shown in Fig. 26 (page 82), the pattern of movement of sewage in a horizontal-flow tank is very complex, consequently the length cannot be calculated on a theoretical basis. For small tanks the ratio of width to length is usually within the range of 1:2 to 1:4. With larger works the tanks may be up to 100 m long, with the width of individual tanks being governed by the number required and the limitations of the scraping mechanism.

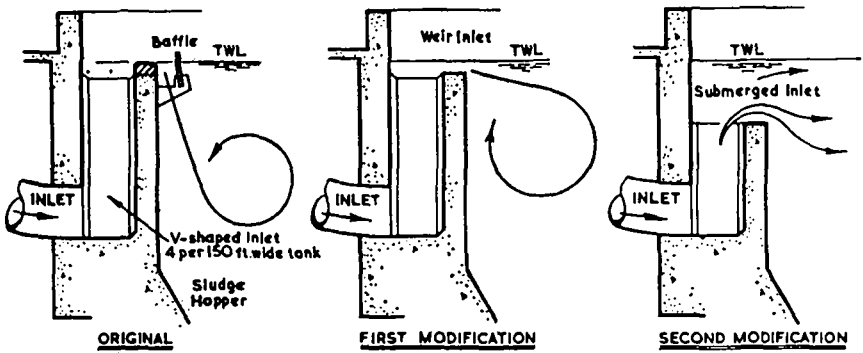
2.3.4 Weir overflow rate

The weir overflow rate is determined by the maximum rate of flow and the total length of the outlet weirs. The maximum value should not exceed 450 m³/m d and 300 m³/m d is preferable, although Table 3 shows that, in practice, reasonable efficiencies are obtained at higher rates.

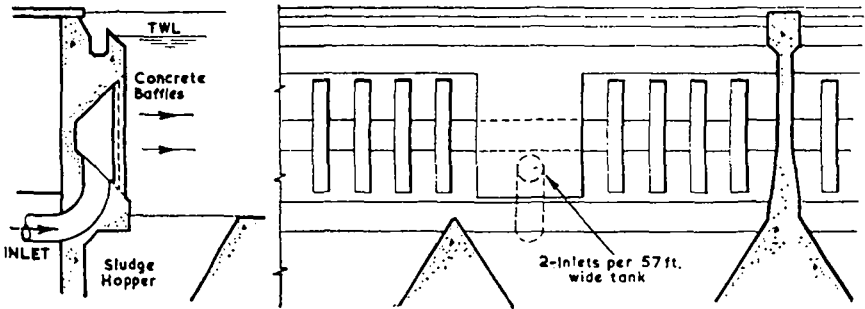
2.4 Design

2.4.1 Inlet

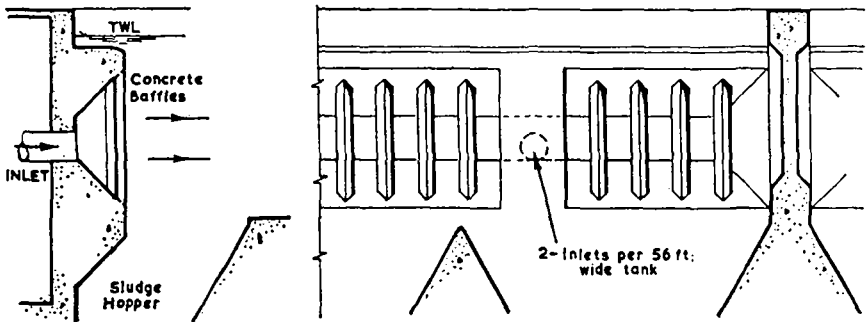
In the distribution system serving the tanks the sewage should have a velocity of at least 0.3 m/s, otherwise solids will be deposited in the channels or pipelines. At the inlet to the tank the velocity should be reduced to about 0.005 m/s and the design must provide for this to take place without creating undue turbulence. Also, whereas the combined width of the inlet penstocks will probably be only 6 per cent of the tank's width, the design should aim at distributing the flow uniformly over the full width of the tank, and to do this over a flow range of up to 6 to 1.



(a) Mogden Sewage Works, 1931: Secondary sedimentation tanks. Length/width ratio 1.38 to 1; average water depth 12 ft.



(b) Ryemeads Sewage Works, 1951. Length/width ratio 2.95 to 1; average water depth 11.83 ft.



(c) Wanlip Sewage Works, 1960. Length/width ratio 3.32 to 1; average water depth 11.19 ft.

Fig. 8. Inlets to horizontal-flow tanks.

In addition to dissipating the kinetic energy and promoting a uniform distribution of the flow, the design of the inlet should be as simple as practicable, with the minimum of surfaces on which grease and fats can collect, or of orifices which are liable to blockage. Vertical eddies may be destroyed by the use of baffles with vertical slots and the depth of flow at the inlet should be as great as possible to provide adequate density mixing (see Fig. 8), consistent with not interfering with the deposition of solids in the sludge hoppers or trough. Hamlin and March¹⁸ found from experiments with a full-scale horizontal-flow tank at Coleshill works that density currents tended to form with low velocities in the inlet zone and that a high velocity at the inlet tended to promote mixing and inhibit density currents. The smaller the tank the more important the inlet design.

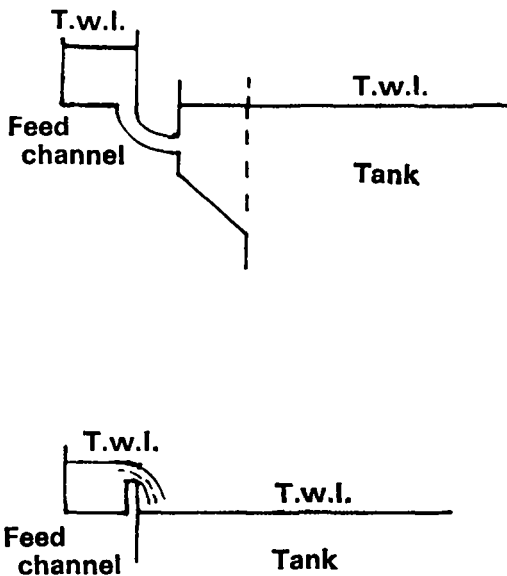


Fig. 9. Feed channels with a free discharge.

The feed channel may receive sewage through openings controlled by penstocks which can be closed when it is necessary to isolate the tank, or adjusted to control the flow into the tank. An alternative design is for the channel to receive sewage through a pipe or pipes which should preferably discharge in an upward direction, with the floor of the channel falling towards the inlet or inlets to maintain self-cleansing conditions.

The feed channel may have a free discharge or be drowned. With a free discharge (see Fig. 9) the water level in the channel is independent of that in the tank but such an arrangement is wasteful of head, promotes a high inlet velocity and may cause a submerged "waterfall" effect due to the directional velocity of the incoming sewage and to density effects. When the feed channel is drowned the connection between the channel and the body of the tank may also be drowned, or they may have a common water surface. With the submerged entry inlets shown in Fig. 10 the water level in the feed channel is controlled by the level of the outlet weir. Solids may therefore be deposited in the channel, particularly at low flows, and scum may collect in it. However, satisfactory distribution of flow between a number of tanks is obtained if their outlet weirs are all at the same level.

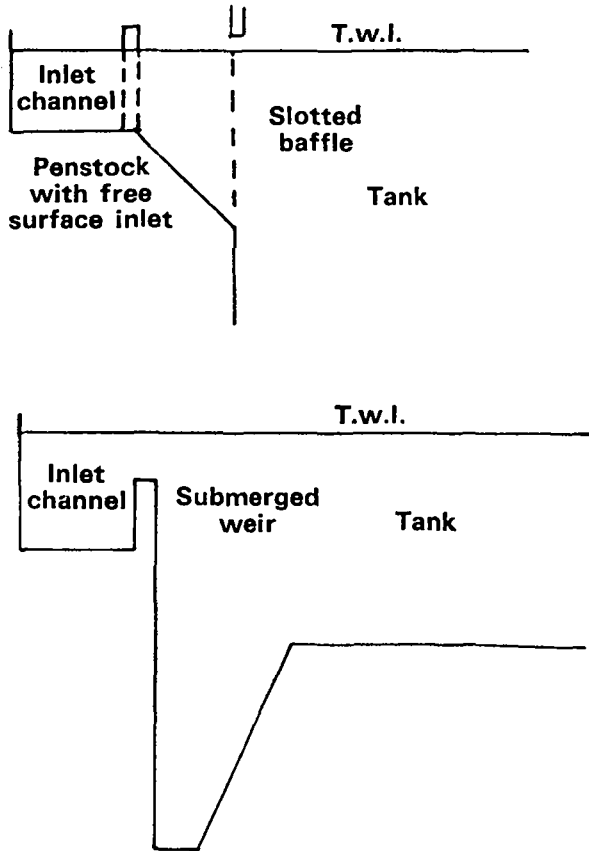


Fig. 10. Submerged entry inlets to horizontal-flow tanks.

Drowned, free-surface entry inlets as shown in Fig. 11 are an improvement over submerged entry inlets because there is unlikely to be a build up of scum in the feed channel. Distribution of flow is again controlled by the outlet weirs of the tanks and deposition of solids can occur at low flows, particularly with the submerged outlet type of inlet. Also if the submergence of the weir is insufficient, currents can be set up. At the Beckton works¹⁹ it was found that when the degree of submergence was increased so that the depth of sewage flowing over the weir was 200 mm instead of 50 mm the pattern of movement in the tanks was greatly improved. In other cases depths of submergence of between 400 mm and 900 mm have been used.

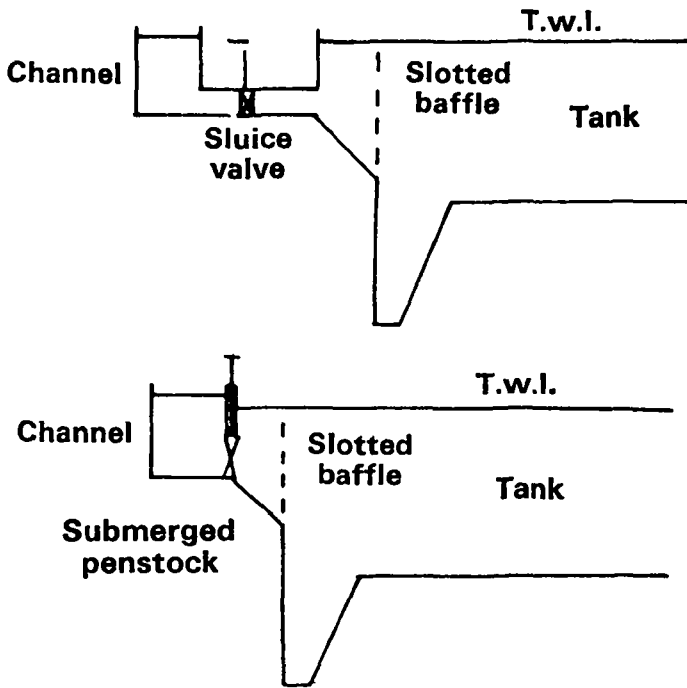


Fig. 11. Drowned, free-surface entry inlets to horizontal-flow tanks.

Figure 8, from a paper by Oakley²⁰, shows how the design of inlets for horizontal-flow tanks has been improved. In (a) the sill of the weir was progressively lowered, from being at the same level as that of the outlet weir to being deeply submerged. In (b) and (c) improvements were made to the method of admitting the sewage, to the design of the inlet baffle and to the shape of the wall under the inlet. However, Townend²¹ criticized (b) and (c) on the grounds that the divergent splay of the inlet was so far down the wall that a descending current could interfere with delivery of sludge into the hoppers.

For tanks at Sheffield, Holroyd¹¹ used a baffle chamber having 14 vertical slots 0.23 m wide and 1.83 m long in a tank 22.9 m wide, and this was followed by a hydraulic diffusion grid extending across the full width of the tank. The grid was 2.44 m deep and was constructed of 100-mm pitch fibre pipes set vertically at 0.20 m centres.

On the other hand, White and Allos²² concluded as a result of experiments that refinements in inlet design were unlikely to produce substantial improvements in settlement.

2.4.2 Outlet

The outlet is usually a weir across the full width of the tank, protected by a scum baffle and discharging into a channel. An adjustable metal weir plate should preferably be used so that it can be accurately set along its length and level with the outlet weirs of other tanks. Sometimes a double-edged trough set a short distance in front of the end wall is used, connected by pipes to the effluent channel; by reducing the overflow rate there is less likelihood of scouring sludge from the tank.

In a few cases where the sewage contains industrial wastes, to equalize the strength of the settled sewage the outlet weir is carried part way along each side of the tank as well as across the end so that sewage is withdrawn from the tank after varying periods of retention.

2.4.3 Floor

On small works which might have manually-desludged tanks the slope of the floor should be such that the sludge can be readily moved by squeegees and yet not so steep that workmen are liable to slip when cleaning the tank. Slopes ranging from 1 in 200 to 1 in 20 have been used, with 1 in 40 being the most usual. To facilitate cleaning, the floor has sometimes been given a cross fall of 1 in 40 to a central channel running the length of the tank and falling 1 in 100 to a sludge sump at the inlet end.

With mechanically-desludged tanks the floor should have a fall of at least 1 in 200 to sludge hoppers or a trough at the inlet end. In some cases the angle between the walls and the floor is chamfered.

2.4.4 Collection of sludge

Manually de-sludged tanks. In a manually-cleaned tank there is a floating-arm draw-off or telescopic valve through which supernatant water is withdrawn before the sludge is pushed manually by means of squeegees to the sludge outlet (see 5.2.1).

Mechanically-desludged tanks. Mechanical scrapers used in horizontal-flow tanks for sweeping sludge to the outlet or outlets are of two main types:

- (a) travelling-bridge scrapers, and
- (b) flight scrapers.

Travelling-bridge scrapers. These consist essentially of a power-driven bridge spanning the tank from which is suspended either a vertical (Plate 1) or a trailing (Plate 2) blade. The bridge traverses the tank on rails, the blade being lowered when sweeping sludge to hoppers or a trough at the inlet end of the tank and raised for the return journey. The blade has a replaceable edge of synthetic rubber or similar material, whilst its usual speed of travel is about 1.2 m/min when sweeping and about 2.4 m/min when on the return journey, the return speed depending on the drive. The bridge is driven by an electric motor and may be rope-hauled, with polyurethane tyres, or have a rack and pinion drive, or it may have a traction drive on rails. The rack and pinion drive has the advantage over a traction drive in that the possibility of cross-winding or crabbing is eliminated and control over movement of the bridge by an integrator (or the number of revolutions of the driving wheel) is simplified.

With the rack and pinion and traction drives the blade is hoisted by an electric motor, power being supplied by a cable using a spring-reeled or positively wound drum mounted on the bridge, whilst movement of the bridge is controlled by limit switches at each end of the tank or by an integrator. With the rope-hauled bridge the blade is raised and lowered by actuating ramps. When ramps are used in conjunction with a traction drive this involves control by complicated interlocking limit switches. Fig. 12 shows a trailing-blade scraper with a rack and pinion drive sweeping the sludge to hoppers.

When withdrawal of sludge is carefully controlled, hoppers produce a thicker sludge than a trough, but they are more costly to construct and where a single cross-concentrator directs the sludge and scum to one chamber serving two tanks there is only one sludge outlet for every pair of tanks instead of a number of outlets.

Fig. 13 shows a vertical-blade scraper with cross collectors serving two tanks.

With travelling-bridge scrapers there should be a footpath between pairs of tanks to provide access to the bridge if movement is interrupted when the scraper is part way along the tank.

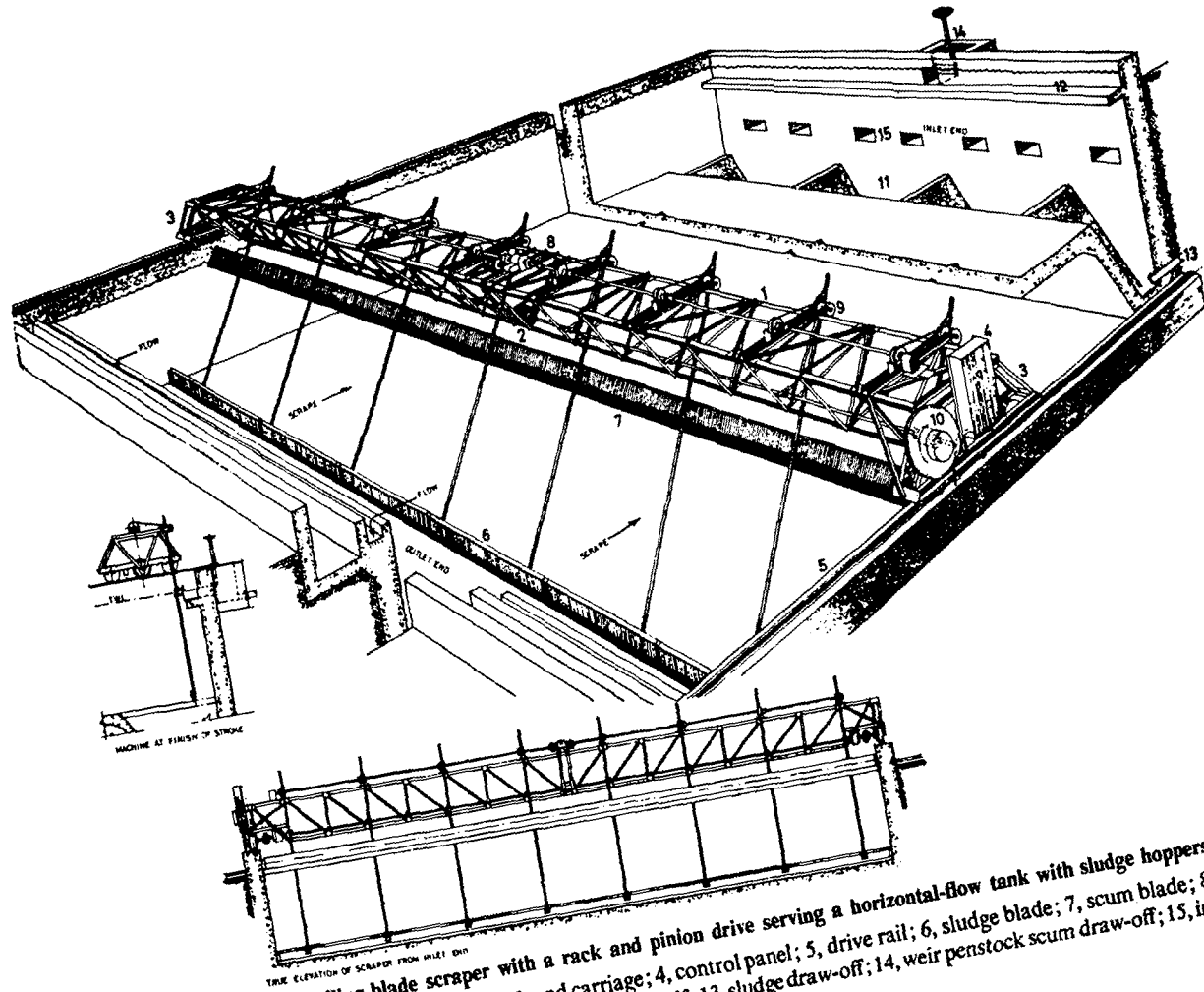


Fig. 12. Tralling-blade scraper with a rack and pinion drive serving a horizontal-flow tank with sludge hoppers. 1, Scraper main beam; 2, scraper main drive; 3, end carriage; 4, control panel; 5, drive rail; 6, sludge blade; 7, scum blade; 8, hoist drive; 9, roller guides; 10, cable drum; 11, sludge hoppers; 12, scum shelf; 13, sludge draw-off; 14, weir penstock scum draw-off; 15, inlet apertures.

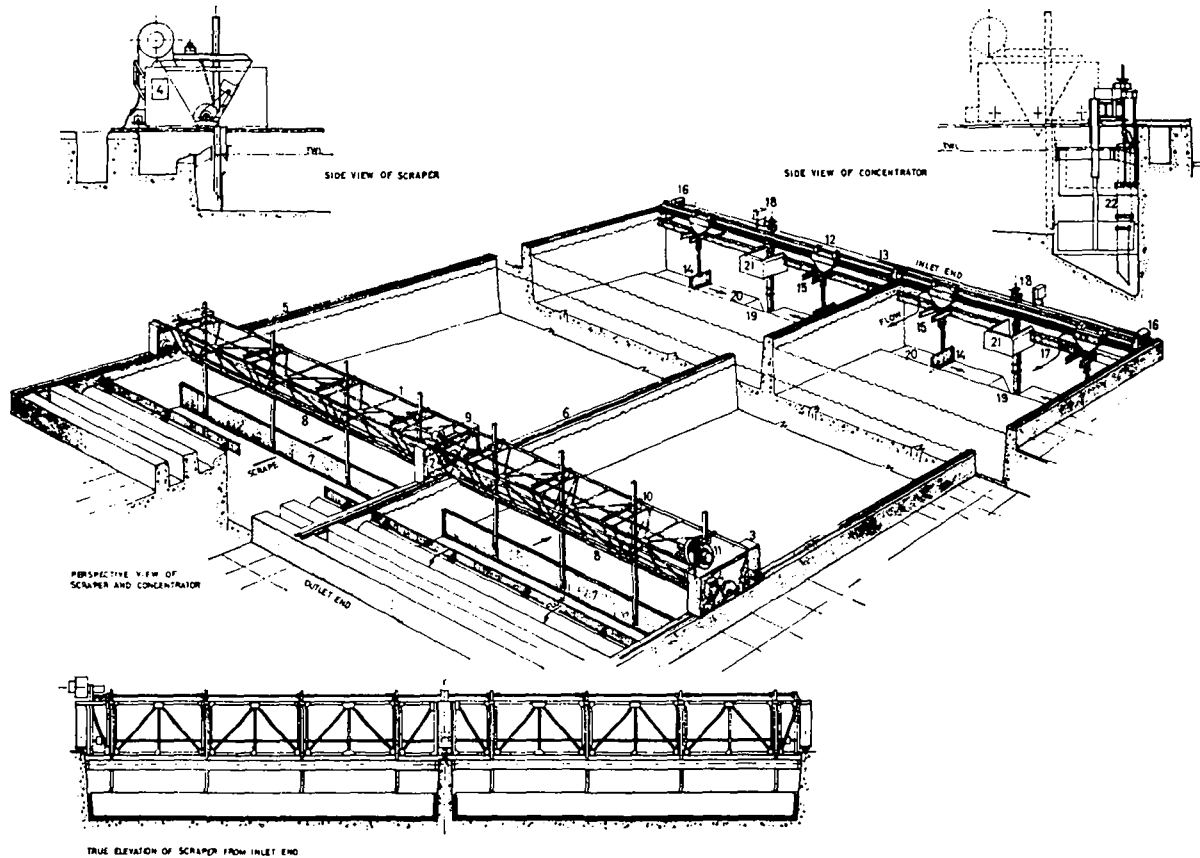


Fig. 13. Vertical-blade scraper serving two horizontal-flow tanks, with cross collectors.

- 1, Scraper main beam; 2, scraper main drive; 3, end carriage; 4, control panel; 5, drive rail; 6, idler rail; 7, sludge blade; 8, scum blade; 9, hoist drive; 10, hoist roller guides; 11, cable drum; 12, concentrator; 13, concentrator guide track; 14, concentrator sludge blade; 15, concentrator scum blade; 16, concentrator drive motor; 17, scum baffle; 18, concentrator control station; 19, sludge draw-off chamber; 20, sludge sump; 21, scum draw-off chamber; 22, hydrostatic valve.

Travelling-bridge scrapers may be single span or one machine may span several tanks, or a single-span scraper may be used on more than one tank, an electrically-driven transporter travelling on a transverse track being used to transfer the machine from one tank to another. Alternatively, the tanks may be arranged in two rows, with the inlet ends of one set of tanks backing on to the outlet ends of the other set so that one scraper can serve two tanks in line with each other. Yet another arrangement is for the inlet ends of both sets of tanks to be in the middle with the operating gallery in between. In some cases primary sedimentation tanks and storm tanks have been combined in one of these ways.

An advantage of travelling-bridge scrapers is that they can be automatically controlled to sweep tanks in any desired sequence of operational movements. At the Mogden works²³, for example, scrapers serving 64 m long second-stage primary tanks start by sweeping one third of the floor length, where most of the sludge is deposited, then two thirds and finally the complete length, in succession, at the end of which a period of rest for up to 4 h is allowed.

Flight scrapers. With this type of scraper (Plate 3) the blades or "buoyant flights" span the tank and are attached to endless chains, one on each side of the tank. The chains run on sprocket wheels supported from the side walls of the tank, two near the floor and two just below the water surface, and the chains are driven from a common shaft by an electric motor mounted on the tank wall at the inlet end. The flights move along the tank floor at about 0.6 m/min and sweep the sludge into hoppers, or sometimes a trough with a chain flight cross conveyor or blade concentrators at the inlet end. They then return along the surface, sweeping the scum to the outlet end of the tank. When there are three blades these are equally spaced, as shown in Fig. 14. With the "buoyant flight" scraper (Plates 4 and 5) the blade is attached to a tubular boom which, when submerged, makes it slightly buoyant, thereby reducing the load on the chains and on the guide rails in which they slide but still exerting sufficient pressure on the floor to move the sludge.

Since there is a separate scraper for each tank, only one tank is affected if a breakdown occurs, and owing to their simplicity the scrapers can be operated by unskilled labour. However, the whole of the equipment is submerged so it is essential that the chains and sprockets shall be fully corrosion resistant and receive regular maintenance. Also, as scum is withdrawn at the outlet end of the tank, difficulty may be experienced in delivering it into the sludge main.

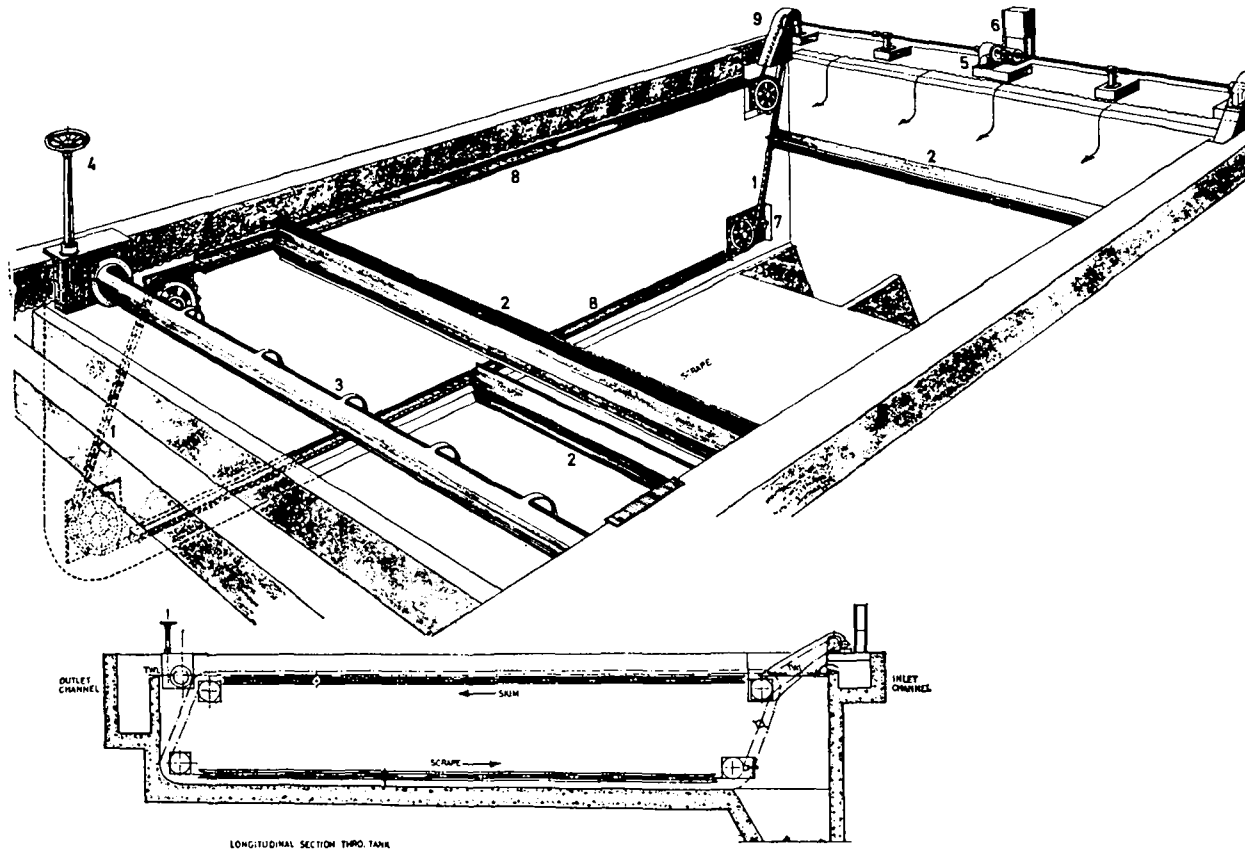


Fig. 14. Flight scraper with three blades serving a horizontal-flow tank.

1, Chain conveyors; 2, scraper/scum blades; 3, scum collector (pivoting type); 4, operating headstock to collector; 5, drive unit; 6, control point; 7, tension adjusters; 8, chain guides; 9, chain guards.

A modified form of flight scraper with a single blade, suitable for tanks up to 9 m wide, uses a large-diameter light-alloy tube from which a trailing blade is suspended. The tube is supported by and receives its motion from two endless chains running in guides mounted on the tank copings. As it follows the chain path the blade sweeps the floor to the sludge hopper and is then lifted clear for the return journey. The chains are driven by an electric motor through a cross shaft and chain reduction units, and control is by push-button. This scraper has the advantage that the chains are above water, simplifying maintenance.

Modification of tanks designed for manual desludging. On a large works where horizontal-flow tanks were not designed for mechanical desludging and it has not been considered feasible to modify them to enable a conventional scraper to be installed, a considerable economy in manpower can result from modification of the tanks to enable specially designed scrapers to be used. Modification has usually involved removing cross walls and levelling the floor or giving it a slope of perhaps 1 in 200 towards the sludge outlet at the inlet end of the tank. A power-driven squeegee, a rope-hauled scraper blade or a travelling-bridge scraper with a vertical blade may then be used.

Power-driven squeegees. A scraper blade is attached to a lightweight machine or a light tractor or bulldozer which is lowered into the tank by a crane or runs into the tank down a specially constructed ramp.

Rope-hauled scraper blade. This consists of a steel-lattice frame fitted with a steel and rubber blade which spans the full width of the tank. The frame is mounted on two bogies and is hinged to allow the blade to be lowered for forward movement and lifted for reverse. The machine runs on two rails fixed to the tank floor and is hauled by nylon ropes connected to a winch mounted at one end of the tank and driven by an electric motor.

Travelling-bridge scraper with vertical blade. A travelling-bridge scraper of the vertical-blade type may be used in conjunction with one or two cross conveyors. When the main scraper blade reaches the end of its travel it forms the fourth side of a compartment bounded by the end wall and two side walls of the tank. The sludge within the compartment is swept by a cross conveyor to the sludge outlet if this is in one corner of the tank or by two conveyors operating together if the outlet is at the centre. The blades are suspended from a carriage and are driven by an electric motor, with ramps lifting the blades for the return journey. The concentrator is usually operated manually by push-button but the drives of the main blade and the concentrator blades may be electrically interlocked if desired. Sometimes it is possible to form a trough

in the floor across the inlet end of the tank for receiving the sludge instead of using the main blade to form a compartment.

An advantage of a travelling-bridge scraper with a concentrator is that the tank does not have to be emptied each time it is desludged, as with the other two methods. Also, there is only one sludge outlet instead of two or more as with deep hoppers. However, the cross conveyors add to the maintenance required.

2.4.5 Sludge withdrawal

Manually-desludged tanks. The withdrawal of sludge from manually-desludged tanks is dealt with in 5.2.1.

Mechanically-desludged tanks. With mechanically-desludged tanks the sludge is withdrawn under pressure due to a differential head. When hoppers are provided there are usually two or more of these with sludge draw-offs in each tank, whereas a tank equipped with a vertical-blade travelling-bridge scraper operating in conjunction with concentrator blades has the advantage of only one sludge outlet.

The flow through each draw-off is controlled by a valve which may be manually or mechanically operated. With electrical operation the desludging sequence may be:

- (a) manually controlled by push-button from a distance,
- (b) manually started but automatically stopped, or
- (c) timer or automatically controlled.

Methods of controlling the desludging sequence are described in 5.2.5.

2.4.6 Scum collection and withdrawal

Manually-desludged tanks. It is usual for a scum baffle to span the tank near its outlet end. The purpose of this is to trap the scum and prevent it from passing over the outlet weir with the effluent, so that it can be removed along with the sludge when the tank is emptied. The distance between the scum baffle and the outlet weir should be within the range of 0.6 m to 1.5 m. The depth of submergence should be from 0.3 m to 0.6 m. If less than this, scum might escape under the baffle and pass out with the effluent; if greater, the baffle might interfere with the free flow of effluent over the outlet weir. The baffle may be of wood, precast concrete, galvanized iron, aluminium alloy, asbestos cement, or of fibreglass or other synthetic material.

Tanks with travelling-bridge scrapers. With this type of scraper a blade at water level (Fig. 13) sweeps scum to the inlet end of the tank at the same time as the main blade is sweeping the sludge. Alternatively, a single blade is used, with scum being swept to the outlet end on the return journey. With one design there is a ledge a little below water level at the inlet end together with a weir penstock over which the scum can pass. When the machine reaches the end of its travel the scum is trapped between the blade and the end wall of the tank. It can then be directed towards the weir by a squeegee or a jet of water or compressed air. With another design the scum is pushed up a ramp into a channel for disposal along with the sludge.

When a vertical-blade travelling-bridge scraper operates in conjunction with a sludge concentrator at the inlet end of the tank, scum blades are suspended from the same carriage as that supporting the blades for concentrating the sludge. Scum is trapped between the main scum blade and a baffle which spans the tank and auxiliary transverse scum blades push it up ramps and into a box at the centre of the tank. The blades are lifted in the same way as the sludge concentrator blades for the return journey.

Tanks with flight scrapers. Scum is swept towards the outlet end of the tank by the blade or flight during its return journey and is removed by a pivoting collector. With the "buoyant flight" scraper, at the end of the scraper cycle a flight stops when 1.8 m from the scum baffle protecting the outlet weir. The channel thus formed is then skimmed by an auxiliary transverse scraper so that the scum discharges into a chamber at the side of the tank.

2.5 Performance

The Water Pollution Research Laboratory⁵ investigated the performance over a period of 4 days of a mechanically-desludged horizontal-flow primary tank at a sewage works. The tank had a capacity of 6230 m³ and surplus activated sludge was added intermittently to the crude sewage during the day-time. The mean retention period during the test was 5.7 h and the surface loading ranged from 3.5 to 13.8 m³/m² d, with an average of 8.4 m³/m² d. The SS content of the sewage was reduced from 550 to 154 mg/l, a reduction of 72 per cent. This compared with 71 to 77 per cent for an "ideal" tank. Tests on the effluent showed that no significant amount of settleable solids passed through the tank.

Table 3 gives information on primary tanks at a number of sewage works and shows their performance. In almost every case the SS contents of the sewage and effluent were lower, and the percentage removal less than in the

TABLE 3. PERFORMANCE OF HORIZONTAL-FLOW PRIMARY SEDIMENTATION TANKS

| Sewage-treatment works | Average daily flow (tcm) | Primary tanks | | | | | | | | Suspended solids | | | BOD | | | Sludge production | | Sludge dry solids | | Ref. No. |
|---|--------------------------|---------------|--------------|--------------|-------------------|--------------------------|---|---|-----------------------|---------------------|-----------------------|-------------|---------------------|-----------------------|-------------|-----------------------------|-------------|-------------------|--------------------|----------|
| | | Number | Length (m) | Width (m) | Average depth (m) | Ratio of length to width | Weir overflow rate* (m ³ /m d) | Surface loading* (m ³ /m ² d) | Retention period* (h) | Crude sewage (mg/l) | Settled sewage (mg/l) | Removal (%) | Crude sewage (mg/l) | Settled sewage (mg/l) | Removal (%) | Average (m ³ /d) | Litres/hd d | Per cent | Volatile content % | |
| Cambridge .. | 40.2 | 2 5 | 33.9 38.3 | 16.3 19.7 | 1.8 1.7 | 2.1 2.0 | 305 | 8.4 | 5.0 | 260 | 135 | 49 | 210 | 150 | 29 | 202 (B) | 1.7 | 3.8 | 72 | 24 |
| Darlington .. | 13.4 | 2a | 47.0 | 12.8 | 2.8 | 3.7 | 530 | 11.2 | 6.2 | 295 | 195 | 34 | 280 | 215 | 24 | 137d (B) | 1.5 | 5.9 | 64 | 25 |
| Kew | 32.0 | 11 | 31.1 | 9.1 | 1.8 | 3.3 | 320 | 10.3 | 5.0 | 310 | 150 | 51 | 210 | 160 | 24 | 264 (AL) | 3.2 | 3.7 | 75 | 26 |
| High Wycombe Nottingham (Stoke Bardolph) | 25.2 | 11 | 41.3b | 11.3b | 1.3b | 3.7b | 205 | 17.6 | 6.4 | 300 | 115 | 62 | 270 | 150 | 44 | 54 (BL) | 0.9 | 6.6 | 76 | 27 |
| | 154.1 | 6 | 91.4 | 34.1 | 1.9 | 2.7 | 750 | 8.2 | 5.6 | 240 | 140 | 42 | 310 | 220 | 30 | 1714 (AL) | 3.7 | 2.2 | 72 | 28 |
| Oldham .. | 49.2 | 8 | 39.0 | 11.0 | 2.0 | 3.6 | 545 | 14.1 | 3.4 | 305 | 130 | 57 | 290 | 160 | 44 | 110d (ABL) | 0.7 | 6.8 | 63 | 29 |
| Oxford .. | 12.5 | 3 | 45.7 | 15.2 | 3.3 | 3.0 | 275 | 6.0 | 13.1 | 390 | 105 | 73 | 350 | 180 | 49 | 103 | 2.2 | 5.3 | 73 | 30 |
| Oxford .. | 16.3 | 2 | 45.7 | 15.2 | 3.3 | 3.0 | 535 | 11.7 | 6.7 | 415 | 125 | 70 | 315 | 150 | 52 | 108 | 2.3 | 4.0 | 79 | 30 |
| Rotherham (Aldwarke) .. | 27.5 | 2 | 93.0 | 12.0 | 1.8 | 7.8 | 1150 | 12.3 | 3.7 | 200 | 80 | 61 | 215 | 145 | 32 | 224 (AL) | 2.3 | 3.8 | 73 | 31 |
| Scunthorpe .. | 11.3 | 4e | 16.0 | 8.0 | 2.7 | 2.0 | 370 | 22.5 | 2.9 | 310 | 150 | 51 | 325 | 207 | 36 | 61 (ABL) | 1.1 | 6.6 | — | 32 |

* Based on average daily flow

a Two tanks (out of three) in operation

b Average of all tanks

c Same tanks but under different operating conditions

d Sludge from horizontal-flow tanks and radial-flow tanks is combined

e Consists of 4 hoppers and 4 tanks constructed as one unit.

A Includes surplus activated sludge

B Includes sludge from biological filters

L Includes works' liquors

HORIZONTAL-FLOW TANKS

test by the Water Pollution Research Laboratory. It appears that with horizontal-flow tanks the SS content of the effluent normally exceeds 100 mg/l and that SS removals range from 40 to 70 per cent.

The dry solids content of the sludge withdrawn from manually-desludged tanks depends on many factors, including its inorganic content, whether it contains secondary sludge, and the skill of the operator, but it is usually within the range of 6 to 8 per cent. Similarly, the dry solids content of the sludge from mechanically-desludged tanks is usually within the range of 3 to 7 per cent.

3. Radial-Flow Tanks

3.1 Arrangement

Figure 15 shows diagrammatically the main features of a radial-flow tank.

3.2 Application

With the introduction of the activated-sludge process and the consequent development of efficient scraping mechanisms for circular tanks, the radial-flow tank came into use for primary sedimentation.

An equal division of flow can be more readily achieved with radial-flow tanks and they are more convenient for mechanical collection of the sludge. Also, since the scraper bridge tends to be less obtrusive, the appearance of a works can be improved by their use. However, there is a maximum radius beyond which most scrapers cannot function efficiently, so that on a large works there may be an unnecessarily large number of units. The electric cables for the scraper drive are usually carried in a duct to the centre of each tank, making protection and renewal difficult, and the feed pipe and sludge pipe have also to be laid under the tank floor.

It has been suggested that with the greater concentration of flow at the centre of a radial-flow tank, efficient diffusion into the body of the tank is more difficult to achieve than with a horizontal-flow tank, but Townend³³ has pointed out that if the central diffusion chamber has a diameter of only one-sixth of the tank diameter, its discharging periphery will be equally as long as the width of a horizontal-flow tank of normal proportions in relation to tank capacity.

3.3 Design Criteria

3.3.1 Surface loading

From tests on the settlement of sewage in radial-flow primary sedimentation tanks, 3.3 m and 15.2 m diameter, White and Allos²² concluded that the retention period is the most important design criterion, although the surface loading should receive consideration. With radial-flow tanks the surface loading should not exceed $45 \text{ m}^3/\text{m}^2 \text{ d}$ at maximum flow.

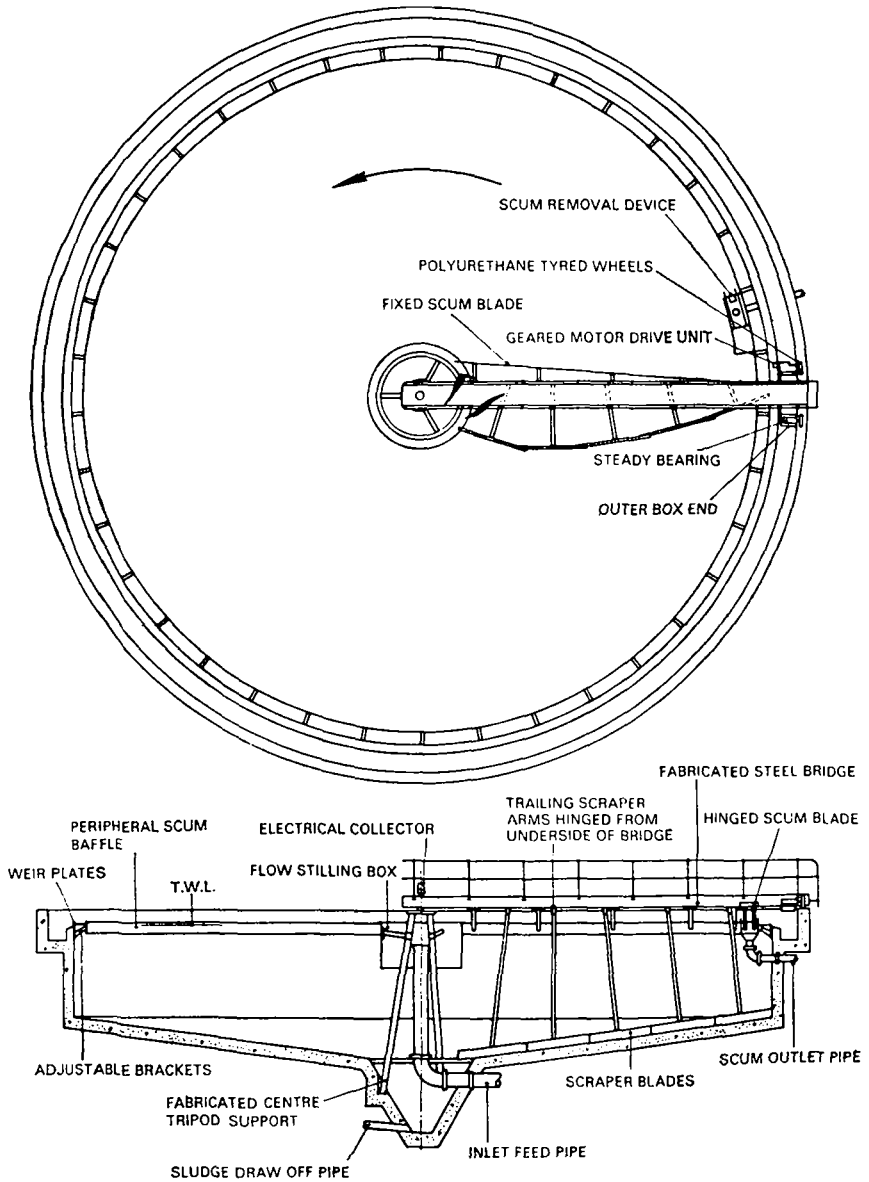


Fig. 15. Main features of a radial-flow primary tank.

3.3.2 Retention period

The retention period is usually about 2 h at maximum flow, sometimes reducing to 1.5 h when the maximum receiving full treatment exceeds 3 DWF. The capacities of radial-flow tanks of diameters ranging from 12 to 30 m and with floor slopes ranging from $7\frac{1}{2}^\circ$ to $22\frac{1}{2}^\circ$ are given in Table 4.

3.3.3 Dimensions

TABLE 4. CAPACITIES OF RADIAL-FLOW TANKS

| Tank diameter (m) | Volume per m of side wall depth (m ³) | Volume of conical portion (m ³) | | | |
|----------------------|--|--|------------|------------|-----------------------|
| | | Floor slope | | | |
| | | $7\frac{1}{2}^\circ$ | 10° | 15° | $22\frac{1}{2}^\circ$ |
| 12 | 113 | 30 | 40 | 61 | 94 |
| 15 | 177 | 58 | 78 | 118 | 183 |
| 18 | 254 | 101 | 135 | 205 | 316 |
| 21 | 346 | 160 | 214 | 325 | 502 |
| 24 | 452 | 238 | 319 | 485 | 750 |
| 27 | 572 | 339 | 454 | 690 | 1067 |
| 30 | 707 | 465 | 623 | 947 | 1464 |

Diameter. The diameter of a radial-flow tank is controlled by the design of the scraper, ranging from a minimum of 5 m to 15 m for a fixed-bridge scraper to 50 m for a rotating-bridge scraper. Above this diameter a special design of both scraper and tank is necessary.

Depth of vertical side. The depth of the vertical side should not be less than 1.5 m from the water level and it is usually from one sixth to one tenth of the diameter.

Slope of floor. The floor slope depends upon the type of scraper used, but a $7\frac{1}{2}^\circ$ slope to the horizontal is common. In a series of tests with model tanks, Clements³⁴ found that a slope of 10° gave the best results; flat-bottomed tanks gave a slightly lower performance and the worst results were obtained with tanks having floor slopes of 20° to 30° . If too great the heavy sludge may be swept to the centre so quickly that it is inadequately mixed with the lighter sludge and an uneven load is imposed on the scraper.

3.3.4 Weir overflow rate

If the weir overflow rate at maximum flow is less than $100 \text{ m}^3/\text{m d}$ the rate at minimum flow will be too low to prevent surface tension from affecting flow over the weir. If the weir is continuous, the diameter of a radial-flow tank is therefore limited because of the relatively long length of its peripheral weir. However, this difficulty may be overcome by using other forms of weir (see 3.4.2).

3.4 Design

3.4.1 Inlet

The feed pipe usually runs beneath the floor of the tank to the centre, then turns upward and ends in a bellmouth a little below water level or in a diffuser with vertical or horizontal slots or circular ports discharging below the surface. Alternatively, the feed pipe may enter through the side of the tank, although in this position it might interfere with the motion of the scraper and the effects of directional velocity imparted by the change in direction from a horizontal to a vertical flow might not have been eliminated before discharge.

When the feed pipe ends in a bellmouth, the outlet may be surrounded by a cylindrical diffuser which, in turn, is surrounded by a deflector drum. The diffuser has a series of vertical slots and the sewage passing through them is deflected downward by the deflector drum. The purpose of the diffuser is to dissipate the kinetic energy of the incoming sewage and to promote uniform distribution. Alternatively, there might not be a deflector drum, the sewage flowing through ports directly into the body of the tank. Whichever method is adopted, the design must ensure that settled sludge is not disturbed by the flow of sewage. Diffusers and deflector drums vary greatly in design, from a steel, aluminium alloy or fibreglass drum mounted on or supported by a feed pipe, or slung from the bridge and rotating with the scraper, to a concrete box with ports supported on piers built up from the edge of the sludge hopper.

The diameter of the deflector drum varies, according to the design of the tank, from 10 to 20 per cent of the tank diameter, the surface area of the drum ranging from 1 to 4 per cent of the tank area, although sometimes a drum with an area equal to 5 per cent of the tank area is used³⁵. The area of the drum is usually neglected when calculating the surface loading. The deflector drum should extend 0.15 m above water level and the depth below water level ranges with different types of scraper and different designs of tank from 40 to 95 per cent of the side water depth of the tank. Scum usually

collects within the drum and is difficult to remove unless there is an opening at the water level through which the scum can be swept into the body of the tank. Alternatively, the drum may be omitted and the diffuser extended to above water level so that the scum can pass through the slots or ports.

The inlets to the radial-flow primary tanks at Mogden works³³ were originally as shown in Fig. 16 (a), with a deflector drum surrounding the central inlet. They were then altered as shown in Fig. 16 (b) because it was found that deflection of the sewage downward tended to interfere with sludge deposited at floor level. The feed pipe now discharges just below the bottom of the deflector drum and the whole is surrounded by a diffuser to promote a pure radial flow.

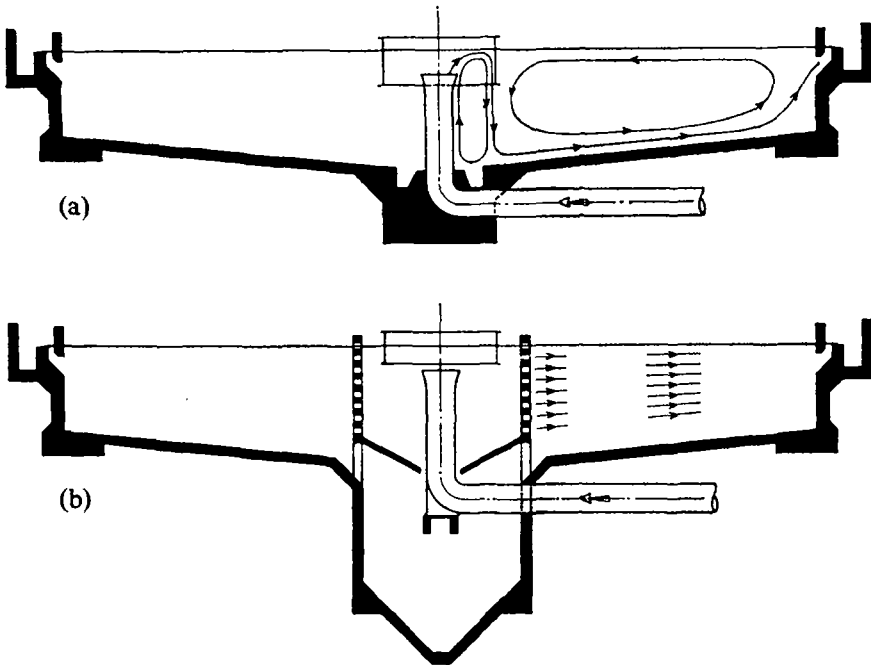


Fig. 16. Radial-flow primary tank at Mogden Works: (a) before modification, (b) after modification.

However, White and Allos²², experimenting with a full-scale radial-flow primary tank, found little difference in the results before and after removal of the vertical feed pipe and deflector drum and they considered that improvements in the design of inlets were unlikely to lead to a significant improvement in performance.

3.4.2 Outlet

The outlet is usually a peripheral weir, which is protected by a scum baffle and discharges into a channel. It is important that the weir shall be level throughout its length and if continuous it should preferably be fitted with adjustable metal weir plates so that these can be accurately levelled. To increase the overflow rate the weir may either be castellated or consist of a series of V-notches, which should be sufficient in number to limit the maximum discharge per notch to 30-40 m³/d, with the depth of flow being restricted to 35 mm. An advantage of the V-notch weir is that an accurate setting of the weir plate is less important. Castellations may reduce the effective length of the outlet weir by up to 60 per cent, depending on the number and length of the castellations.

3.4.3 Floor

The floors of radial-flow tanks slope from the periphery to a central sludge hopper and often have a concrete fillet between the vertical wall and the floor. When it is being laid the floor should be screeded as accurately as possible and consideration should be given to the position and finish of expansion joints.

The sludge hopper is usually conical and should be sufficiently deep to promote desirable consolidation of the sludge and to prevent overlying water from breaking through to the sludge outlet during withdrawal. The side should slope at least 60° to the horizontal and when the tank is to be desludged once a day the hopper should hold at least one day's production of sludge. With a production of 0.07 kg dry solids/hd d and sludge at 5 per cent solids, a capacity equivalent to 1.4 litres/hd d will be required. In addition, capacity will be needed for storing solids in secondary sludge and works liquors returned to the primary sedimentation tanks. The feed pipe usually enters the tank in the sludge hopper and the supporting beams may interfere with access to the sludge outlet if the hopper is of limited diameter.

3.4.4 Collection of sludge

Scrapers suitable for radial-flow primary tanks are of two types, i.e.:

- (a) fixed-bridge scrapers, and
- (b) rotating-bridge scrapers.

Ring scrapers were at one time employed but are not currently being installed because of their high cost. Suction-type scrapers are usually used in secondary settlement tanks and therefore, as with chain scrapers, are not dealt with in this manual.

Fixed-bridge scrapers. With this type of scraper (Fig. 17) the bridge spans the tank and supports a walkway with handrailing providing access to the drive unit. The drive unit is mounted at the centre of the tank and consists of

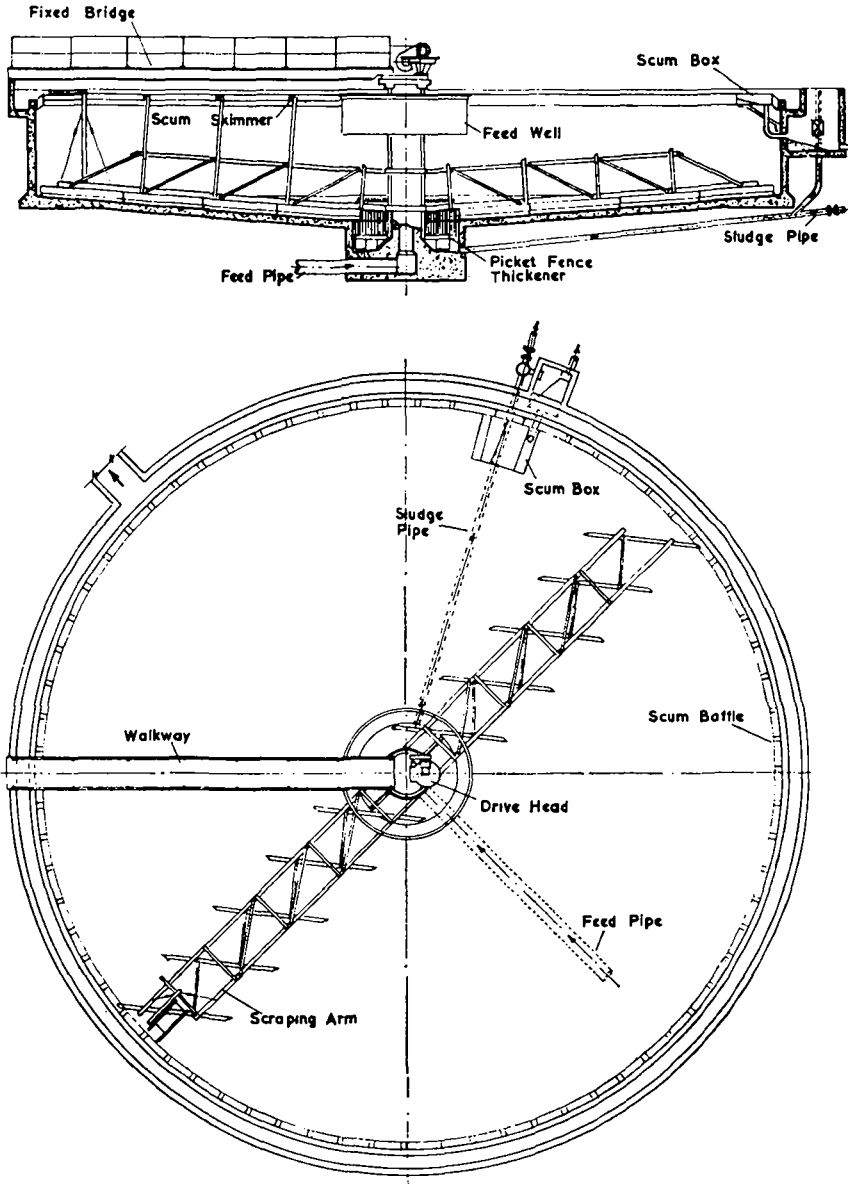


Fig. 17. Radial-flow tank with fixed-bridge scraper.

an electric motor driving a vertical shaft through reduction gearing. The shaft supports the two scraper arms and has a special watertight bearing at floor level.

The feed pipe is usually laid beneath the floor to the centre of the tank and then turns upward to discharge into a deflector drum. In one design the feed pipe discharges into a vertical rotating pipe terminating below the water surface in a diffuser which is surrounded by a rotating deflector drum. If entering the tank from the side, the pipe can be supported by and under the bridge but in this case difficulty is experienced in operating a scum skimming blade without the supporting members fouling the feed pipe. In one design, however, this difficulty has been overcome by supporting the skimming blade from a rotating deflector drum so that the scraper arms rotate beneath the pipe and the scum skimming blade above it.

The electric supply cable for the motor is carried along the bridge and this arrangement is much simpler than the power supply to a rotating-bridge scraper.

With tanks up to 15 m diameter the bridge structure is usually fabricated from channels or joists suitably braced, whilst a lattice design is used for tanks of a larger diameter.

Rotating-bridge scrapers. There are two types of rotating-bridge scraper, viz. full bridge and half bridge, extending over the diameter and radius respectively of the tank. A full-bridge scraper (Plates 6 and 7) is usually centrally supported and one end of the bridge carries the drive motor, the other end being supported on an idler wheel. A half-bridge scraper is pivoted at the centre and is supported on a "spider" or cage attached to the feed pipe, on a concrete platform supported by a steel tripod, or on legs (usually of reinforced concrete) rising from the sludge hopper.

The bridge, which carries the scraper blades, is driven by a motorized gear-box and depends on a traction grip on a rail or tank coping, the wheels having polyurethane tyres. Most designs incorporate a scraper blade to prevent the accumulation of snow or ice on the track.

The electric supply system is more complicated than with a fixed-bridge scraper, the cable having to be laid in a duct in or under the tank floor and carried up the side of the feed pipe or in the central column. However, with tanks up to 18 m diameter, the cable may be carried overhead, being supported by a catenary wire. When laid in a duct, modern methods of sealing have reduced the earlier hazards. In either case there is a slip-ring assembly at the tank centre, with a cable to the drive motor.

A push-button control unit with an isolator is installed on the bridge adjacent to the motor, or if located near the tank it is much more accessible in case of emergency or during desludging. Further, a land-based control can be placed in a weatherproof housing, which facilitates maintenance, and if desired, automation can be more readily applied. From the point of view of safety, all machines must comply with the ESB regulations and the Factory Acts.

Scraper blades. In the earlier design of scraper a continuous helical blade was used but this was unable automatically to adjust itself to the profile of the floor if the screed finish was inaccurate.

Blade arrangements now normally used in primary sedimentation tanks are either:

- (a) a series of blades arranged in echelon (Plate 8) at an angle of about 45° to a rotating radial arm (Fig. 17), the number depending on the diameter of the tank, or
- (b) a series of straight-blade sections arranged to form a continuous volute (Plate 7 and Fig. 18).

With blades arranged in echelon the sweeping process is more gradual since, unless the blades overlap, the unit must make as many revolutions as there are blades to convey an annulus of sludge from the periphery of the tank to the central hopper, although less load is imposed on the scraper mechanism.

Scraper blades are often attached to hinged arms and are trailing, relying on their weight or on a spring-loaded action to prevent their being lifted from the floor by an accumulation of sludge. With one design the angle of contact with the floor produces an undershot effect and it is claimed that in this case an accumulation of sludge tends to promote contact. When on a hinged arm the blade automatically adjusts itself to the profile of the tank floor.

Blades are edged with renewable rubber or rubber substitute wearing strips or have a metallic edge. However, the weight of the trailing portion should not be such as to produce undue wear, and with some of the larger scrapers buoyancy devices are attached to the blades to reduce this.

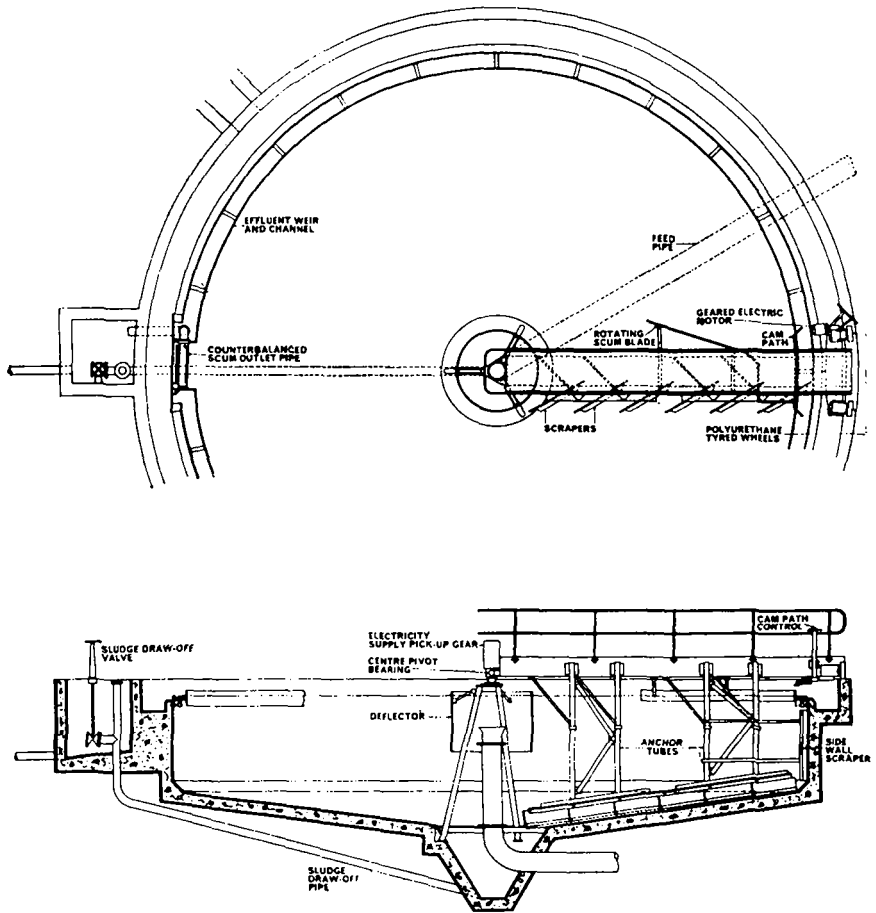


Fig. 18. Radial-flow tank with rotating half-bridge scraper.

Scraper blades are supported from a framework carried from the bridge and if freely attached to the bridge structure they can be lifted for examination without having to empty the tank.

Speed of scrapers. With primary sedimentation tanks the peripheral speed of the scraper may be within the range of 1.8 to 2.5 m/min. The Working Party on Sludge Disposal³⁶ recommended that the speed should not exceed 1.5 m/min, but especially with large tanks, if it is too low scum will rotate with the skimmer blade and not be swept to the periphery.

Wall scrapers. An additional scraper is sometimes attached to the rotating framework carried by the bridge to maintain the cleanliness of the vertical side wall of the tank (Plate 9).

3.4.5 Sludge withdrawal

Sludge is withdrawn from the central hopper through a pipe running under the floor of the tank to an external inspection chamber where the rate of withdrawal can be controlled by a telescopic screw-down bellmouth weir or an adjustable straight weir. The valve may be hand or power actuated, control being by push-button, or the sequence of operation may be partially or fully automatic using one of the methods described in 5.2.5.

A recent device³⁷ uses compressed air to assist withdrawal of sludge. Air is introduced into a vertical sludge pipe, about 2 m below the water surface, and accumulates until there is sufficient to form a piston which then rises and in doing so lifts a column of sludge so that it discharges into the inspection chamber. The air supply, which is controlled by a solenoid-operated valve with timer, is then cut off. Before air is again admitted, the void which has been created fills with sludge as a result of pressure due to the differential head. Since the air acts as a pump rather than an air lift, the sludge does not become impregnated with air. Also, with the outlet being about 0.075 m above tank water level, there is no loss of head as with normal discharge through a telescopic valve and the discharge ceases automatically if there is an electrical or mechanical failure.

A low-level outlet to the sludge inspection chamber is often provided. This enables a greater hydraulic head to be applied when removing a thick sludge.

3.4.6 Scum collection and withdrawal

Scrapers for primary sedimentation tanks carry a special scum skimming blade (Plate 10) so that as the scraper rotates the scum is swept towards a baffle supported from the peripheral wall and is withdrawn each time the scraper makes either a half or one revolution, according to the number of arms. Withdrawal may take place manually by sweeping the scum over a weir penstock, or automatically by the scum being swept up a ramp (Fig. 19) or tilting tray (Fig. 20) by a hinged blade so that it falls into a trough or hopper, from which it may be flushed by opening a valve. In some designs the outer end of the skimming blade is set back to form a retaining pocket (Plate 10), the scum being automatically withdrawn. Another form of outlet is a slotted pipe fixed in a recess in the tank weir wall (Plate 9); the pipe is pivotally

mounted and counterbalanced so that it can be operated by a cam mounted on the bridge. Flushing of scum from the hopper or trough may be accomplished by the automatic depression of a hinged flap immediately after the scum has been withdrawn, permitting water from the tank to flow into the hopper.

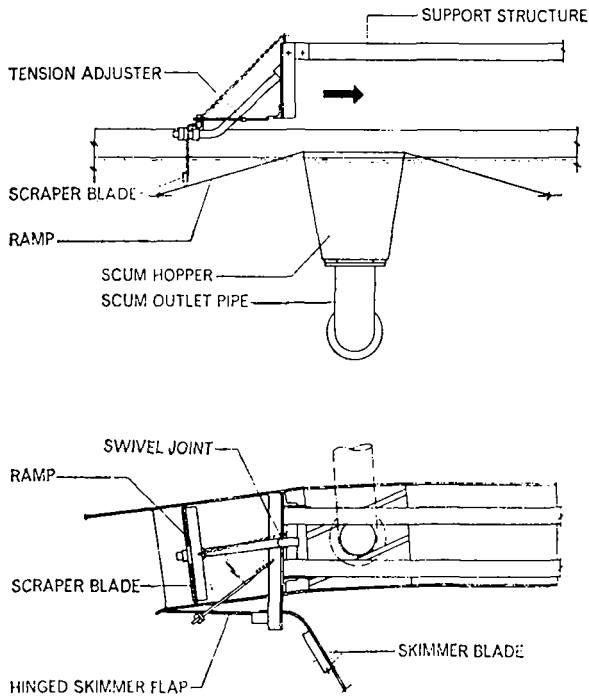


Fig. 19. Scum removal equipment using a ramp with a hinged scraper blade.

3.5 Performance

The Water Pollution Research Laboratory⁵ investigated the performance of two radial-flow primary tanks, each equipped with a central flocculator chamber, when treating sewage which had been macerated and screened. The two tanks operated at slightly different rates of flow and the tests were conducted over a period of two days. Each tank had a capacity of 1086 m³. One had a mean retention period of 8.2 h and the surface loading ranged from 2.8 to 19.4 m³/m² d, with an average of 12.2 m³/m² d. During passage through this tank the SS content of the sewage was reduced from 370 to 110 mg/l, i.e. a reduction of 70 per cent.

With the other tank the retention period averaged 5.2 h and the surface loading ranged from 12.2 to 26.0 m³/m² d, with an average of 19.0 m³/m² d. The SS content of the sewage was reduced from 359 to 117 mg/l, i.e. a reduction of 67 per cent.

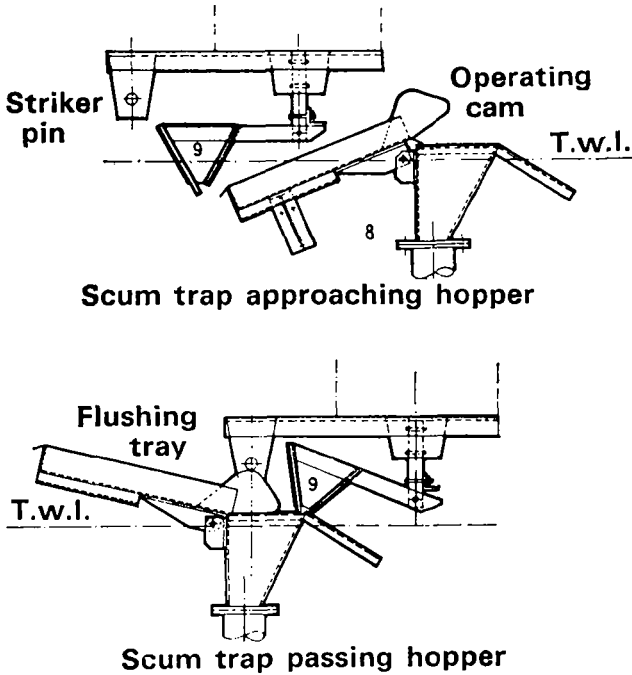


Fig. 20. Scum removal equipment using a tilting tray.

Table 5 gives information on radial-flow primary tanks at a number of sewage works and shows their performance. In most cases the SS content of the crude sewage was lower and that of the effluent higher, the percentage removal of solids being less, than with the tanks investigated by the Water Pollution Research Laboratory. It appears that with radial-flow tanks the SS content of the effluent usually exceeds 100 mg/l and that SS removals range from 50 to 75 per cent.

The dry solids content of the sludge produced depends on many factors, including its inorganic content, whether it includes secondary sludge or works liquors, and the skill of the operator, but it is usually within the range of 3.0-6.5 per cent.

TABLE 5. PERFORMANCE OF RADIAL-FLOW PRIMARY SEDIMENTATION TANKS

| Sewage-treatment works | Average daily flow (tcm) | Primary tanks | | | | | | | Suspended solids | | | BOD | | | Sludge production | | Sludge dry solids | | Ref. No. |
|--|--------------------------|---------------|--------------|---------------------|------------------------------------|---|---|-----------------------|---------------------|-----------------------|-------------|---------------------|-----------------------|-------------|-----------------------------|-------------|-------------------|--------------------|----------|
| | | Number | Diameter (m) | Side wall depth (m) | Ratio of radius to side wall depth | Weir overflow rate* (m ³ /m d) | Surface loading* (m ³ /m ² d) | Retention period* (h) | Crude sewage (mg/l) | Settled sewage (mg/l) | Removal (%) | Crude sewage (mg/l) | Settled sewage (mg/l) | Removal (%) | Average (m ³ /d) | Litres/hd d | Per cent | Volatile content % | |
| Barnsley Lundwood | 15.6 | 6 | 16.7 | 3.0 | 2.4 | 52 | 11.8 | 7.0 | 370 | 150 | 60 | 400 | 250 | 38 | 114 (BL) | 1.5 | 4.6 | 78 | 38 |
| Bournemouth (Holdenhurst) (Kinson) | 8.6 8.9 | 2 2 | 24.4 18.3 | 2.7 2.1 | 4.5 4.4 | 56 77 | 9.2 16.9 | 7.9 3.5 | 420 275 | 125 135 | 71 51 | 305 265 | 150 155 | 50 41 | 59 (AL) 45 (AL) | 1.3 1.1 | 4.1 5.5 | 78 78 | 39 39 |
| Darlington | 14.3 | 2 | 27.5 | 2.1 | 6.6 | 83 | 12.0 | 6.0 | 295 | 140 | 53 | 280 | 180 | 36 | 137†(B) | 1.5 | 5.9 | 64 | 25 |
| Hogsmill Valley | 9.8 | 4 | 30.5 | 3.2 | 4.8 | 108 | 15.0 | 6.7 | 305 | 100 | 67 | 275 | 150 | 45 | 327 (AL) | 1.75 | 4.4 | 75 | 10 |
| Malling | 4.5 | 2 | 19.8 | 2.4 | 4.1 | 38 | 7.3 | 9.7 | 490 | 135 | 72 | 405 | 170 | 58 | 46 | 1.5 | 5.6 | 75 | 40 |
| Oldham | 17.0 | 1 | 33.5 | 3.3 | 5.1 | 161 | 19.4 | 5.2 | 165 | 95 | 43 | 195 | 115 | 41 | 110 (ABL) | 0.7 | 6.9 | 63 | 29 |
| Oxford | 23.2 | 8 | 19.5 | 4.2 | 2.3 | 47 | 9.7 | 7.8 | 405 | 100 | 75 | 370 | 175 | 53 | 86 | 1.0 | 5.3 | 73† | 30 |

* Based on average daily flow

† Sludge from radial-flow tanks and horizontal-flow tanks is combined

A Includes surplus activated sludge

B Includes sludge from biological filters

L Includes works' liquors

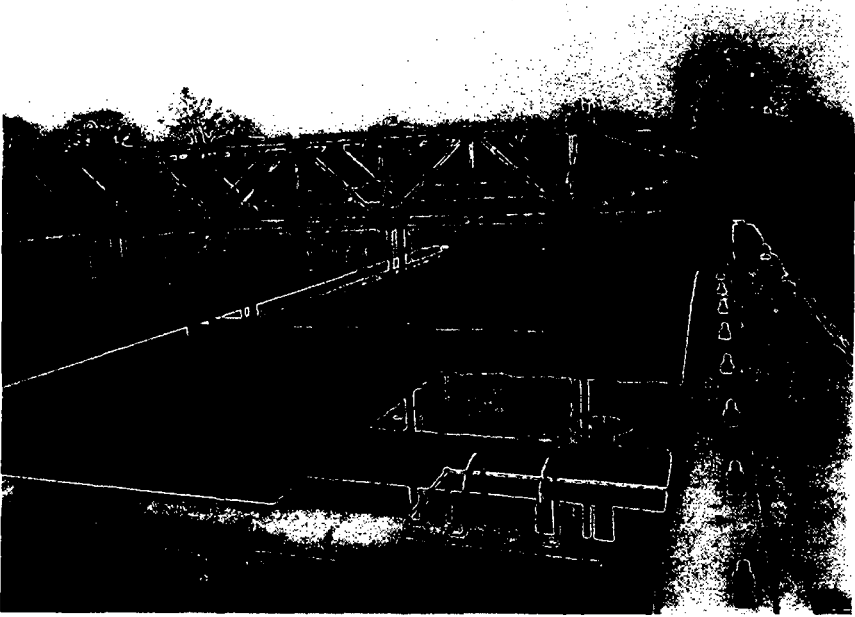


Plate 1. Travelling-bridge scraper with vertical blade.

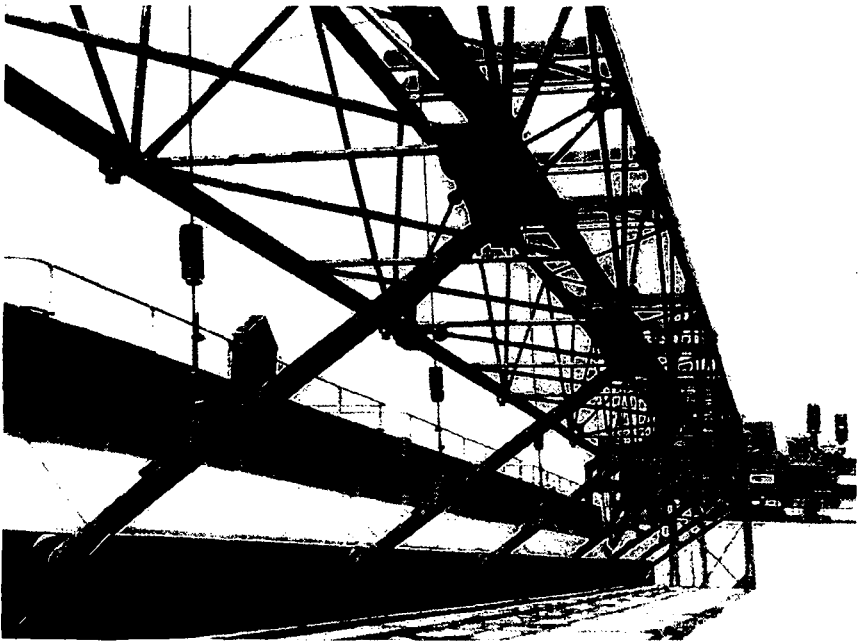


Plate 2. Travelling-bridge scraper with trailing blade.

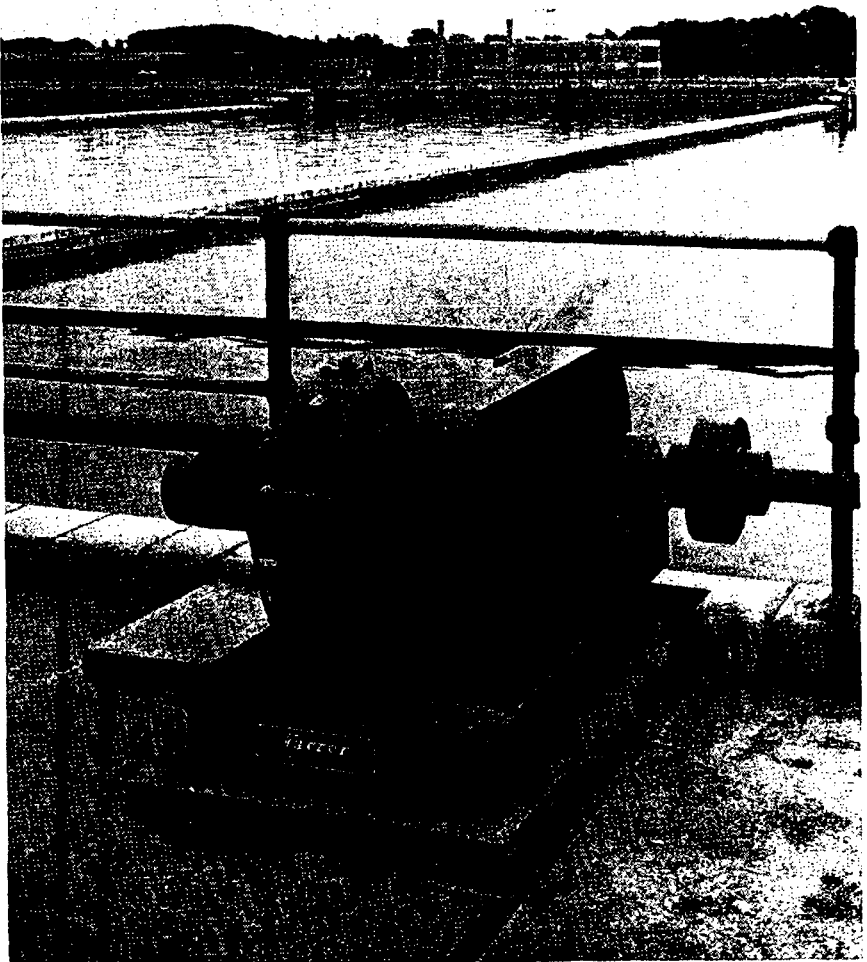


Plate 3. Horizontal-flow tanks equipped with flight scrapers.



Plate 4. Inlet end of horizontal-flow tank equipped with buoyant flight scraper.

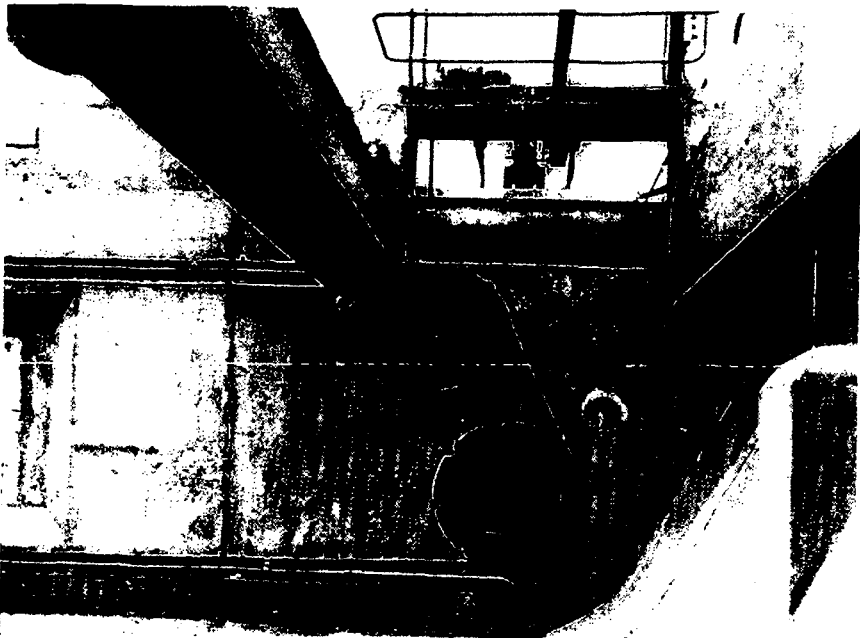


Plate 5. Outlet end of horizontal-flow tank equipped with flight scraper, showing tubular boom at end of travel and scum outlet.

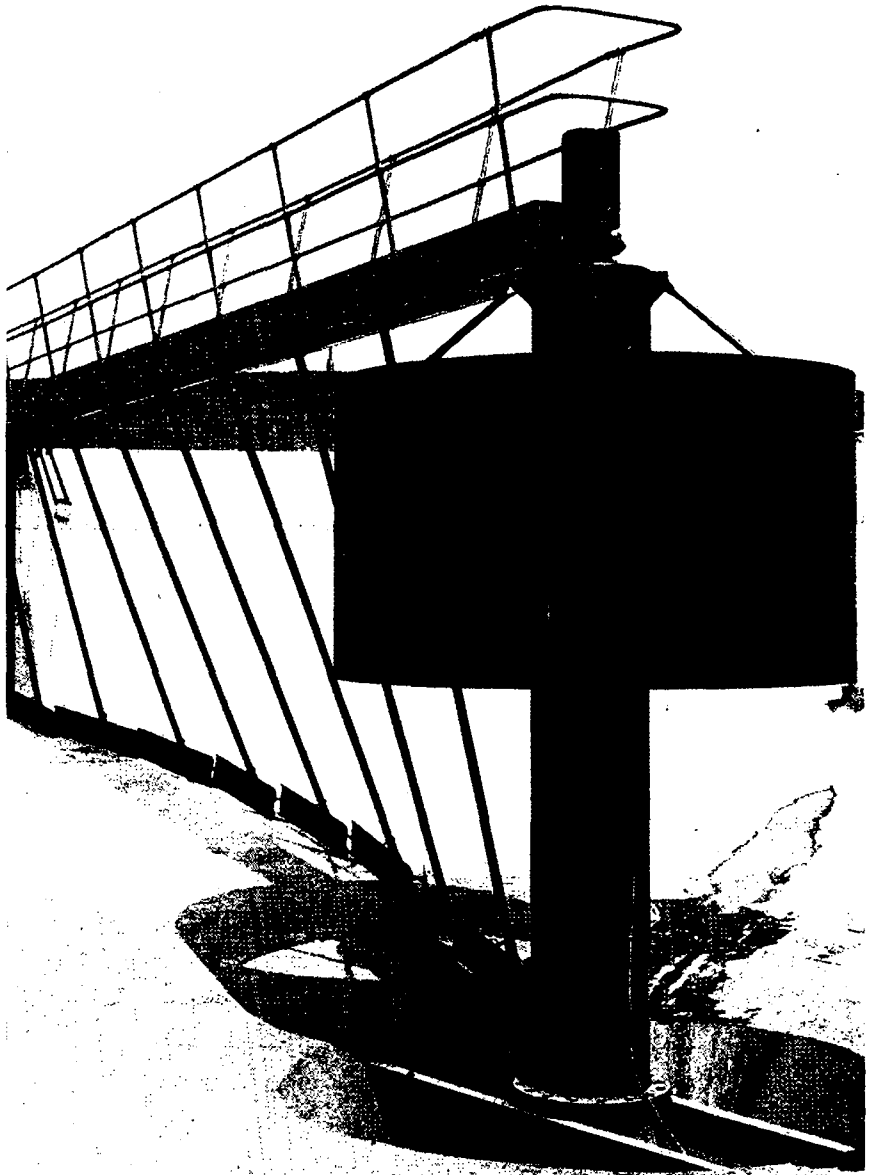


Plate 6. Rotating half-bridge scraper with blades arranged in echelon.

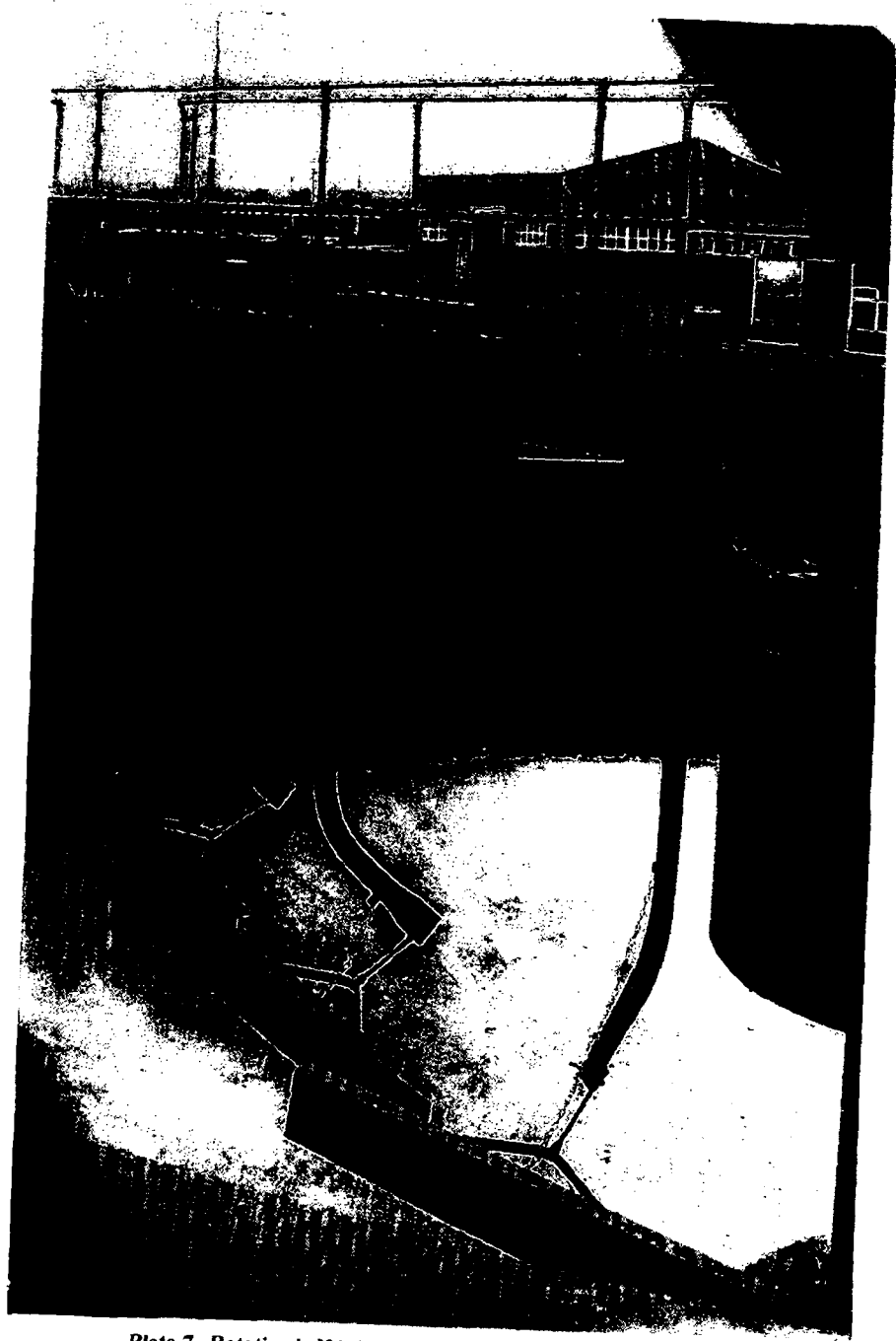


Plate 7. Rotating half-bridge scraper with straight-blade sections.

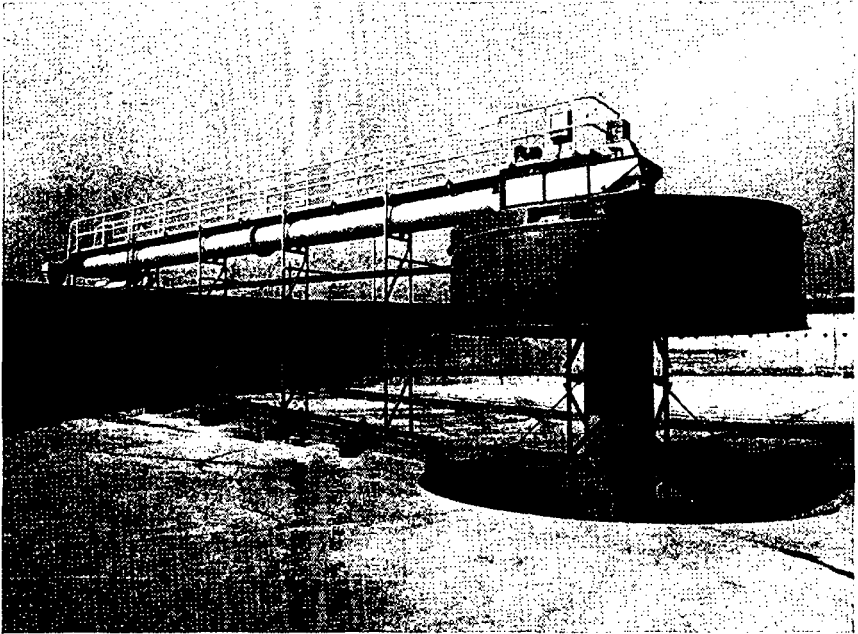


Plate 8. Rotating half-bridge scraper with blades arranged in echelon.

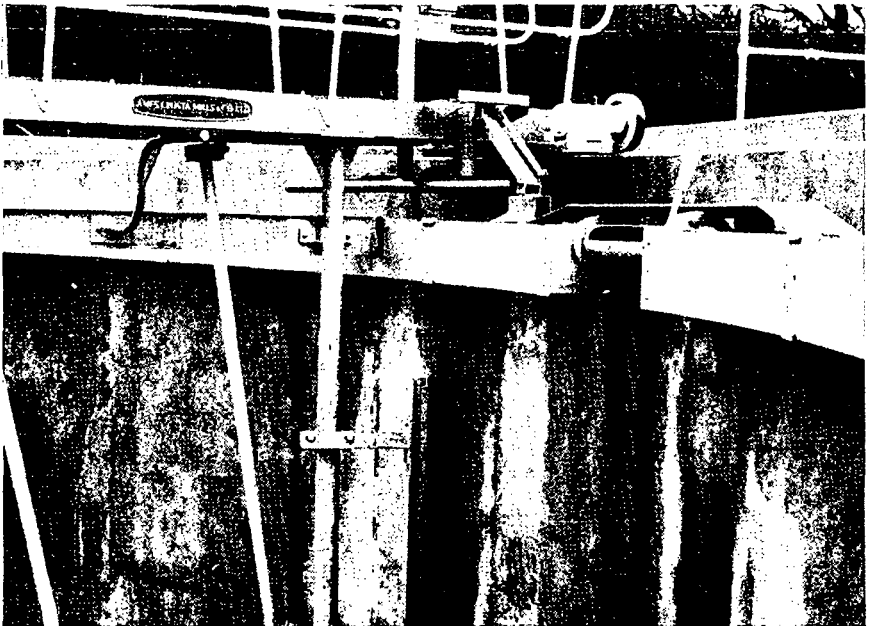


Plate 9. Radial-flow tank, showing slotted scum outlet and scraper for vertical wall.

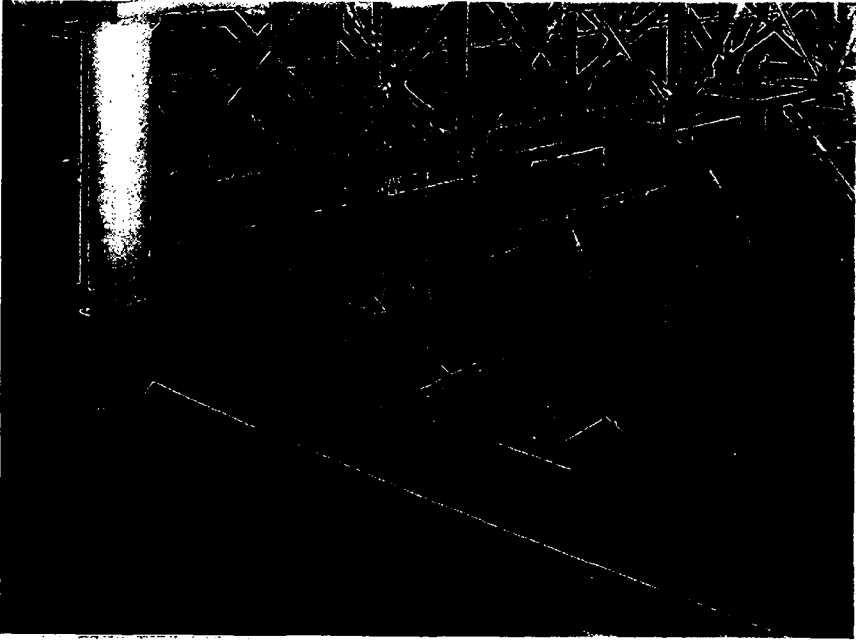


Plate 10. Rotating half-bridge scraper, showing scum skimming blade with retaining pocket, hinged blade, ramp and scum trough.

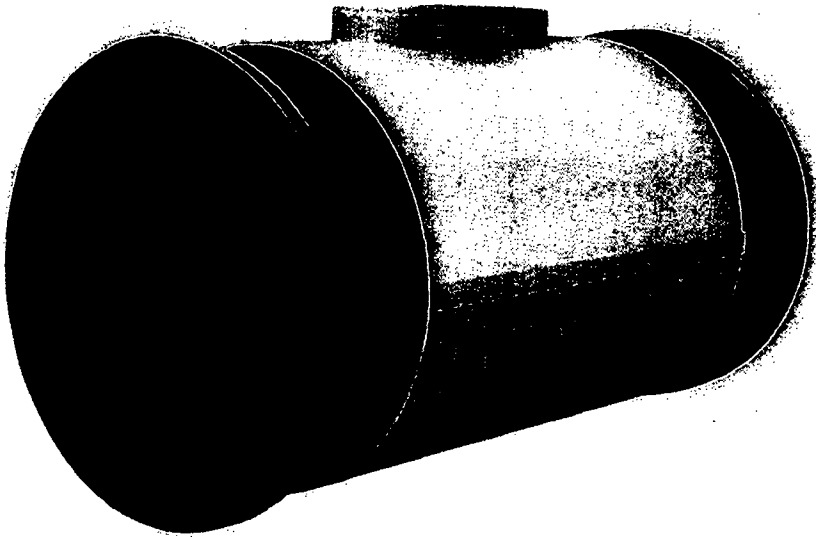


Plate 11. Detector head of magnetic flow meter.



Plate 12. Example of an optical sludge level detector.

4. Upward-Flow Tanks

4.1 Arrangement

Figure 21 shows diagrammatically the main features of an upward-flow tank.

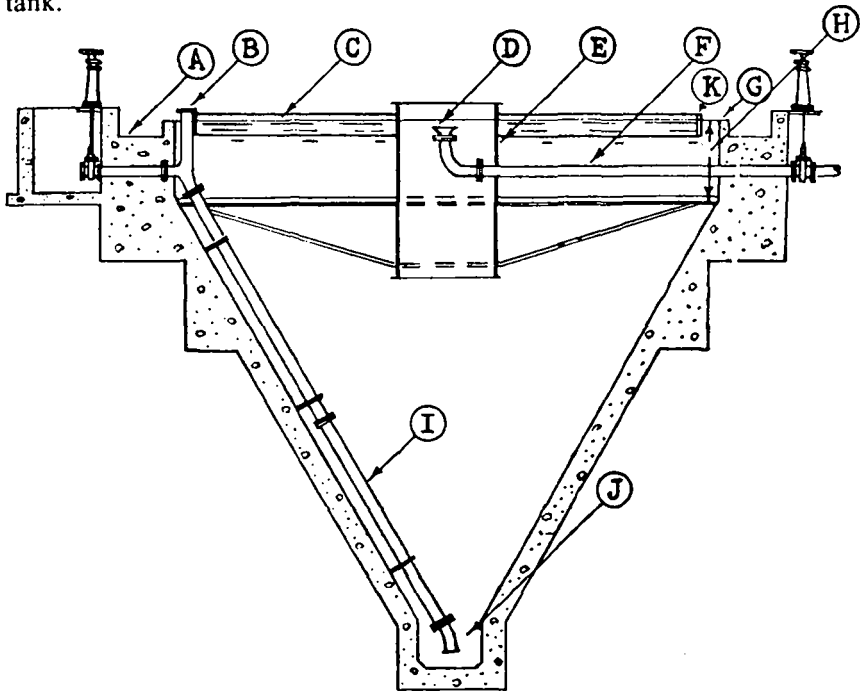


Fig. 21. Main features of an upward-flow primary sedimentation tank.

A, Effluent channel; B, rodding eye; C, top water level; D, bellmouth inlet; E, stilling box; F, feed pipe; G, peripheral weir; H, side water depth; I, sludge pipe; J, sludge sump; K, scum baffle.

4.2 Application

At one time upward-flow tanks were often used on small and medium-sized works for primary sedimentation, but with the introduction and increasing popularity of the mechanically-desludged radial-flow tank, upward-flow tanks are now less frequently installed except for small works.

Upward-flow tanks cost more to construct than horizontal-flow or radial-flow tanks, except when serving a population of less than 8000¹⁶. Also they are difficult to construct in bad or waterlogged ground because of their great depth, although in such cases tanks have been constructed with four hoppers to reduce the depth. When the only alternative was manually desludged horizontal-flow tanks, upward-flow tanks had the great advantage that the sludge could be withdrawn without emptying the tank and with a minimum of inconvenience. However, sludge was apt to lodge on the sloping sides, particularly in the corners if pyramidal where the slope was at a minimum, and turn septic, causing sludge to rise to the surface, where removal was difficult. If the sludge outlet became blocked difficulty was experienced in clearing the blockage and it might even have been necessary to empty the tank, involving the use of a portable pumping set. With desludging taking place through a pressure differential, inefficient operation could easily result in the withdrawal of sludge with a low solids content. However, if properly operated, upward-flow tanks are highly efficient and produce a good effluent.

4.3 Design Criteria

4.3.1 Upward velocity

This should not exceed 1.8 m/h and is often about 1.2 m/h at maximum flow.

4.3.2 Surface loading

With an upward velocity at the tank surface of 1.2 m/h at maximum flow, the surface loading will be 28.8 m³/m² d.

4.3.3 Retention period

The nominal retention period is usually 2 to 3 h, depending on the design frequency of desludging.

4.3.4 Dimensions

Lower portion. If pyramidal, the sides should slope at an angle of not less than 60° to the horizontal, with the corners having a slope of about 50°. With a circular tank the slope may be 45° to the horizontal.

Upper portion. Tanks range from 5 m to 9 m square; if less than this the depth of water over the weir at minimum flow will be less than 2.5 mm and the flow will be affected by surface tension, and if greater, with the pyramidal portion having a 60° slope, the depth and consequently the cost of construction

will be excessive. A tank with sides 7.5 m square, the surface loading being $28.8 \text{ m}^3/\text{m}^2 \text{ d}$, will treat $1620 \text{ m}^3/\text{d}$ at maximum flow. From the length of the sides and the retention period, the total volume of the tank can be calculated. The volume of the upper portion is obtained by deducting the volume of the pyramidal portion, and knowing the surface area, the depth of the vertical sides may be calculated.

4.3.5 Weir overflow rate

With a tank 7.5 m square and treating $1620 \text{ m}^3/\text{d}$ at maximum flow, the maximum overflow rate will be $54 \text{ m}^3/\text{m d}$, which will mean that at minimum flow the velocity will be much too low to be self-cleansing, so V-notch weirs or castellated weirs will need to be used because of this.

4.4 Design

4.4.1 Inlet

The feed pipe enters the side of the tank, turns through 90° when it reaches the centre, terminates in a bellmouth and discharges in a vertical direction a short distance below water level. It should be of such a size that the velocity does not fall below 0.3 m/s at minimum flow. Surrounding the feed pipe is a deflector or stilling box, from 1.0 to 1.22 m square, with the upper end 0.15 m above water level and extending to a little below the bottom of the vertical walls. The deflector box may be of asbestos cement, steel, aluminium alloy, fibreglass or plastics and, together with the feed pipe, is supported by beams spanning the tank; these also support a chequer-plate or open-mesh walkway with handrailing to provide access to the central feed.

4.4.2 Outlet

The outlet is usually a peripheral weir protected by a scum baffle. The weir should preferably be fitted with adjustable metal plates or it may be castellated or consist of a series of V-notches. Alternatively, double-edged troughs may span the tank a short distance from two of the sides.

4.4.3 Lower portion of tank

The steeply sloping sides are necessary to ensure that sludge slides down them without sticking; since the weight of the sludge causing motion is less when it is submerged, a steeper slope is necessary than when the sludge is exposed. At the bottom there may be a small sump into which the sludge pipe dips. Garner⁴¹ considered this to be important as it helps to direct the sludge to the point of maximum pressure at the outlet and so reduces the possibility of water breaking through when desludging the tank. However, such a sump is expensive to construct and it is now usual for the bottom to be a square with 0.75 to 1.0 m sides.

4.4.4 Sludge withdrawal

Sludge is withdrawn from the bottom through a pipe located inside the tank and terminating a short distance above water level. At least 1.2 m, and preferably 1.5 m, below water level the pipe has a horizontal branch which discharges into an inspection chamber at the side of the tank. Sludge is withdrawn through this branch, whilst the vertical extension is used as a rodding "eye". Sludge is withdrawn under pressure due to a differential head and discharges over a telescopic screw-down bellmouth weir or a swinging arm. The mouth of the sludge pipe should be $1\frac{1}{2}$ pipe diameters above the bottom of the tank to prevent blockage at this point, and if it is chamfered so that it is in a vertical plane this will facilitate both withdrawal of sludge and rodding, if this becomes necessary. The pipe should be at least 150 mm diameter.

4.4.5 Scum collection and withdrawal

Scum is retained by a baffle which should be at least 0.3 m from the peripheral wall and supported by it. At intervals a light squeegee is used for sweeping the scum to an adjustable weir at the side of the tank. Scum will also collect within the deflector box and this should be removed at intervals.

4.4.6 Washout

A valve-controlled washout discharging into the inspection chamber at floor level provides water for flushing the sludge main and enables a portion of the tank contents to be drained by gravity when it is necessary to empty the tank.

4.5 Performance

The Water Pollution Research Laboratory⁵ investigated the performance over a period of four days of a circular upward-flow primary sedimentation tank at a works when treating sewage which had passed through comminutors and screens, with sludge from biological filters being added every morning. The tank had a capacity of 273 m³ and the surface loading ranged from 1.4 to 25.5 m³/m² d, with an average of 10.8 m³/m² d. The SS content of the sewage was reduced from 477 to 164 mg/l, a reduction of 65 per cent. This reduction is similar to that reported for upward-flow tanks at other sewage works, although the data available are very limited.

The dry solids content of the sludge withdrawn from upward-flow tanks varies widely, depending on the frequency of withdrawal and the skill of the operator, but averages 3 to 4 per cent.

5. Operation and Maintenance of Primary Sedimentation Tanks

5.1 Sludge Level Detection

Instruments which are currently manufactured for detecting sludge levels have either optical or ultrasonic sensing heads.

The optical sensors, of which an example is shown in Plate 12, are of the "extinction" type similar to that described by Briggs and Knowles⁴² (Fig. 22). The output is arranged to give either an increase in reading to a present maximum value, or a fall to zero. In practice in either case, there is usually a slight change in reading as the probe is lowered through the supernatant

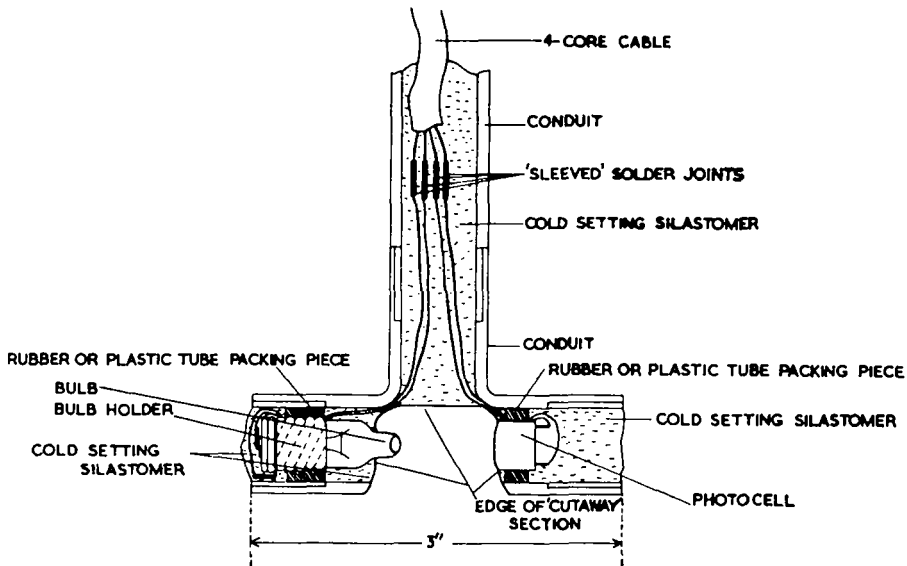


Fig. 22. Diagram of optical assembly of photoelectric sludge-level detector.

liquor, followed by erratic changes in the transitional region just above the sludge, over depths varying between a few centimetres and 1 m, depending upon the sludge properties and the size and design of the tank. The sludge level is taken as the mean depth indicated by a high (or in some instruments, a

zero) reading, obtained as the probe is passed through the interface alternately from above and below.

Ultrasonic instruments can detect the level of an interface from the "time of flight" of a reflected signal or the attenuated value of pulsed high frequency sound. Reflection types work best where there is a sharply-defined boundary between air and a liquid or solid. Probes measuring the attenuation of sound intensity make a direct measurement through a known sludge path length and are less likely to suffer from extraneous reflected signals. This type has been shown to be able to detect sludge levels, and also to be able to measure the concentration of sludge.

Both optical and ultrasonic attenuation types have been designed to follow the rise and fall of the sludge/water interface. The optical instrument can also be calibrated to give an approximate value of the concentration of SS in the supernatant liquor, while the ultrasonic instrument can be calibrated similarly in terms of sludge density. Both types have an electrical output suitable for control purposes.

5.2 Withdrawal of Sludge

The frequency with which tanks are desludged will be controlled by such factors as:

- (a) the type of tank and the type of scraper,
- (b) the requirements of other sections of the treatment plant, i.e. subsequent dewatering and other processes (with some dewatering processes the sludge is dealt with in batches, whilst for digestion units it is better to add the sludge a little at a time and often),
- (c) the need to prevent the sludge from turning septic whilst in the tank, with resulting rising sludge and scum formation,
- (d) local conditions.

The water content of the sludge as withdrawn should be such that it can be pumped without difficulty but when the sludge is to be digested the solids content should be as high as practicable to avoid wasting heat, reducing the retention period in the digestion tanks and producing an excessive amount of liquor.

Local conditions to be taken into consideration include:

- (a) the industrial waste content of the sewage,
- (b) any tendency for the sewage to turn septic,

- (c) the air and sewage temperatures, and
- (d) whether secondary sludge or works liquors are being returned to the primary sedimentation tanks.

The solids content of the sludge will depend to a large extent on the efficiency of the operator if withdrawal is controlled manually. Fig 23 shows the effect on the volume, when a denser sludge is withdrawn, of the dry solids content of the sludge.

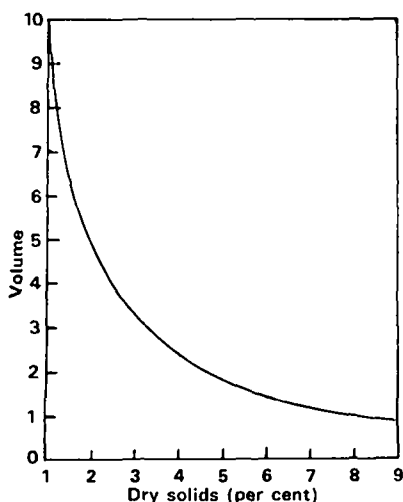


Fig. 23. Relation between dry solids content and volume of sludge.

However, the *rate* at which sludge is withdrawn is important. This must not be so great that there is a possibility of over-lying water breaking through to the sludge outlet, or so low that there is a possibility of solids settling in the sludge pipe and causing blockages.

If the needs of other sections of the treatment plant require that the sludge shall be stored before treatment, a separate tank should be provided rather than relying on storage in the primary tanks.

5.2.1 Manually-desludged horizontal-flow tanks

A manually-desludged tank should be emptied in dry weather when the sewage flow is relatively low. The tank is usually taken out of service the evening before, or at least an hour in advance, to allow the sludge to settle. Supernatant water is then withdrawn through a floating-arm draw-off or a telescopic valve until only sludge is left in the tank. When approaching the sludge level, the rate of withdrawal is slowed down to enable as much water as possible to be withdrawn without disturbing the sludge. The sludge is then

pushed to the outlet by workmen using squeegees. Finally the floor is hosed down with supernatant water or final effluent. Valves, penstocks and supernatant water draw-offs are cleared of rags or solid matter and the sludge pipe is flushed with sewage before the tank is refilled. Since the work is dirty, arduous and time-consuming, manually-desludged tanks are used only on small works, and even then they are now usually emptied by a tank-emptying vehicle.

The Royal Commission on Sewage Disposal⁴³ recommended that manually-desludged primary sedimentation tanks should be emptied at least once a week, but wherever possible such tanks should be modified to take a suitable mechanical desludging device.

5.2.2 Mechanically-desludged horizontal-flow tanks

In practice, the frequency of desludging varies at different works from once a shift to once a day, and with small works once every two days. The time taken to withdraw sludge will depend on the frequency of desludging, the length of the tank, the speed of the machine and, with a machine that is transferred from one tank to another, the time taken to make the transfer. When desludged once a day the time may vary from 0.75 h to 1.5 h per tank.

5.2.3 Radial-flow tanks

With this type of tank it is usual to start the scraper from 15 min to 1 h before starting withdrawal in order to concentrate the sludge in the central hopper. On some works, however, the scrapers are operated on a time basis or continuously. Intermittent use of scrapers reduces wear of scraper blades and wheel tyres.

Attempts have sometimes been made to withdraw sludge continuously throughout the 24 h to provide a constant feed to digestion tanks but the rate of withdrawal is then so slow that the telescopic draw-off valve on the sludge pipe may become blocked. In practice, the maximum frequency is once every 8 h. At many works the operator draws sludge from each of a series of tanks in turn and this sequence is repeated until desludging has been completed.

5.2.4 Upward-flow tanks

The frequency with which sludge should be withdrawn from upward-flow tanks will be determined by experience but will be at least twice a week. When starting to desludge a tank the valve on the sludge pipe should be opened slowly since any sudden change in the rate of discharge may cause

overlying water to break through to the outlet. The valve may then be partially closed to control the rate of withdrawal. When the density of the sludge is seen to fall the valve is closed and it is left for about 10 min whilst further sludge slides down the slopes to the outlet. The valve is then opened again and further sludge withdrawn, the cycle being repeated until all the sludge has been removed.

When the lower portion of the tank is conical a weighted drag chain may be used for dislodging sludge from the sides.

If the sludge pipe becomes blocked the blockage may be removed by ramming a plunger down the pipe from the rodding "eye", or if this is not successful a jet of water or compressed air issuing from a tube thrust down the pipe may be used. If this fails to clear the blockage it will be necessary to empty the tank using a mobile pump after first running off supernatant water down to the level of the washout.

5.2.5 Automatic control of sludge withdrawal

Remote control by closed-circuit television. This method is used on a limited number of large works. The desludging sequence is started manually by push-button and a monitoring camera showing the sludge being withdrawn over an adjustable bellmouth is switched on. A view of the sludge is transmitted over closed-circuit television to a central control building where its withdrawal is monitored. When the operator judges that withdrawal should cease the valve on the draw-off is closed by push-button.

Control by manual start and automatic stop. Richards and Kirk⁴⁴ found that there was a direct relationship between the dry solids content of sewage sludge and its specific gravity or density. A measure of the density of sludge may be gained by methods based on the differential air-reaction principle or on its viscosity. There is also a relation between the electrical conductivity of the sludge or its absorption of gamma rays, and the dry solids content of the sludge. It was therefore considered that measurement of one of these as the sludge flowed along a pipeline might be used as a means of monitoring the flow, with the valve in the pipeline being closed automatically when a pre-set and adjustable level had been reached. In 1962 the Water Pollution Research Laboratory⁴⁵ studied a number of methods of measurement and produced a viscometer which they used "for the rapid determination of the solids content of crude sludges from 5 different sewage works, using the appropriate calibration curve for each works". However, it was considered that "the use of ultrasonics might be more satisfactory in the long term, provided that portable and sufficiently inexpensive equipment can be developed".

Townend²³ installed a control system at Mogden Works based on the electrical conductivity of the sludge. However, it was found that the behaviour of the device was erratic and that the conductivity was affected by the age of the sludge and its inorganic content.

An electronic density detector is sometimes used in conjunction with Rotork-actuated telescopic valve (Fig. 24). A sensing probe is located near the centre of each tank and the tanks are scanned in turn for perhaps 20 min, the search being continuous. However, at the Southampton (Millbrook) works it was found that continuous supervision was still needed and wear was excessive so the use of the detector was discontinued⁴⁶.

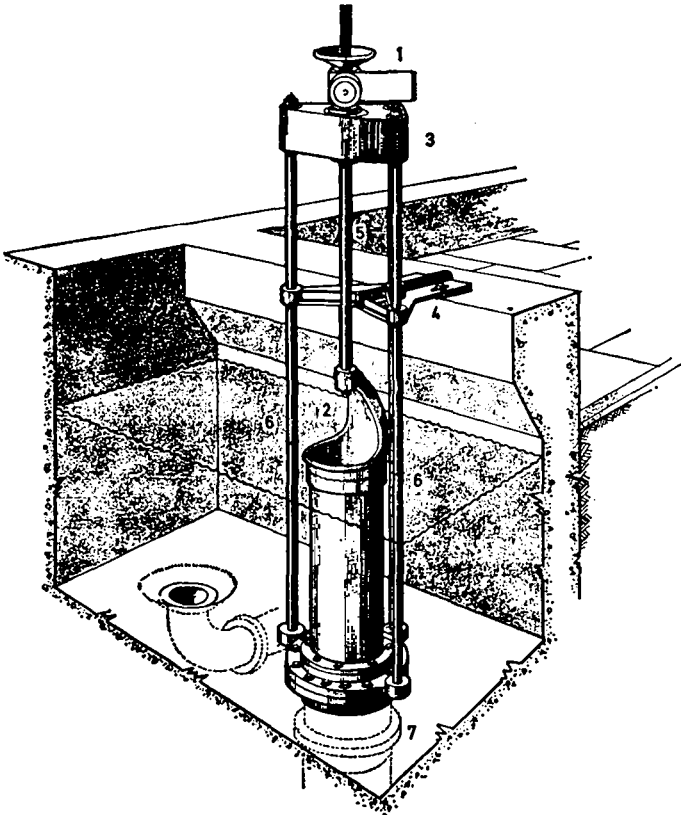


Fig. 24. Rotork-actuated telescopic valve.

- 1, Rotork actuator; 2, sliding tube assembly; 3, platform; 4, steady bracket; 5, operating spindle; 6, pillars; 7, puddle flange.

Richards and Kirk⁴⁴ experimented at Bristol with two makes of instrument based on the air-reaction principle but found that the results were “unreliable and erratic”. They therefore decided to use a magnetic flow meter (Plate 11) on each draw-off from the primary sedimentation tanks which, after being calibrated against a gamma-ray meter, would record the rate of flow through the pipe and therefore the viscosity (which is related to the solids content) of the sludge, they having calculated that the rate of flow in the pipe would vary from 26.5 l/s with sludge at 8 per cent dry solids to 38 l/s with sludge at 4 per cent dry solids. In 1969 Lewin⁴⁷ reported that magnetic flow meters at Oxford were “working to within acceptable limits”.

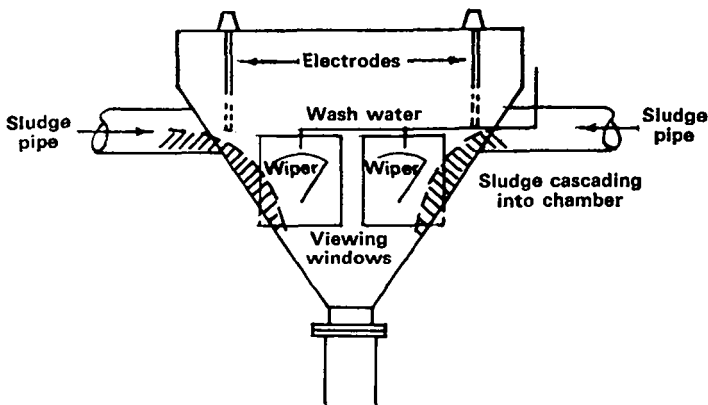


Fig. 25. Arrangement for automatically stopping withdrawal of sludge from a sedimentation tank.

An arrangement for automatically stopping withdrawal of sludge from tanks which is being used at several works is shown in Fig. 25. This depends for its operation on the arc described by the sludge as it cascades from a horizontal pipe into a conical chamber. When thick, the “throw” of the sludge is short but as the sludge becomes thinner the “throw” increases until it touches an electrode, which causes a pneumatically-operated valve to close and stop withdrawal. The position of the electrode is adjustable and it can be set, according to experience, so that withdrawal ceases when the dry solids content of the sludge has fallen to a pre-determined level. When starting withdrawal a delay mechanism allows for the initial discharge of a thin sludge from the pipeline.

An instrument has recently been placed on the market⁴⁸ which ultrasonically senses the density of the sludge. An electronic control unit generates

an electrical signal which is converted into an ultrasonic signal. This is directed across the pipe section through the sludge where it is received and re-converted into an electrical signal. This signal is amplified and used to actuate a relay which closes the valve on the draw-off when the density of the sludge has fallen to a certain level. Sonic equipment is to be used in connection with sensing density differences in sludge being withdrawn from primary sedimentation tanks at the Carbarns works⁴⁹.

Another new instrument⁵⁰ passes gamma rays through the sludge. The source head, which is supplied with a caesium-137 source, is clamped to the draw-off pipe. Gamma rays pass through the sludge and are absorbed in proportion to its density. The rays reaching the detector produce a current which is inversely related to the density. The detector chamber is heated and thermostatically controlled to eliminate temperature variation and moisture condensation. It is claimed that the device can measure dry solids concentrations ranging from 0.1 to 10 per cent.

Recently the Water Pollution Research Laboratory⁵¹ have reported that they are investigating a method of measuring sludge solids concentrations based "on measurement of the root mean square value of the noise component of a signal from a simple conductivity sensor and correcting the measurement (by means of an inverse multiplication technique) for variations in the mean conductivity of the sample", it being considered that this might form "the basis of design of a relatively cheap and robust instrument for continuous monitoring and control purposes".

Automatic control of desludging sequence. Timers may be used for initiating and controlling the desludging sequence at set intervals, operation of the valves on the sludge draw-offs being controlled by cams actuated by a geared motor, the cam settings determining the order in which the valves are operated. At the end of the sequence the timer stops the motor. This method is used at Sheffield (Blackburn Meadows) works¹¹ for controlling the withdrawal of sludge by electrically-driven centrifugal pumps.

Desludging using air-lift principle. Equipment which operates on the principle of an intermittent air lift has successfully been introduced on many works. Adjustable timers operate a solenoid valve fitted in the air discharge pipework, controlling the amount of air delivered and the period of time between each discharge of air. Each discharge of air lifts a quantity of sludge, with a "piston" effect from the sludge pipe⁵².

5.3 Operating Difficulties

Rising sludge. If the sludge rises to the surface in *all* the tanks due to gasification, evidenced by bubbles rising with the sludge, this may be due to one or more of the following causes:

- (a) the frequency of desludging is inadequate,
- (b) sludge is not being completely removed from the tanks when desludging,
- (c) the sewage is turning septic within the sewerage system,
- (d) the return of secondary sludge containing oxidized nitrogen to the tanks is resulting in denitrification (difficulties with denitrification have been experienced at several works, see 1.4.3),
- (e) the return of liquor containing partially digested sludge,
- (f) the return of digested sludge or liquor from digestion tanks, or
- (g) the presence in the tanks of zones in which sewage or sludge is stagnating and turning septic.

If rising sludge occurs in an individual tank this may be due to:

- (a) unequal distribution of the sewage flow or load,
- (b) a defect in the scraper, such as a blade having become detached,
- (c) sludge being deposited on the underwater steelwork of the scraper, turning septic and rising to the surface in large lumps, or
- (d) sludge clinging to the side of a hopper and not being withdrawn with the other sludge.

High concentration of suspended solids in settled sewage. If the high concentration of suspended solids is present in the effluent from *all* the tanks this may be due to:

- (a) overloading,
- (b) sludge accumulating in the tanks,
- (c) secondary or works liquors being returned at too fast a rate, or
- (d) the presence of an industrial waste in the sewage.

If only in the effluent from an individual tank it will possibly be due to inequality of distribution of sewage between the tanks or to short-circuiting.

Excessive amount of floating matter in the settled sewage. This may be due to:

- (a) defective scum removal arrangements,
- (b) the scum baffle being too near the outlet weir,

- (c) disturbance of scum due to a strong wind,
- (d) the scraper travelling too fast, or
- (e) the presence, abnormally, of certain industrial wastes in the sewage.

Blockage in sludge pipe. This may be attributed to:

- (a) poor design of the pipeline (see 1.5.4),
- (b) production of an abnormally thick sludge due to infrequent desludging,
- (c) the presence of grit or shredded rags which have matted together in the sludge,
- (d) disintegrated media in the secondary sludge returned from biological filters, or
- (e) an object falling into the tank which has partially blocked the sludge outlet or has lodged in the pipe.

Blockages may be cleared by rodding, by using a hydraulically-propelled cleaning tool, a jet of water or compressed air, or by the use of a positive-displacement pump.

5.4 Periodical Emptying of Mechanically-desludged Tanks

Mechanically-desludged tanks need emptying periodically, usually annually, when the following should be attended to:

- (a) grit deposits removed from the floor, underwater parts of the scraper hosed down and sludge or rag which has been deposited on it removed; objects which have fallen into the tank since it was last emptied are also removed;
- (b) the scraper is inspected for wear and corrosion and any defective, broken or badly worn parts are replaced, and
- (c) the tank structure is inspected and defective areas are repaired.

5.5 Maintenance

The following maintenance should be carried out at regular intervals:

- (a) the inlet and outlet weirs and the effluent channel brushed daily;
- (b) the scum removal equipment hosed down, preferably with a high-pressure cleaner used hot or cold;
- (c) ridges of fat and scum which accumulate on the inlet baffle, walls and scum baffle at the water line scraped off, say, every month;
- (d) mechanical equipment lubricated and maintained in accordance with the manufacturer's instructions, and
- (e) ferrous metal-work above water level repainted every three years and that below water level repainted every five to ten years.

6. Pattern of Flow in Primary Sedimentation Tanks

6.1 Methods of Investigation

Flow patterns in sedimentation tanks may be studied by the use of:

- (a) chemical tracers;
- (b) radioactive tracers;
- (c) float techniques;
- (d) temperature differentials.

The first two methods have been the subject of a note by the Water Pollution Research Laboratory⁵³.

6.1.1 Chemical tracers

In the past, dyes and inorganic salts have usually been used for determining the flow pattern or the retention period in sedimentation tanks.

Dyes give a quick, semi-quantitative indication of the flow pattern but they may:

- (a) undergo a colour change through reacting with substances in the sewage,
- (b) be absorbed on to solids present in it, or
- (c) be masked by the colour or turbidity of the sewage.

Also they fade in sunlight, although rhodamine-B fades less rapidly than fluorescein but is somewhat more expensive. Spectrophotometric techniques are available for determining very much lower concentrations of tracer at a specific wavelength.

When common salt is used to determine the retention period in a sedimentation tank a concentrated solution containing a known amount of salt is added as a single dose and the concentration in the effluent is determined at frequent intervals. The average retention period is the time taken to discharge 50 per cent of the salt. Alternatively, a curve may be drawn showing the

relation between concentration and time and the average retention period is represented by the location of the vertical gravity axis under the curve. The accuracy of this method suffers from the sewage already containing a high and varying concentration of chloride, whilst the addition of further salt may affect the density of the sewage and therefore the pattern of flow.

Lithium is normally present in sewage in only very low concentrations and if it used as a tracer instead of common salt much less is required and the low concentrations involved can be readily determined by a simple flame photometer. The use of lithium by the Water Pollution Research Laboratory has been described by Agg, Mitchell and Eden⁵⁴. The cost of the relatively small amount of lithium carbonate required is reasonable and the method of application is the same as with common salt. Mixing of the lithium with the sewage must be complete and the flow should be nearly constant during a measurement.

6.1.2 Radioactive tracers

For determining the flow pattern, bromine-82 (as ammonium bromide) may be used. This is added as a single dose and the flow pattern in the tank is indicated by recordings of counts made by "immersion counters" suspended in different parts of the tank. Alternatively, samples may be taken and the counts made in the laboratory using a gamma-scintillation counter.

This method is sensitive and reliable, and the low concentrations of radioactive material used can be measured quickly and accurately; also the amount of material used is so small that it does not affect the density of the sewage. However, the use of this method is restricted by the high cost of the equipment, the specialized knowledge required and the hazards involved. Because of these hazards, the use of radioactive tracers is subject to an authorization procedure in accordance with the provisions of the Radioactive Substances Act 1960.

6.1.3 Float techniques

For studying flow patterns, float techniques are cheap, give quick results, the density of the sewage is unaffected, and the technique is easy to apply. Floats may, however, be fouled by gross solids in the sewage.

Clements and Price⁵⁵ recently used a two-float technique for studying flow patterns in primary sedimentation tanks at a number of sewage works. Acting on the theory that the ratio of the effective flow-through time to the effective settling time in an ideal tank is unity, they devised a technique for

measuring this ratio, which they called the "time ratio". By dividing a tank into equal divisions of length and of breadth and measuring the velocity at the centre of each sub-division, both in the top half of the tank and in the bottom half, they were able to plot the horizontal flow pattern through the tank, to determine whether there was any possibility of scour occurring and to calculate the time ratio.

6.1.4 Lag in temperature change from inlet to outlet

Experiments by Cox⁵⁶ at Croydon (Beddington) and Oxford (Sandford) Works have indicated that the actual retention period in primary sedimentation tanks may be determined from curves showing variations in temperature of the sewage entering and leaving them. During the test period the flow through the tanks should be reasonably constant and the curves are plotted from continuous recordings of the two temperatures. Since the peaks and lows in the curve showing the temperature of the tank effluent occur later than in the corresponding curve for the sewage entering the tanks, to obtain the best mean fit of the two curves it is necessary to "step back in time" the curve showing variations in temperature of the effluent. The extent to which this is necessary is a measure of the actual retention period. The nominal retention period is calculated from the capacity of the tanks and the average rate of flow through them, taking into account sludge stored in the tanks and any withdrawn during the test period. The difference between the nominal and actual retention periods indicates the extent to which the design diverges from the ideal or theoretical and hence the influence this may have on the efficiency of solids removal. This method is not as precise as techniques using tracers but is less tedious and more simple, and Cox claims that by its use the actual retention period can be calculated to within ± 10 min.

6.2. Patterns of Flow

6.2.1 Horizontal-flow tanks

Burgess and Green^{19,57-59} used the radioisotope bromine-82 for examining the pattern of flow in primary tanks, 67 m long by 22.9 m wide, at Beckton Works. Initially it was found that when the sewage entered the tank most of it streamed down the slope of the inlet weir wall and flowed across the floor of the sludge trough. When the inlet weir was modified so that the depth of sewage flowing over the sill was increased by four times and the inlet velocity was reduced by about 75 per cent the flow fanned out before reaching half way down the slope and the danger of scouring sludge from the trough was eliminated. However, when the vertical distribution of the flow was measured at intervals of 6 m along the centre line of the tank it was found that about half of the sewage was passing straight through to the outlet while the remainder was returning in a reverse current towards the inlet as shown in Fig. 26.

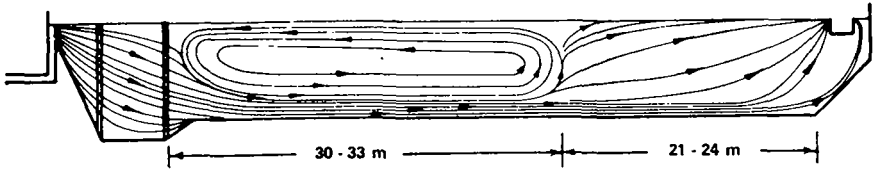


Fig. 26. Pattern of flow in a horizontal-flow tank at Beckton Works determined by radioactive tracer.

Clements and Price⁵⁵ used their two-float technique for determining the horizontal flow pattern in sedimentation tanks. Fig. 27 shows the pattern in a primary sedimentation tank at Rotherham.



Fig. 27. Horizontal flow pattern in primary tank at Rotherham, determined by two-float technique

6.2.2 Radial-flow tanks

Tebbutt¹² used fluorescein when studying the comparative performance of pilot-scale peripheral-feed and centre-feed tanks and found that, for all practical purposes, the performances of the two tanks were the same, but the results suggested the possibility of operating conventional tanks at overflow rates considerably higher than those commonly used.

7. Special-Purpose Sedimentation Tanks

7.1 Sedimentation/Flow Balancing Tanks

The extent of the diurnal variations in flow and strength of sewage reaching a treatment works varies with each works^{60,61}. In dry weather both flow and strength may vary in the ratio of 4:1, making a diurnal variation in load of 16:1 if the peak strength coincides with the peak flow.

Variations in strength may be equalized to a certain extent by the mixing which occurs during passage of sewage through a sedimentation tank. However, good mixing is not conducive to efficient sedimentation and sedimentation tanks are designed to reduce mixing to a minimum. A design of horizontal-flow tank to equalize the strength of the settled sewage is described in 2.4.2.

The Water Pollution Research Laboratory⁴⁵ used laboratory-scale biological filters to determine the effect on treatment of diurnal variations in the flow of settled sewage. The results showed that, despite the fact that with non-uniform flow considerable changes in the constituents of the effluent occurred throughout the day, the effluent deteriorating as the flow increased, the *average* composition of the effluent from the filters was similar (except for synthetic detergents) whether the flow was uniform or non-uniform.

Variations in the rate of flow may be equalized by:

- (a) control of the pumping rate when the sewage is pumped,
- (b) providing specially designed sedimentation tanks,
- (c) using storm tanks for balancing, or
- (d) designing the sedimentation tanks to fulfil the dual function of sedimentation and balancing.

When a horizontal-flow primary sedimentation tank is to be used for balancing there are usually two outlet weirs, one at the minimum and the other at the maximum water level, the discharge of effluent until the upper overflow weir is reached being through valve-controlled orifices. Scum is retained in the tank by a floating scum baffle. The capacity to be provided

between the two outlet weirs will depend on the characteristics of the flow, but it is usually equivalent to between 3 and 6 h DWF⁶². When emptying a balancing tank all the sludge must be removed, or any remaining should be left covered with water to prevent odour nuisance.

Unfortunately a sedimentation/flow balancing tank is not as efficient as a tank designed for sedimentation only, but it is to be preferred to the installation of a separate balancing tank. It has been suggested⁶³ that a good quality settled sewage is to be preferred to an effluent containing more suspended matter but with its flow equalized. For this reason few sedimentation/flow balancing tanks have been constructed in the UK.

7.2 Sedimentation/Storm-sewage Tanks

With small works it is becoming increasingly the practice for storm-sewage tanks to be dispensed with, the capacity of the sedimentation tanks being increased so that in wet weather they can treat flows up to 6 DWF, or even more. With sedimentation tanks having a capacity equivalent to 9 h DWF the retention period at 6 DWF would be 1.5 h. This simplifies plant operation and increases flexibility, with tanks being taken out of service in dry weather.

With larger works the storm tanks are sometimes used for accommodating peak flows in dry weather, i.e. receiving sewage during the day when the flow is high for return to the primary sedimentation tanks during the night. At such times the storm tanks therefore act as flow balancing tanks.

Where horizontal-flow primary tanks are used the storm tanks are sometimes of the same size and arranged alongside so that they can be operated as additional sedimentation tanks in dry weather. At one works, for example, there are five primary sedimentation tanks and three storm tanks served by two travelling-bridge scrapers, their combined capacity being equivalent to 12 h DWF.

At other works the horizontal-flow primary tanks and the storm tanks are arranged in two rows, with the inlet ends of one set of tanks backing on to the outlet ends of the other set so that one travelling-bridge scraper can serve two tanks in line. Some of the tanks serve a dual purpose, being used as primary sedimentation tanks or storm tanks as required. This arrangement economizes in space and increases flexibility in operation.

7.3 Sedimentation/Sludge Thickening Tanks

One design of radial-flow primary sedimentation tank is equipped with a "picket-fence" thickener (Fig. 19) which is attached to the scraper and rotates with it. The rods of the thickener form void channels through which water is displaced upwards, resulting in withdrawal of a denser sludge.

7.4 Two-stage Sedimentation Tanks

Many years ago manually-desludged horizontal-flow primary sedimentation tanks were sometimes divided into two compartments by a cross wall, with the first compartment, in which the bulk of the heavier solids settled, of relatively small capacity so that it could be emptied at more frequent intervals and without the necessity for emptying the main compartment.

When the Mogden Works was designed it was thought advantageous to divide primary sedimentation into two stages using two sets of tanks. The bulk of the heavier sludge would settle in the first-stage tanks and be removed at more frequent intervals than the smaller amount of watery sludge settling in the second-stage tanks, which were of larger capacity and cheaper construction. Also the surplus activated sludge was to be returned to the inlet of the first-stage tanks and it was thought that settlement would take place in them and the sludge be dealt with before it had time to turn septic. In 1947 Townend⁶ reported that over a 10-year period, on average, the concentration of SS had been reduced from 238 to 69 mg/l, an overall reduction of 71 per cent, despite the return of surplus activated sludge adding the equivalent of 120 mg/l SS and the sewage containing large volumes of organic industrial wastes. After the works had been in operation for 12 years Townend⁶ reported that "the primary stage has produced more than 80 per cent of the total amount of mixed sludges on the basis of dry solids removed. This proportion, however, is very variable, depending on the rate of flow and the condition of the tanks. The secondary tanks have always been a good standby to the primary stage and during certain periods have been called upon to do most of the work. In wet weather, the velocities in the primary tanks are such that considerably more sludge is passed forward to the secondary stage. The maintenance of fresh conditions, however, is of even more importance, as any fermenting action will rapidly reduce the work done by either stage. Thus in cases where it is necessary to have sludge removed as speedily in the second stage as in the primary, one of the main reasons for stage treatment will have disappeared, for economy must not be gained at the expense of performance in operations of this kind".

It is now generally accepted that a single tank with a capacity equal to the combined capacity of two tanks in series will give a better effluent, involve less loss of head, operation will be simplified and only one type of sludge will have to be dealt with instead of a dense sludge from the first stage and a more flocculent sludge from the second stage.

8. Aids to Sedimentation

8.1 Pre-aeration

Pre-aeration has been used at several works with tanks providing about 0.5 h retention and using 0.1 to 0.2 m³ air per m³ of sewage treated. However, when the Water Pollution Research Laboratory⁶⁴ compared the performance of a primary tank receiving sewage which had passed through a pre-aeration tank with that of an identical tank receiving sewage which had not passed through such a tank it was found that for practical purposes, pre-aeration had no significant beneficial effect on performance.

Pre-aeration is mainly of value as a means of mixing and of equalizing the load on the sedimentation tanks. It can also be of value where the sewage is prone to septicity by releasing any free sulphide and volatile organic materials in the sewage, with consequently less risk of sludge rising in the sedimentation tanks. It has also been found⁶⁵ that the addition of surplus activated sludge to the sewage before it enters the pre-aeration units gives improved results; this also applies to sludge from biological filters. Finally, pre-aeration assists the separation of fats and grease from the sewage.

8.2 Chemical Treatment

For many years it was a common practice, especially with industrial sewages, to add a suitable chemical or mixture of chemicals to the sewage to remove colloidal matter and the very finely divided suspended matter called "pseudo-colloidal matter". The effluent produced was therefore more highly clarified than that produced by plain sedimentation.

The purpose of the chemical or chemicals was to neutralize the electrical charge on the colloidal particles so that when they collided with each other or with particles of suspended matter they coalesced to form a flocculent precipitate which settled as sludge.

The chemicals most commonly used were lime and aluminoferric (a compound containing 92 per cent hydrated aluminium sulphate together with a small amount of ferric sulphate). Sulphuric acid and chlorinated coppers

were also used. The application of polyelectrolytes is currently being investigated.

Because of the high cost, chemical treatment is only used as a temporary expedient to relieve an overloaded works by improving the efficiency of sedimentation.

8.3 Mechanical Flocculation

Mechanical flocculation aims at improving the efficiency of settlement by promoting conditions under which the agglomeration of finely divided suspended solids can occur, with adsorption of colloidal matter on to the flocs. Forty years ago mechanical flocculation was used at several works in the West Riding of Yorkshire^{66,67} where sewage containing a high proportion of wool scouring waste was being acidified prior to sedimentation, the flocculation taking place in baffled channels⁶⁶ or by using vanes rotating about a horizontal axis⁶⁷. In one case⁶⁷ it was claimed that the amount of potential secondary-sludge forming material in the sewage was reduced by about 20 per cent. Results of experiments at another works⁶⁸ treating a mainly domestic sewage without the use of chemicals in which four tanks, each 11.6 m diameter, were used, two of which were equipped with moving grilles to promote flocculation, showed that very gentle stirring could produce flocculation and thus improve settleability.

On the other hand, laboratory experiments carried out by Stones¹⁴ indicated that where chemical precipitation with lime or sulphuric acid was used, if the period allowed for sedimentation was adequate mechanical flocculation offered no advantage, and that without chemical treatment, mechanical flocculation was ineffective.

Consequently the evidence available on the value of mechanical flocculation is conflicting and indicates that it is likely to be of marginal benefit only, involving extra equipment and maintenance costs. It is not present practice, therefore, to make provision for it.

9. Products of Primary Sedimentation

9.1 Settled Sewage

Tables 3 and 5 show that even after sedimentation the sewage still contains from 30 to 50 per cent of the suspended matter present in the crude sewage, much of it in a finely divided state. It also, of course, contains all the impurity present in solution in the original sewage. It is therefore unsuitable for discharge without further treatment unless the dilution available is adequate such as, for instance, when this is to estuarial or coastal waters.

9.2 Sludge

9.2.1 Characteristics

Typical mixed sludges have the following characteristics:

| Characteristic | Range, etc. | Remarks |
|---------------------------|---|---|
| Physical texture .. | | Heterogeneous viscous mixture of solids ranging from granular to flocculent material and water. Industrial wastes can have marked effect. |
| Colour | Greyish/black | Darkens as it turns septic. |
| Odour | Usually offensive | Hydrogen sulphide given off if sludge turns septic. |
| Specific gravity .. | Range 1.015-1.030 | |
| Dry solids content .. | Range 2-10 per cent | |
| pH value | Range 4.5-7.5 | |
| Total alkalinity | Range 300-1500 mg/l | |
| Volatile acids content .. | Range 800-2000 mg/l | Increases if sludge turns septic. |
| Specific resistance .. | Range 100-300 × 10 ¹² m/kg at 49 kPa | Alternatively, the capillary suction time (CST) is often used. |
| Dry solids: | | |
| Organic and volatile | Range 55-80 per cent | |
| Grease | Range 10-25 per cent | Petroleum-ether extractable matter. |
| Surfactants | Range 0.25-1.75 per cent | |

Some 20 to 45 per cent of the heavy metals present in the sewage will be concentrated in the sludge⁶⁹.

9.2.2 Production

The amount of sludge produced may be arrived at from actual measurements or by calculation from the concentration of suspended matter in the sewage before and after settlement and the dry solids content of the sludge. Neither method will be very accurate because of the difficulty of measuring volumes of sludge and of obtaining representative samples.

The amount produced will depend on many factors, including the population served, industrial wastes in the sewage, whether secondary sludge or works liquors are returned to the primary sedimentation tanks, the efficiency of the tanks and the dry solids content of the sludge.

In 1967 the results were published of a survey organized by the Institute of Water Pollution Control, together with data obtained by the Water Pollution Research Laboratory⁷⁰, which included information on suspended matter in domestic sewage.

The IWPC survey included data from works serving populations ranging from 1200 to 90 000 persons, suspended matter due to industrial wastes present in the sewages having been deducted to give that derived from domestic sewage. Also the figures given were for primary sludge only. The amount of suspended matter in the crude sewage averaged 0.062 kg/hd d and in the settled sewage 0.018 kg/hd d, so the amount of sludge produced was equivalent to 0.044 kg/hd d. For design purposes, to these amounts must be added the solids from any secondary sludge and works liquors returned for treatment.

The data obtained by the Water Pollution Research Laboratory were from small works treating domestic sewage. Suspended matter in the crude sewage was equivalent to 0.085 kg/hd d and in the settled sewage 0.018 kg/hd d, so the sludge produced was equivalent to 0.067 kg/hd d.

In 1969, Swanwick, Shurben and Jackson⁷¹ published data obtained from 142 sewage works serving populations ranging from 2200 to 3 million persons. These showed that the amount of primary and secondary sludge averaged 1.86 litres/hd d, containing 0.082 kg dry solids of which 0.057 kg was volatile matter, the volatile matter content of the dry solids averaging 72.5 per cent. Returns from a further 104 works serving populations ranging from 500 to

91 000 persons showed that for primary sludge only, the amount averaged 0.73 litre/hd d containing 0.054 kg dry solids of which 0.039 kg was volatile matter, the volatile matter content of the dry solids averaging 72.2 per cent.

Tables 3, 5 and 6 show that the amount of sludge produced daily per head of population varies widely and may be greatly affected by industrial wastes present in the sewage and the extent to which treatment is carried. With the works mentioned the volume ranged from 0.7 to 4.4 litres/hd d.

Table 6 shows the amount of sludge produced at a number of sewage works in terms of dry solids per head per day. The amount of mixed sludge ranged from 0.051 to 0.189 kg dry solids/hd d, depending on the nature and proportion of industrial waste in the crude sewage. The amounts of sludge from biological-filter plants ranged from 0.051 to 0.110 kg dry solids/hd d, and from activated-sludge plants from 0.058 to 0.189 kg dry solids/hd d.

The increasing use of garbage grinders in hotels and restaurants and the increasing use of disposable bed-pans and blankets in hospitals are contributory factors to a high sludge production particularly in regional medical centres.

9.3 Scum

After preliminary treatment, sewage still contains coarse synthetic solids, such as plastics, polythene and terylene wrapping materials, that have passed through the preliminary treatment plant. Also debris resulting from comminution or disintegration of coarse solids, together with fats, oils, grease and soaps. These rise to the surface of primary tanks to form scum. In addition, this may contain sludge which has risen to the surface due to gasification.

Scum should be removed at regular intervals since it may cause odour nuisance, blockages in pipelines and of the arms of biological-filter distributors, attract birds which drop excreta and debris on copings and foot-paths, and because it spoils the appearance of the tanks.

Scum is usually disposed of along with the sludge.

TABLE 6. EFFECT OF INDUSTRIAL WASTE WATERS ON PRODUCTION OF SLUDGE FROM PRIMARY SEDIMENTATION TANKS

| Sewage-treatment works | Population served by works | Average daily flow (tcm) | Industrial waste | Main industrial waste waters present in sewage | Sludge production | | Sludge dry solids | | Ref. No. |
|--------------------------------|----------------------------|--------------------------|----------------------------------|---|-----------------------------|-------------|-------------------|-----------|----------|
| | | | Percentage of average daily flow | | Average (m ³ /d) | Litres/hd d | Average (kg/d) | kg/hd day | |
| Bedford | 90 000 | 25.6 | 12 | Brewing; plating and metal finishing; rubber processing | 100 (BL) | 1.1 | 6 540 | 0.067 | 72 |
| Blackburn | 120 000 | 63.6 | 19 | Brewing; textile manufacture; plating & metal finishing | 240 (B) | 2.0 | 12 000 | 0.100 | 73 |
| Bolton (Ringley Fold) | 252 000 | 93.2 | 15 | Textile manufacture; paper & board making; leather tanning | 904 (A) | 3.6 | 29 000 | 0.115 | 74 |
| Colchester | 85 000 | 20.7 | 10 | Engineering; paper coating; abattoirs | 279 (ABL) | 3.3 | 8 250 | 0.096 | 75 |
| Coleshill | 245 300 | 64.0 | 10 | Engineering; plating and metal finishing | 690 (AL) | 2.8 | 20 900 | 0.085 | 88 |
| Doncaster: | | | | | | | | | |
| Balby | 17 800 | 6.9 | 46 | Engineering; plating & metal finishing | 33 (B) | 1.9 | 1 350 | 0.076 | 76 |
| Sandall | 101 800 | 24.1 | 10 | Plating & finishing; engineering; food processing | 132 (B) | 1.3 | 5 220 | 0.051 | 76 |
| East Kilbride: | | | | | | | | | |
| Aillers | 30 000 | 10.4 | 8 | Food processing; plating & metal finishing | 41 (ABL) | 1.4 | 1 930 | 0.064 | 77 |
| Philipshill | 35 200 | 12.9 | 6 | Metal plating & finishing; latex manufacture | 65 (AL) | 1.9 | 2 670 | 0.076 | 77 |
| Falkirk | 62 000 | 28.0 | 50 | Chemical industry; food processing; metal finishing | 170 (AL) | 2.7 | 4 260 | 0.068 | 78 |
| Havant & Waterloo (Budds Farm) | 114 000 | 36.0 | 8 | Chemical industry; plating & metal finishing; general manufr. | 141 (BL) | 1.2 | 7 330 | 0.064 | 79 |
| Manchester (Davyhulme) | 780 000 | 386.4 | 35† | Chemical industry; engineering; rubber processing | 1900 (A) | 2.4 | 130 000 | 0.167 | 80 |
| Maple Lodge | 517 000 | 139.7 | 14 | Paper and board making; film processing | 463‡ (L) | 0.9‡ | 32 000 | 0.062 | 89 |
| Newbridge | 22 000 | 9.4 | 40 | Food processing; rubber manufacture; meltings | 86 (A) | 3.9 | 4 150 | 0.189 | 81 |
| Osgoldcross | 39 000 | 10.0 | 12 | Sweet manufacture; fat & bone processing; abattoirs | 51 (L) | 1.3 | 2 360 | 0.060 | 82 |
| Palmersford | 15 300 | 3.4 | Nil | Nil | 30 (BL) | 1.9 | 1 340 | 0.088 | 90 |
| Pudsey (Houghside) | 20 000 | 6.8 | 30 | Textile manufacture; food processing; leather tanning | 31 (BL) | 1.6 | 1 580 | 0.079 | 83 |
| Saddleworth | 14 800 | 5.5 | 43 | Textile manufacture; paper and board making | 65 (ABL) | 4.4 | 2 600 | 0.176 | 84 |
| Sheffield (Blackburn Meadows) | 546 000 | 166.0 | 25 | Iron and steel making; food processing; brewing | 1038 (AL) | 1.9 | 67 760 | 0.124 | 85 |
| Spensorough | 38 000 | 13.6 | 33 | Wool scouring and dye liquors; metal finishing | 67 (BL) | 1.75 | 4 000 | 0.105 | 86 |
| Stalybridge & Dukinfield | 52 000 | 19.0 | 22 | Plating and metal finishing; textile manufacture | 60 (ABL) | 1.15 | 2 700 | 0.052 | 87 |

† 35 per cent by volume; 65 per cent by load
‡ After consolidation

A Includes surplus activated sludge
B Includes sludge from biological filters
L Includes works' liquors

10. Septic Tanks

10.1 Cesspools and Septic Tanks

Cesspools or septic tanks are frequently used for receiving the sewage from houses and other premises which are too isolated for connection to the public sewer. A cesspool is simply a storage tank which should be emptied at regular intervals by a tank-emptying vehicle. A septic tank is a continuous horizontal-flow tank in which the sludge is retained sufficiently long for the organic content to undergo anaerobic digestion. When sludge is eventually removed, some is left in the tank to act as a "seed" to initiate further digestion. A septic tank therefore combines the functions of sedimentation and sludge digestion.

10.2 Arrangement

Roof and surface water, disinfectants and chemicals discharged from water softening plants should be excluded from septic tanks if at all possible.

There should be two compartments or tanks in series and if serving over 60 persons there should be two tanks operating in parallel, each having two compartments, the capacity of the first compartment being twice that of the second. For populations over 100 the two tanks may in certain circumstances have single compartments.

With two-compartment tanks (Fig. 28), each compartment should be at least 1.5 m deep from water level, the length of the first compartment being twice its width. Connection between the two compartments may be by submerged horizontal orifices or by vertical slots. When horizontal orifices are used there should be at least two, the top of the orifices being from 0.225 to 0.3 m below water level and the vertical dimension from 0.075 to 0.15 m, whilst the combined width should be at least 0.225 m. With vertical slots there should be two, with a combined width of at least 0.225 m, extending the full water depth of the tank, the gaps being at each end of the partition.

For installations serving more than 30 persons where site conditions are difficult the two compartments may be side by side and connected by a submerged orifice in the dividing wall at the far end of the compartments so that the outlet adjoins the inlet.

PRIMARY SEDIMENTATION

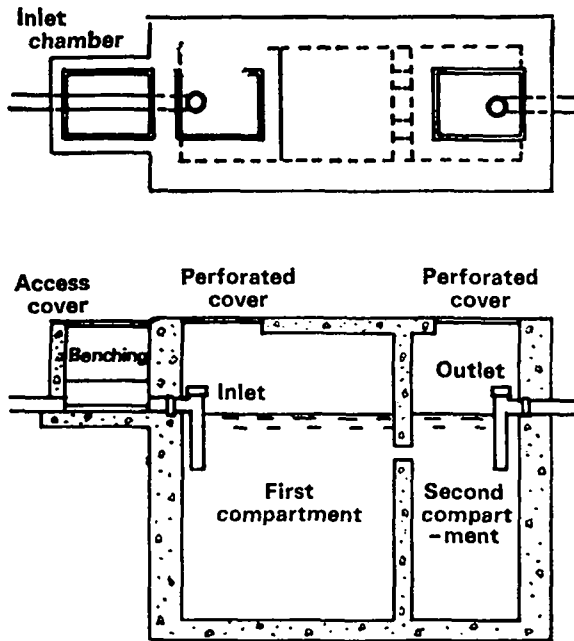


Fig. 28. Two-compartment septic tank suitable for treating sewage from up to 30 persons.

10.3 Design Criteria

Capacity. The total capacity of a septic tank or tanks is based on the population served. For populations up to 300 the following formula⁹¹ has been recommended for calculating the total capacity:

$$C = 180P + 2000$$

where C = total capacity of tank or tanks (litres)

P = population served.

Where garbage grinders are installed, the factor $180P$ should be increased to $250P$ since additional solids will be produced. With schools and factories which are occupied part time it is recommended that the factor should be $90P$.

Another authority⁹² recommends that the capacity should be based on 68 litres/hd d for tanks desludged at 6-monthly intervals, and a minimum of 108 litres/hd d for tanks desludged at 12-monthly intervals.

10.4 Design

Guidance on the design of septic tanks for small sewage-treatment works is given in the British Standards Institution Code of Practice 302:1972, entitled "Small Sewage-Treatment Works".

10.4.1 Inlet

The pipe conveying sewage to the septic tank should not be less than 100 mm diameter and preferably 150 mm diameter. If laid with a steep gradient, to reduce turbulence in the tank the gradient should be reduced to not more than 1 in 50 for the last 12 m.

A tank 1.2 m wide or less should have one inlet, and tanks over 1.2 m wide two inlets. Where there is a single inlet this may consist of a T-shaped dip-pipe of the same size as the incoming drain, fixed inside the tank with the vertical leg extending from above scum level to 0.45 m below water level.

Where there are two inlets the tank may be fed from a small chamber in which there is a channel terminating in a shallow sump, the invert of the channel being 0.05 m above water level. Each inlet consists of a bend with one end level with the floor of the sump, which is at least 0.075 m above water level, and the other end from 0.3 to 0.53 m below water level. A baffle extends across the full width of the tank, 0.15 m from the inlet end and from 0.15 m above water level to 0.15 m below the inverts of the feed pipes.

10.4.2 Outlet

With a tank up to 1.2 m wide the outlet may consist of a dip pipe fixed inside the tank and similar to that at the inlet. Wider tanks may have a weir protected by a scum baffle, with a deflector fixed to the end wall 0.15 m below the bottom of the scum baffle and protruding 0.15 m into the tank to prevent rising sludge from reaching the weir.

10.4.3 Floor

With a two-compartment tank serving up to 30 persons the floors of both compartments may be flat. With a larger tank, serving over 30 persons (Fig. 29), the floor of the second compartment may be flat and that of the first compartment may have a fall of 1 in 4 horizontal to the inlet end. There should be a valve-controlled connection at floor level between the two compartments, and if there are two tanks operating in parallel there should be a valve-controlled connection between them with its invert 0.6 m below water level to enable top water to be decanted from one tank to the other.

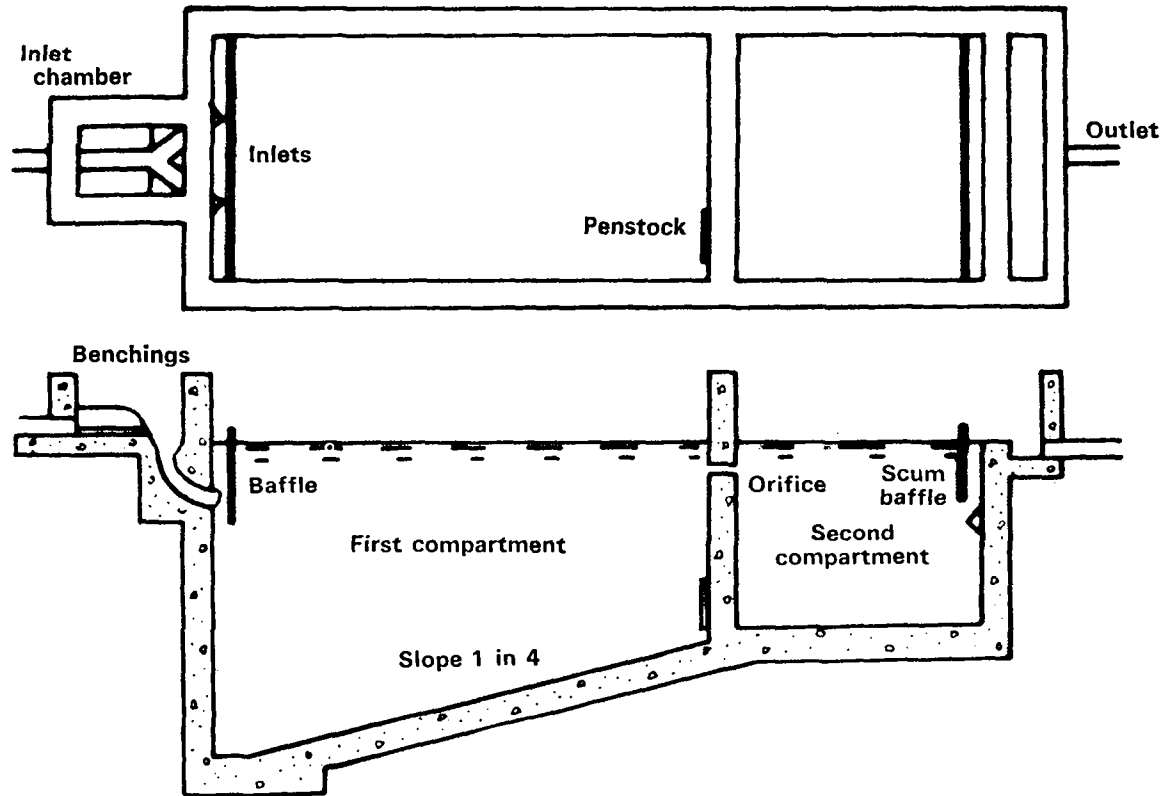


Fig. 29. Two-compartment septic tank suitable for treating sewage from over 30 persons.

10.4.4 Sludge withdrawal

Sludge is removed by a tank-emptying vehicle.

10.4.5 Scum collection

When the effluent is withdrawn through a dip pipe this extends to 0.45 m below water level and scum is retained in the upper portion of the tank. With larger tanks scum is retained by a baffle fixed 0.15 m in front of the outlet weir and extending from 0.15 m above to 0.45 m below water level. When sludge is withdrawn from the tank the scum is not removed but is left in the tank.

10.5 Operation

Every 6 to 12 months sludge should be withdrawn from the tank, leaving a small amount in the first compartment, together with the scum. When there are two interconnected tanks operating in parallel one tank should be completely emptied. Supernatant water and some sludge is then decanted from the other tank into it, after which the sludge is withdrawn from the second tank, leaving behind some to act as a "seed". The decanting valve is then closed and the two tanks resume normal operation.

10.6 Performance

Little information is available on the performance of septic tanks. The Water Pollution Research Laboratory⁹³ determined the performance of five types of tank, including a single-compartment "septic" tank and a tank with two compartments in series. The single-compartment tank was rectangular and had a capacity of 1.82 m³; the compartments of the two-compartment tank were precast concrete pipes, the first compartment having a capacity of 1.82 m³ and the second 1.09 m³. Because of the intermittent flow of sewage and the short run of the sewers it was impracticable to obtain representative samples of crude sewages but over a period of two years samples of the effluents were collected over 24 h on one day each week, the day changing to allow for possible variations from day to day. The tanks were completely emptied at the end of the first year and then every six months, consequently they were not operated for the whole of the time as true septic tanks, with some sludge being left behind in a compartment each time a tank was emptied. Table 7 shows the results obtained, indicating that the quality of the effluents varied widely.

TABLE 7. PERFORMANCE OF SINGLE-COMPARTMENT "SEPTIC" TANK AND OF A TANK WITH TWO COMPARTMENTS IN SERIES

| | Single compartment tank | | Tank with two compartments in series | |
|--|-------------------------|--------|--------------------------------------|--|
| | | | | |
| Average number of persons served | 14.2 | 10.2 | 30.5 | |
| Average sewage flow (m ³ /d) | 1.14 | 0.74 | 2.55 | |
| Nominal retention period in sedimentation space (h) | 39 | 95 | 27 | |
| Suspended solids in settled sewage (mg/l): | | | | |
| Average | 99 | 79 | 108 | |
| Range | 35-278 | 16-221 | 28-241 | |
| Average BOD (mg/l) | 420 | 305 | 495 | |
| Mean content of suspended solids in effluent (kg dry matter/hd d)* | 0.0045 | 0.0082 | — | |
| Periods of experiment: | | | | |
| Single compartment tank | 27-5-51 to 5-5-53 | | | |
| Tank with two compartments in series: | | | | |
| Persons served — 10.2 | 27-5-51 to 25-11-52 | | | |
| Persons served — 30.5 | 26-11-52 to 5-5-53 | | | |

* Period 27-5-51 to 12-6-52

Table 8 summarizes results recorded by a Scottish river purification board⁹⁴.

TABLE 8. PROPORTION OF SEPTIC TANK EFFLUENTS WITH SUSPENDED SOLIDS CONTENT OF LESS THAN 100 mg/l

| Population served | Capacity of tank (m ³) | Proportion of samples of effluent with a suspended solids content of less than 100 mg/l (per cent) |
|-------------------|------------------------------------|--|
| 80 | 15.91 | 89 |
| 80 | 6.82 | 75 |
| 90 | 4.32 | 92 |
| 160 | 53.64 | 80 |
| 200 | 31.82 | 96 |
| 270 | 45.46 | 96 |
| 280 | 33.19 | 50 |
| 380 | 31.82 | 29 |
| 450 | 93.19 | 56 |

10.7 Sludge Production

The amount of sludge produced will depend on the reduction in the concentration of suspended solids in the sewage during passage through the tank, the extent to which digestion has taken place, and on the dry solids content of the sludge. According to Imhoff and Fair⁹⁵, sludge accumulates in

septic tanks at a rate of 0.36 l/hd d, equivalent to 66 l in 6 months. Based on experience with a large number of tanks, Ackers⁹⁶ concluded that when desludged every 6 months the volume of sludge to be provided for averages 57 l/hd plus an allowance of 20 per cent, or 11 l/hd, for "seed" sludge left in the tank, or a total of 68 l/hd.

Nicoll⁹⁷ has given particulars of sludge produced from a number of septic tanks in Aberdeen county. With seven single-compartment tanks and the period since last desludging averaging 8 months, the dry solids content of the sludge varied from 8.7 per cent at the inlet end to 10.2 per cent at the outlet end. With four installations, each containing two tanks in parallel, desludged at intervals of about 8.2 months the dry solids contents were 14.7 and 9.9 per cent respectively. The dry solids content of the sludge from eighteen installations averaged 8.8 per cent.

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