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COMBINED TREATMENT OF DOMESTIC AND INDUSTRIAL WASTEWATERS

by

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COMBINED TREATMENT OF DOMESTIC AND INDUSTRIAL WASTE WATERS

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LIST OF SYMBOLS AND ABBREVIATIONS

AOR	$\frac{kgO_2}{h}$	actual oxygen rate
BOD	mg/l	biological oxygen demand
c	mg/l	dissolved oxygen concentration in waste water
C	rate/m^3	total rate of charge per m^3
C_{SOA}	mg/l	oxygen saturation concentration in air at standard conditions
DO	mg/l	dissolved oxygen concentration
COD	mg/l	chemical oxygen demand
$\frac{do}{dt}$	$\frac{mg\ l}{h}$	oxygen transfer rate
F/M	$\frac{kg\ BOD}{kg\ MLVSS\ d}$	food to micro-organisms ratio (sludge load)
Kd	d^{-1}	cell decay rate
$K_{La_{20}}$	h^{-1}	mass transfer coefficient
K_s	mg/l	concentration of rate limiting substrate when $\mu = \frac{\mu max}{2}$
L_{br}	kg/d	daily BOD removal
MLSS	mg/l	mixed liquor suspended solids
MLVSS	mg/l	mixed liquor volatile suspended solids

NH_4-N	mg/l	ammonium nitrogen concentration
O_{2ww}	kg/d	oxygen demand of waste water
pH		
Q	m^3/d	waste water flow
R	m^3/d	sludge recycle rate
S	mg/l	effluent BOD_7
S_o	mg/l	influent BOD_7
SOR	$\frac{kg\ O_2}{h}$	standard oxygen rate
Sr	$\frac{kg}{m^3 \times d}$	substrate removal rate
Ss	mg/l	suspended solids in influent or effluent waste water
SS_{RAS}	mg/l	return sludge concentration
SVI	ml/g	sludge volume index
t	h	time
T	^oC	temperature
V	l or m^3	volume of aeration basin
X	mg/l	total solids concentration (aeration + clarifier)

X_o	mg/l	MLVSS concentration under aeration
Y	$\frac{\text{kg cells}}{\text{kg BOD}}$	cell yield coefficient
β		ratio of dissolved oxygen saturation concentration for waste water to that of clean water
α		ratio of oxygen transfer rate for waste water to that of clean water
μ	$\frac{\text{kg}}{\text{kg x d}}$	microbial growth rate
μ_{max}	$\frac{\text{kg}}{\text{kg x d}}$	maximum growth rate
Θ_c	d	mean cell residence time or sludge age
d		day or days
h		hour
Dom		domestic waste water
Tan		tannery waste water
Tex		textile waste water
pp		pages
BLMRA		British Leather Manufacturers Research Association

Note: The units in the text are sometimes converted for convenience such as mg to kg and l to m^3.

LIST OF APPENDICES

Appendix 1 - 4 Tabulated values of results and control parameters used during the experiment for

1. domestic waste waters
2. textile + domestic
3. tannery + domestic
4. tannery + textile + domestic

Appendix 5 - 7 Graphical results of settleability test

ABSTRACT

This thesis comprises two parts. In part I (chapters 2 - 6) the activated sludge process fundamentals, modifications, process kinetics and its capabilities are discussed. In addition domestic, textile and tannery waste water characteristics and their effects on activated sludge treatment, alone or when they are combined, is briefly presented. Besides consideration is given on managerial and economic aspect of combined treatment.

Part II (chapters 7 - 11) is an original work of the author on combined treatment of tannery and/or textile waste waters with domestic sewage in an activated sludge model.

Four tests were conducted. Domestic sewage alone, textile and domestic, tannery and domestic and textile, tannery and domestic. Upto 30 % of the industrial waste waters were mixed with domestic sewage in the two cases while when all were mixed 60 % industrial to 40 % domestic sewage was reached. In all cases, upto the proportion described, good substrate removal and complete nitrification were obtained. Some problems, like poor settleability, were encountered during the experiment. These are dealt in the text. However, these problems did not so much affect the performance of the process and good results were still obtained.

Finally few oxygen uptake rate tests made for toxicity and inhibition indicated that both waste waters can sometimes be toxic and sometimes not depending on their strength. Still, upto 30 % both were found to be non-toxic for any strength.

1. INTRODUCTION

Municipalities and industries account for the largest portion of waste discharge that occur. Industries discharge an enormous variety of materials which include the most toxic of pollutants. Industrial waste sources, like municipal wastes, are concentrated in specific areas of a country. As the population of a country expands, so does the need for manufactured goods. Consequently, the volume of the industrial wastes that will be treated in municipal sewage treatment plants increases. Some of these can be directly discharged to municipal sewage treatment plants, but others must be pretreated at the source.

Environmental control should move into the direction of pollution avoidance rather than control. The public has and can tolerate some pollution, but the condition may come to the point that many may suffer or even die because of it.

This problem, specially, is not so serious in the developing world as the number and size of industries is not so extensive yet.

Thus most of these industries are and were discharging their waste water directly to the natural water bodies. Besides cheap labor, this is another economic reason that developed countries benefit when they start manufacturing in a developing country.

But, nowadays, with current pollution control legislations in almost all the developing countries, what was once a free facility is now a charge on an industry and it is not surprising that investigations are afoot to determine the most effective and economic ways to dispose of trade effluents.

The main industries of concern in Ethiopia, for example, are textile, tannery, food processing, breweries, beverages etc. Tannery and textile industries being among the largest industrial consumers of water, they are selected to be dealt in this paper.

Combined treatment of industrial and domestic sewage can be very economical as the cost of one big plant is cheaper to construct than smaller ones for the same overall capacity. Also operation costs are cheaper in running one big plant than smaller ones. But one should not also forget the complexity, higher maintenance frequency of sewerage system and the need for more qualified personnel to run a bigger plant. Besides proper precaution must be taken to prevent inhibition by the industrial part.

The material presented in this paper presents a literature survey on activated sludge process and findings from a research work with an objective to generate comparative data from the different waste waters and their combinations. The experience in two major industrial categories should provide invaluable guidance as to the options available and the results obtainable.

2. ACTIVATED SLUDGE PROCESS

2.1 General

Activated sludge is a suspension of micro-organisms, both active and dead, in a wastewater consisting of entrapped and suspended colloidal and dissolved organic and inorganic materials.

The activated sludge process is an aerobic, biological process which uses the metabolic reactions of micro-organisms to attain an acceptable effluent quality by removing substances exerting an oxygen demand. /5/

The basic activated sludge system consists of:

1. A single or multiple reactor basins designed for plug or completely mixed flow.

2. An oxygen source which disperses pressurized or atmospheric air or oxygen containing gases into the reactor basin mixed liquor.

3. A means of mixing the reactor basin.

4. A secondary settling basin to separate the mixed liquor suspended solids from the treated wastewater.

5. A means of collecting the solids in the settling basin and recycling them to the reactor basin.

6. A means of wasting excess activated sludge from the system.

Depending on wastewater characteristics a primary settling tank may or may not be provided.

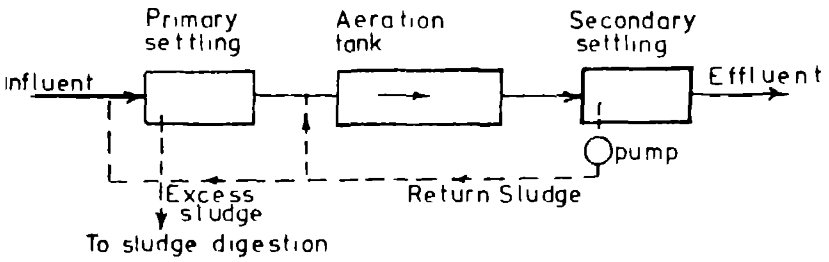


Figure 1. Conventional activated-sludge process. /1/

2.2 Modifications of activated sludge process

Since its introduction, the activated sludge process has undergone many variations and adoptations. These are:

2.2.1 The conventional process

This consists of a primary settling basin, aeration tank (reactor), a final clarifier and return sludge line and excess sludge removal line. Aeration and mixing are uniformly supplied along the basin. This leads to an oxygen shortage at the inlet end and excess at the outlet. /8/ This can cause lower efficiency of BOD removal at the inlet and upto nitrification at the outlet.

2.2.2 Tapered aeration

This is identical to the conventional process except that greater number of diffusers are installed at the inlet than at the outlet. This is because the oxygen demand decreases along the length of the aeration basin and hence the demand is lower at the end than at the beginning.

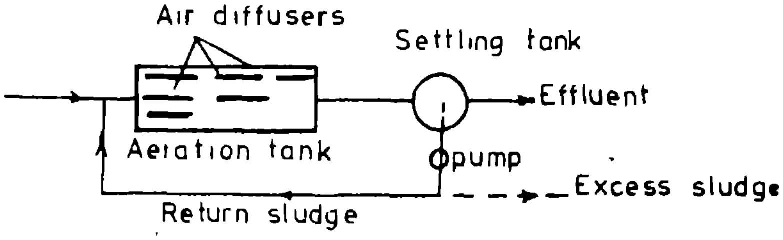
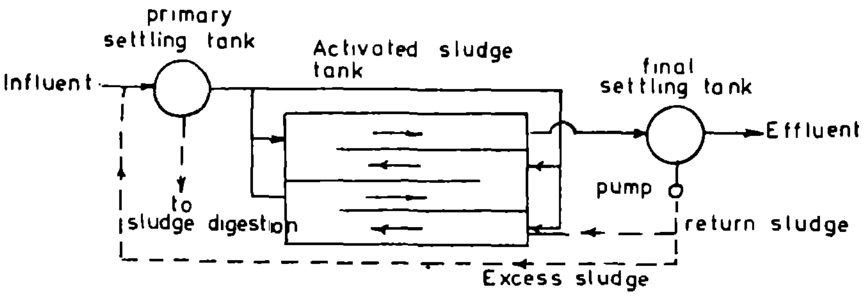


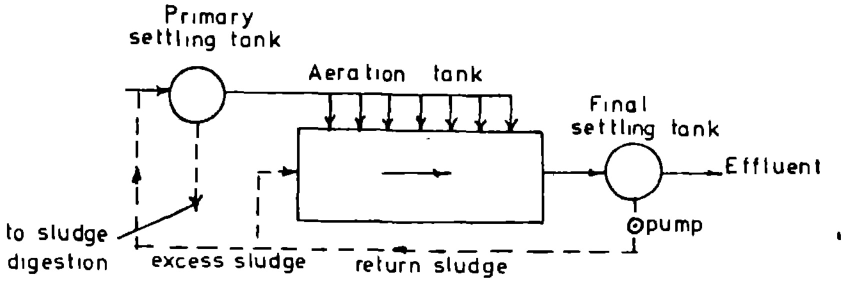
Figure 2. Tapered aeration. /1/

2.2.3 Step aeration

In this case, wastewater is added to the aeration tank at a number of points along the course of flow of the mixed liquor through the tank, and the return sludge is applied at the beginning of the aeration tank. With this arrangement the activated sludge is relieved of the full load at the forward end of the tank, and the tank operates more uniformly and more efficiently. /13/



a) Step Aeration

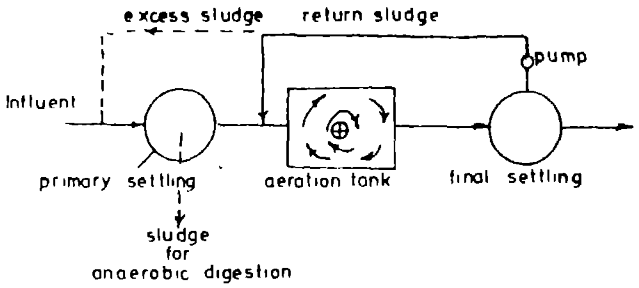


b) Step Aeration (step loading)

Figure 3. Activated-sludge process: (a) step aeration; (b) step aeration (step loading). /1/

2.2.4 Completely mixed activated sludge process

This system works on the principle that the entire contents of the aeration tank should be thoroughly and completely mixed to ensure uniform distribution of influent wastewater, activated sludge and oxygen throughout the aeration tank.



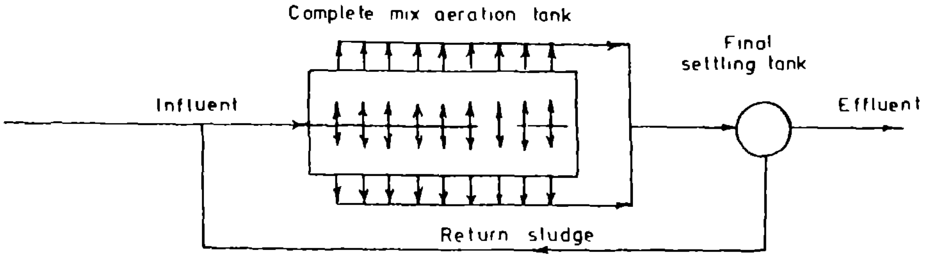


Figure 4. Complete mixed activated-sludge process (aeration may be either by mechanical surface aerators or compressed air). /1/

2.2.5 High rate activated sludge process

Sometimes called modified aeration, it operates at a very high sludge loading or food to micro-organism ratios compared to the conventional process and consequently lower cell residence time or sludge age. The aeration tank contains smaller concentration of flocs. It has also a short hydraulic detention time.

Because more of the incoming organic matter is synthesized to sludge organisms, total oxygen requirements are less than in the conventional process, but the rate of oxygen demand is higher per unit mass of mixed liquor volatile suspended solids. /8/

2.2.6 Extended aeration

This process is characterized by low values of food to micro-organisms ratio, low net sludge yield, and hence high sludge age, achieved by providing longer detention time and higher concentration of MLSS than in the conventional process. Primary sedimentation and anaerobic digestion are usually omitted. Such plants can be designed for high BOD removal.

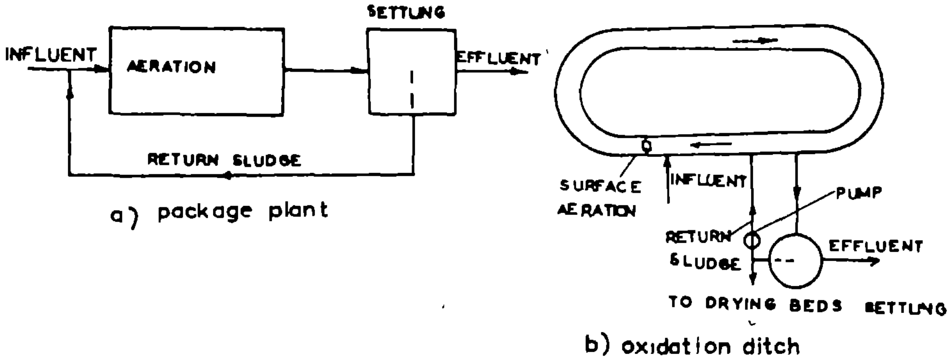


Figure 5. Extended aeration: (a) package plant;
(b) oxidation ditch. /1/

2.2.7 Contact stabilization or bioabsorption

In contact stabilization the adsorptive property of the activated sludge is utilized. Activated sludge adsorbs suspended and colloidal solids quickly, but it does not do so with dissolved organic matter. The removal of dissolved matter takes place by adsorption inside the microbial cell and by metabolic activity. The adsorption stage is separated from the oxidation stage so as to achieve better plant control and higher degree of purification.

The process can be better explained by the following diagram.

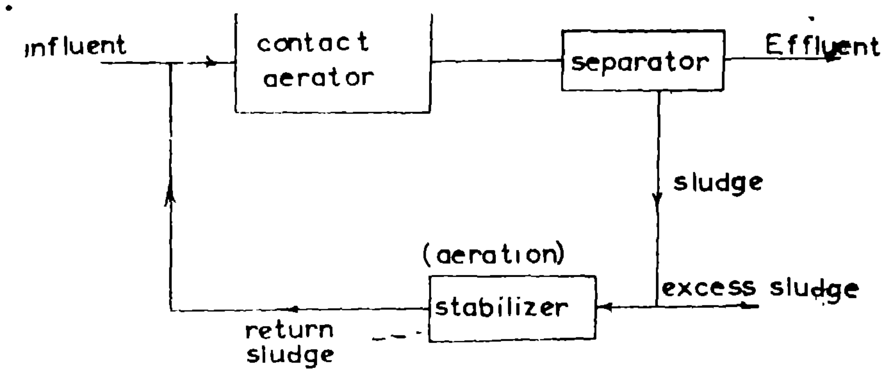


Figure 6. Biosorption or contact stabilization process. /1/

Aeration period in the contact tank is short, usually 15 - 30 minutes.

Contact stabilization can be achieved in step aeration activated sludge plants, if the air supply rates to the different sections of the tank can be achieved.

The process has an advantage because it has high BOD removal with stabilized sludge, primary sedimentation can be eliminated shock loads can be adsorbed and it is adaptable to rate of flow variations.

2.2.8 Kraus and Hatfield Process

This was developed to overcome nitrogen deficiencies in the treatment of high carbohydrate wastes which give rise to sludge with very poor settling characteristics.

The process flow patterns can be seen from the following figures 7 and 8.

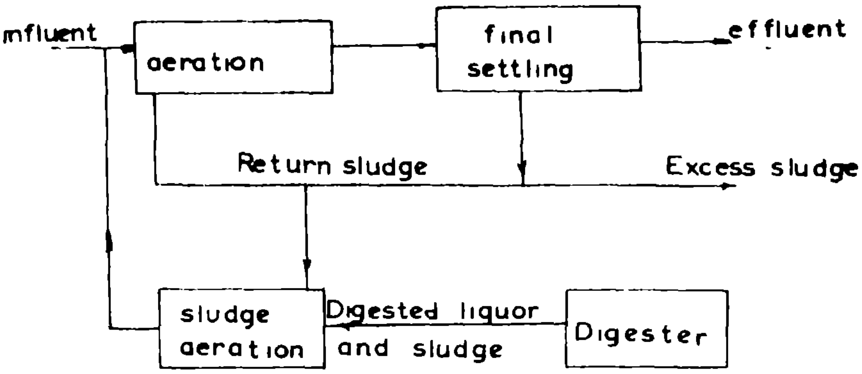


Figure 7. Kraus process. /1/

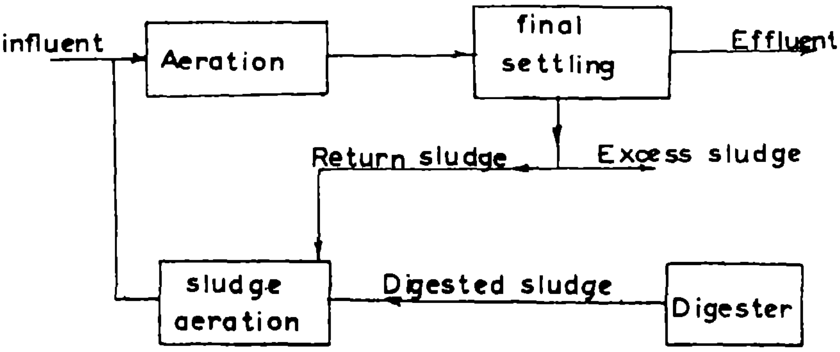


Figure 8. Hatfield process. /1/

The difference in the two processes lies on the amount of return sludge going to sludge aeration and the type coming from the digester. Actually in the Kraus process only a small portion goes to the sludge aeration.

2.2.9 Pure oxygen systems

In this process, completely mixed chambers are used in series and each chamber is covered. By increasing oxygen concentration from the normal 20 % to 80 % higher oxygen transfer rate is attainable than in air systems. This helps to maintain higher MLSS concentration which enables some degree of treatment in a much smaller aeration volume, reduced sludge accumulation, good SVI and efficient nitrification.

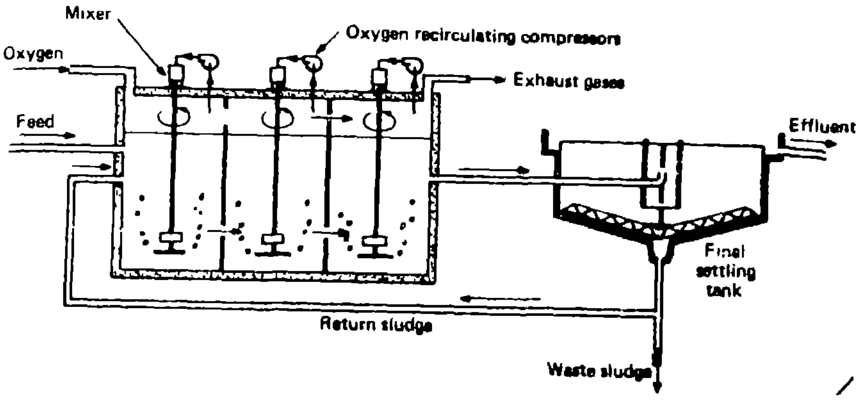


Figure 9. Typical arrangement of pure-oxygen activated-sludge process. /8/

2.2.10 Deep shaft process

This method was developed as a result of research into methods of improving oxygen transfer in diffused air systems. This can be achieved by an increase in oxygen partial pressure and by an increase in the total pressure applied to the system. In this process, a circular shaft is drilled to a depth of 60 - 150 meters, lined and fitted with a second liner concentric with the first but suspended clear of the floor of the outer shaft. The process can be better explained by the diagram in figure 10.

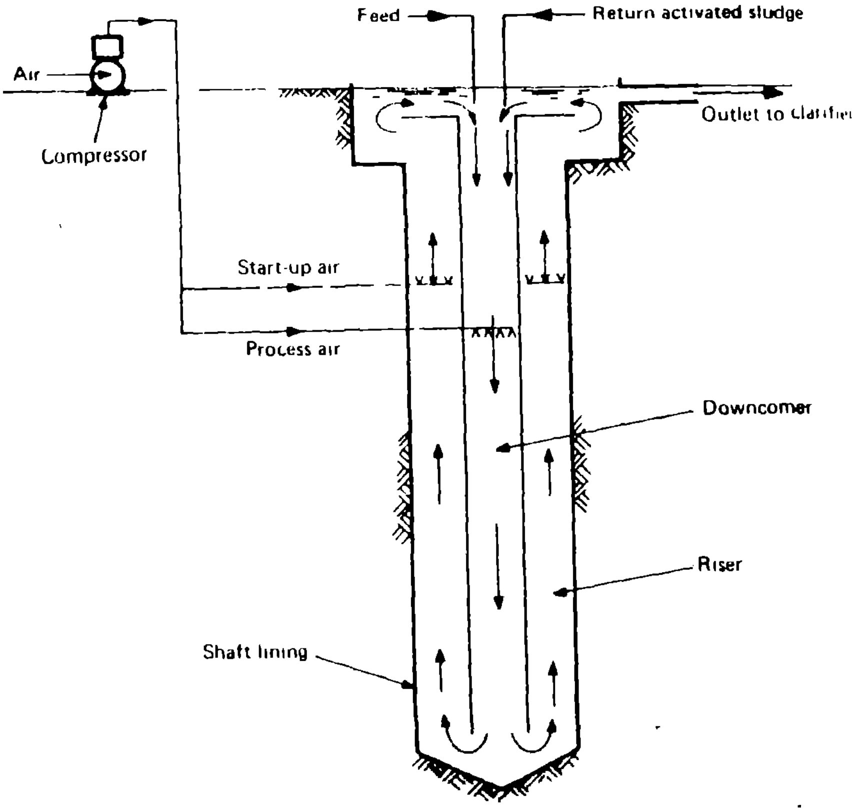


Figure 10. The deep shaft process. /8/

A second generation of the deep shaft systems is being used for new sewage treatment works. It was realized that the process could be adopted to treat industrial and domestic wastewaters. /10/

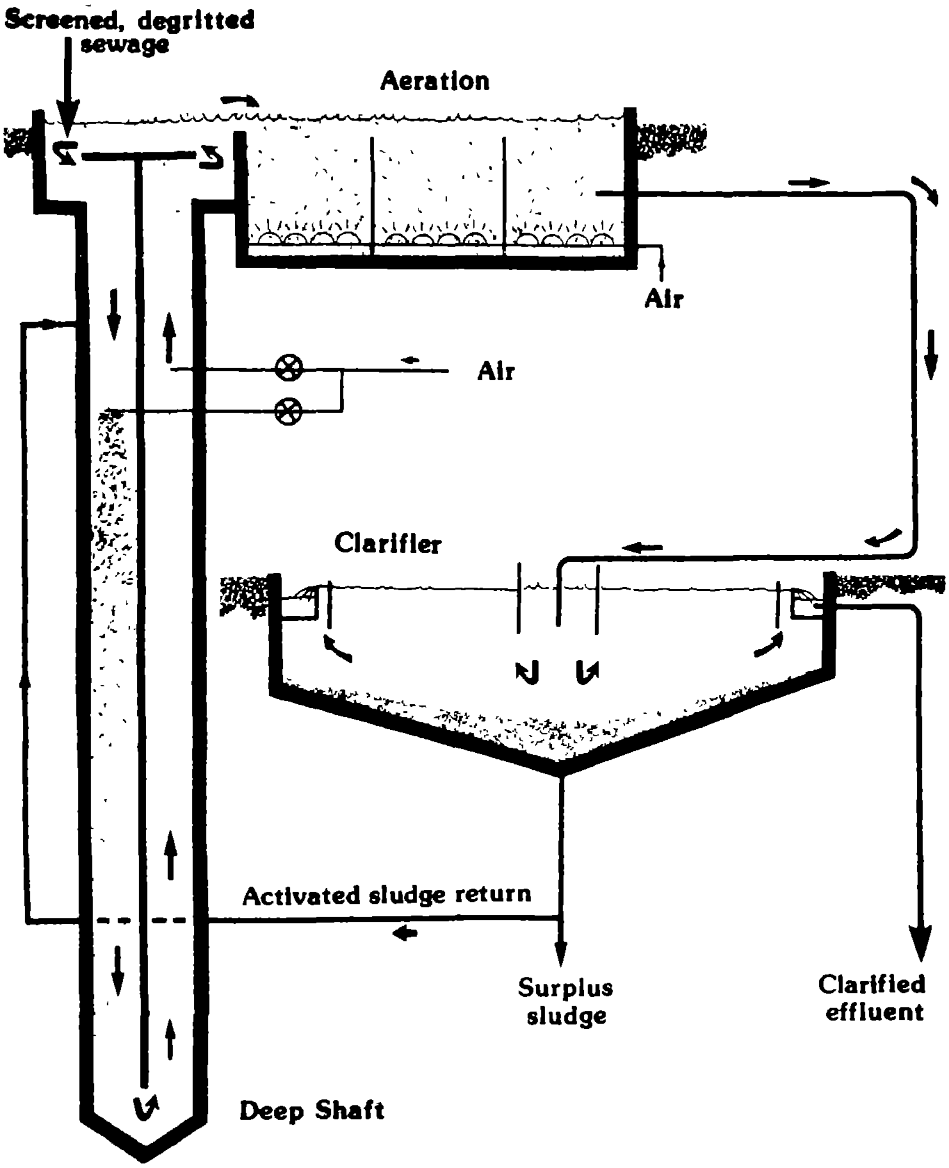


Figure 11. Deep Shaft II. /10/

Table 1. Typical design parameters for activated sludge processes. /8/

	Parameter					
Process modification	θ_c, *d*	*F* $\frac{kg\ BOD_5/d}{kg\ MLVSS}$	*Volumetric loading* $\frac{kg\ BOD_5}{m^3.d}$	*MLSS mg/L*	*Detention time* V/Q,*h*	*RAS rate R/Q*
Conventional	5-15	0.2-0.4	0.3-0.6	1500-3000	4-8	0.25-0.5
Complete mix	5-15	0.2-0.6	0.8-2.0	3000-6000	3-5	0.25-1.0
Step aeration	5-15	0.2-0.4	0.6-0.9	2000-3500	3-5	0.25-0.75
High rate	0.2-0.5	1.5-5.0	1.2-2.0	200-500	1.5-3	0.05-0.15
Contact stabilisation	5-15	0.2-0.6	0.9-1.2	Contact unit 1000-3000 Stabilisation unit 4000-10 000	0.5-1.0 3.6	0.25-1.0
Extended aeration	20-30	0.04-0.15	0.15-0.4	3000-6000	18-36	0.75-1.50
Oxidation ditch (intermittent)	30+	~0.03	0.12-0.18	4000-6000	~24	see text
Kraus process	5-15	0.3 -0.8	0.6 -1.6	2000-3000	4-8	0.5 -1.0
Pure oxygen systems	8-20	0.25-1.0	1.6 -4.0	6000-8000	1-3	0.25-0.5

3. PROCESS CAPABILITIES

The activated sludge system has a capacity of removing carbonaceous BOD, and of nitrification. The rate and extent of BOD removal depends on the relative quantities of soluble, colloidal and volatile suspended solids.

The system can be used for domestic commercial or trade (industrial) wastewater treatment or a combination, if designed properly. Actually it may be most appropriate method where land is expensive or unavailable and where good operational facilities may exist.

Poor effluent quality can be attributed to

a) inadequate detention time within the aeration system
b) inadequate mixing and sludge recirculation rate
c) lack of sufficient oxygen in the reaction basin
d) presence of toxic or inhibitory pollutents
e) lack of nutrients.

4. MAIN PROCESS KINETICS

4.1 Sludge load (F/M)

The various forms of the activated sludge process can be characterized numerically by the relationship between the rate of supply of organic material and the mass of micro-organisms which it is feeding. Neither of these factors can be readily measured but the daily BOD load can be used as an indication of the food supply and the total mass of mixed liquor volatile suspended solids can be used as a measure of the biomass.

The ratio is known as food to micro-organism ratio or sludge load. It can be expressed as:

$$F/M = \frac{(S_O - S)Q}{x_o v} \qquad \frac{\text{kg BOD}}{\text{kg MLVSS day}}$$

where S_O = influent BOD (kg/m^3)
S = effluent BOD (kg/m^3)
v = volume of aeration tank (m^3)
x_o = MLVSS concentration $(kg/m^3$ of aeration tank$)$
Q = mean wastewater flow rate (m^3/day)

4.2 Cell yield

Expressed as:

$$\frac{dx_O}{dt} = Y \frac{dSr}{dt}$$

where $Sr = \frac{S_O - S}{t}$

Y = growth yield coefficient

$\frac{\text{kg cells}}{\text{kg substrate}}$ usual value = 0.4 - 0.8

t = time

4.3 Microbial growth rate (μ)

$$\mu = \frac{dx_o/dt}{x} = \mu_{max} \frac{s}{k_s + s}$$

where x = total solids concentration (aerator + clarifier) (kg/m^3)

s = concentration of rate limiting substrate (kg/m^3)

k_s = concentration of rate limiting substrate at $\mu = \frac{\mu_{max}}{2}$ (kg/m^3)

4.4 Net solids production $(\frac{\Delta x}{\Delta t})$

$$\frac{\Delta x}{\Delta t} = Y \frac{S_o - S}{t} - Kd\ x$$

where Kd = cell decay coefficient (day)$^{-1}$
typical value = 0.04 - 0.1

others as described before.

4.5 Hydraulic detention and cell residence times

4.5.1 Hydraulic detention time (t) can be expressed as

$$t = \frac{V}{Q} \quad (h)$$

where Q = meanflow rate (m^3/h)

V = volume of reactor (m^3)

and it is the time which the wastewater stays from influent to effluent end.

4.5.2 Cell residence time

Also called sludge age or solids retention time, can be expressed as

$$\theta_c = \frac{\text{Weight of solids in the system}}{\cancel{\text{Weight of solids leaving the system/time}}}$$

$$= \frac{x}{(\bar{\Delta} x/\Delta t)}$$

where x = total biomass in the reactor

$\frac{\Delta x}{\Delta t}$ = total quantity of solids withdrawn.

At steady state $\frac{\Delta x}{\Delta t}$ = net solids production, and θ_c gives the mean cell residence time. Sludge age can be also calculated by

$$1/\theta_c = Y\,F/M - Kd\ MLSS$$

where Y = cell yield coefficient
F/M = sludge load
Kd = cell decay coefficient
MLSS = mixed liquor suspended solids

4.6 Cell "Washout" time

The time during which a cell remains in a treatment system (θ_c) must be greater than its doubling time or else the cell would be "washed out" of the system before it has had a chance to multiply and the process would fail. /3/

4.7 Sludge Volume Index (SVI)

It is defined as the volume occupied by one gram of dried solids. It is used to control rate of return sludge to the reactor basin. It also indicates the settling characteristics of the sludge, thereby impacting on return rates and MLSS.

4.8 Return sludge and excess sludge wasting

4.8.1 Return sludge

The amount of return sludge needed depends on the MLSS or MLVSS required in the aeration tank. In activated sludge treatment, upto 100 % of the inflow can be reached for the return sludge rate.

Actually there are two methods for calculating recycling (return) rate.

Method I

Based on SVI sludge recycle rate can be found from

$$R = \frac{Q \ MLSS}{\frac{10^6 - MLSS}{SVI}}$$

where R = sludge recycle rate (m^3/d)
Q = influent rate (m^3/d)
$MLSS$ = mixed liquor suspended solids concentration (mg/l)
SVI = sludge volume index (ml/g)

Method II

The return sludge can be found by

$$R = \frac{Q \ MLSS}{SS_{RAS} - MLSS}$$

where R = sludge recycle rate (m^3/day)
$MLSS$ = desired mixed liquor suspended solids concentration in aeration basin (mg/l)
SS_{RAS} = return sludge concentration (mg/l)
Q = influent rate (m^3/d)

Method one gives proper return rate while method two give an approximate result.

4.8.2 Sludge wasting

In order to maintain a steady state, daily increase of the sludge should be wasted. Wasting of sludge can be done:

- from the aeration tank
- from the pipe between the aeration tank and final settling tank
- from the recycle line.

4.9 Oxygen requirement and transfer

4.9.1 Requirement

The oxygen requirement of a particular micro-organism reflects the way by which it obtains energy. The supply of air must be adequate to

1. Satisfy the BOD of the waste
2. Satisfy endogenous respirtation by the sludge organisms
3. Provide adequate mixing
4. Maintain a minimum dissolved oxygen concentration throughout the aeration tank.

The oxygen demand for carbonaceous oxidation can be estimated from the expression

$$O_{2\,ww} = Y\ Lbr + Kd\ (MLSS)$$

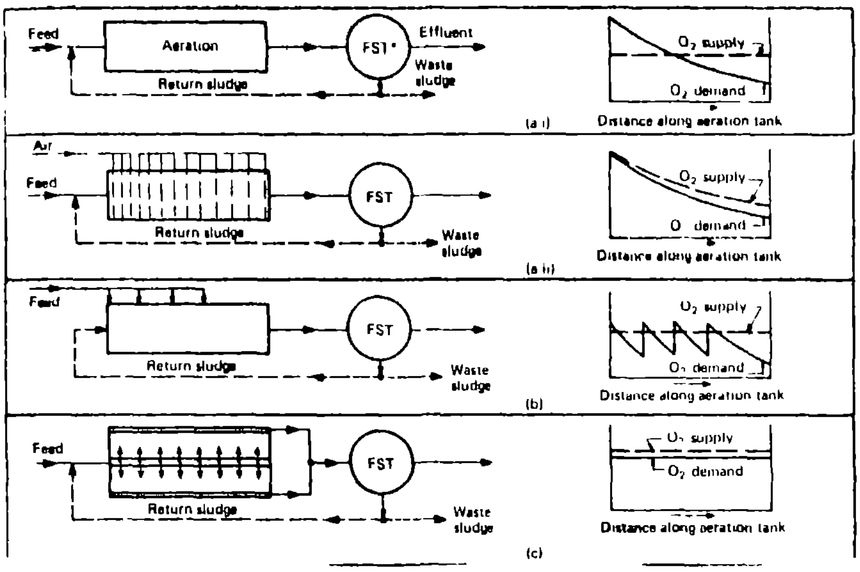
where Lbr = BOD removal each day $\left(\frac{kg}{m^3 d}\right)$

$O_{2\,ww}$ = oxygen demand (kg/d)

rest as before.

The oxygen demand for nitrification must be estimated separately. In general, 4.6 kg of oxygen is required for each kilogram of ammonia nitrogen oxidized.

Oxygen supply and demand curves for some activated sludge modifications are shown below.



FST = Final Settling Tank.

Figure 12.
a-i = conventional activated sludge process
a-ii = tapered aeration activated sludge process
b = step aeration activated sludge process
c = completely mixed activated sludge process./8/

4.9.2 Transfer

It is most common to express the oxygenation rate of a particular activated sludge aeration device either as standard oxygen rate (SOR) or actual oxygen rate, (AOR), both in kg of oxygen per hour. Thus

$$\text{SOR} = \frac{K_La_{20} \times V \times C_{SAS}}{1000} \qquad \frac{\text{kg } O_2}{\text{h}}$$

where K_{L20} = mass transfer coefficient

$$= \frac{dO/dt}{\alpha(\beta C_{SOA}-C)} \times 1.024^{20-T} \qquad \frac{1}{\text{h}}$$

dO/dt = oxygen uptake rate, mg/l·h

α = ratio of oxygen transfer rate coefficient for wastewater to that of clean water (0.8 - 0.94)

β = ratio of the dissolved oxygen saturation concentration for wastewater to that for clean water (0.9 - 0.97)

C_{SOA} = oxygen saturation value in oxygen enriched atmosphere at ambient temperature

C = dissolved oxygen concentration in wastewater, mg/l

v = aeration basin volume, m^3

C_{SAS} = oxygen saturation concentration in air at standard conditions, mg/l.

The actual oxygen transfer rate (AOR) is

$$AOR = \frac{dO}{dt} \times V \times \frac{24}{1000} + \frac{DO \times Q(1+R)}{1000} \quad kg/d$$

where DO = dissolved oxygen concentration of oxygenation basin effluent (mg/l)

Q = hydraulic flow (m^3/d)

R = sludge recycle rate as a fraction of Q.

The required oxygen supply rate is the actual oxygen transfer rate corected by oxygen utilization in the aeration basin

$$\text{ie. oxygen supply} = \frac{AOR}{\text{utilization efficiency}} \quad kg/d$$

5. WASTE WATER CHARACTERISTICS

5.1 General

Treatment of domestic sewage does not present the same problems as industrial effluents. Process waters can contain heavy polluting load composed of an increasingly complex mixture of chemicals whose behavior towards biological systems can be very varied.

The performance of aerobic biological treatment plants which are treating a mixture of domestic and industrial effluents can be put at risk by the presence of hazardous chemicals in the industrial fraction.

Activated sludge organisms are susceptible to biological effects as well as physical and chemical inhibition. Thus industrial wastes entering municipal wastewaters must be scrutinized carefully.

Heavy metals, such as copper, zinc, nickel, lead, cadmium and chromium can react with the microbial enzymes to retard or completely inhibit metabolism.

Non-metallic wastes, including organic compounds (cyanide, phenols), also can be toxic. These materials can be metabolized by bacteria if a sufficient acclimation period is provided.

In general wastewaters which are not compatible with the process include:

a) wastewaters harmful to process biology
b) wastewaters harmful to equipment
c) wastewaters presenting potential safety hazards
d) wastewaters containing materials not properly treated by the processes employed
e) wastewaters deficient with nutrients for aerobic process.

for Community Water Supply

Typical pollutant inhibitory to activated sludge process are shown in table 2 below.

Table 2. Threshold concentrations of pollutants inhibitory to the activated sludge process./5/

Pollutant	Concentration (mg/l)	
	Carbonaceous Removal	Nitrification
Aluminum	15 to 26	
Ammonia	480	
Arsenic	0.1	
Borate (Boron)	0.05 to 100	
Cadmium	10 to 100	
Calcium	2 500	
Chromium (hexavalent)	1 to 10	0.25
Chromium (trivalent)	50	
Copper	1 0	0 005 to 0.5
Cyanide	0 1 to 5	0.34
Iron	1 000	
Lead	0 1	0.5
Manganese	10	
Magnesium		50
Mercury	0 1 to 5 0	
Nickel	1.0 to 2.5	0.25
Silver	5	
Sulfate		500
Zinc	0 08 to 10	0.08 to 0.5
Phenols		
Phenol	200	4 to 10
Cresol		4 to 16
2-4 Dinitrophenol		150

These limits are not international agreed upon. Some researchers set other concentration values for some of these pollutants. The following table is an indication

Pollutant	Limiting concentration in aerobic biological processes by various workers (mg/l)
Chromium (as dichromate)	1 - 2; 10
Copper	1
Zinc	2; 5 - 10

Actually it is often possible to develop a microbial population which is acclimatized to quite high concentrations of some toxic materials.

For example, Edwards et al /7/ operated a work which recieved two extremely high shock doses of dichromate (1440 mg/l as Cr^{+6}) at pH < 4.0. The effluent became turbid and the ammonia content increased with a corresponding reduction in nitrate, but the activated sludge system subsequently recovered. Similarly Moore, et al, found that 50 mg/l Cr^{+6} reduced the BOD removal by only 3 %.

Parameters of special significance for characterizing wastewaters are /2/:

- the Biochemical Oxygen Demand (BOD)
  which defines the biodegradable organic content of the waste
- the Chemical Oxygen Demand (COD)
  which gives a measure of the total organic content, both degradable and refractory
- Suspended, Settleable and Volatile Solids
- Total Solids
- pH, alkalinity and acidity
- Nitrogen and Phosphorus
- heavy metals and inorganic salts.

5.2 Origin and characteristics of domestic wastewater

Domestic wastewater refers to liquid discharge from residences, business buildings and institutions. In contains organic and inorganic matter as suspended, colloidal and dissolved solids. It is also the primary source of nutrients such as nitrogen and phosphorous.

Concentration depends on original concentration in water supply, water usage and per capita water consumption. Thus the characteristics vary from city to city and even from season to season within a city.

Table 3. Domestic wastewater characteristics. /3/

Item	**Range of values contributed in wastes (g/capita/day)**
BOD_5	45-54
Chemical oxidation demand (dichromate)	1.6 to 1.9 x BOD_5
Total organic carbon	0.6 to 1.0 x BOD_5
Total solids	170-220
Suspended solids	70-145
Grit (inorganic, 0.2 mm and above)	5-15
Grease	10-30
Alkalinity, as $CaCO_3$	20-30
Chlorides	4-8
Nitrogen, total, as N	6-12
Organic nitrogen	~0.4 x total N
Free ammonia[a]	~0.6 x total N
Nitrite	—
Nitrate	~0.0 to 0.05 x total N
Phosphorus, total, as P	0.6-4.5
Organic phosphorus	~0.3 x total P
Inorganic (ortho- and polyphosphates)	~0.7 x total P
Potassium, as K_2O	2.0-6.0
Microorganisms present in wastewater	(Per 100 ml wastewater)
Total bacteria	10^9-10^{10}
Coliforms	10^8-10^9
Fecal *Streptococci*	10^5-10^6
Salmonella typhosa	10^1-10^4
Protozoan cysts	up to 10^3
Helminthic eggs	up to 10^3
Virus (plaque forming units)	10^2-10^4

Note: Values given in the table represent approximate daily per capita contributions. To these must be added the contents in the original water supply. Per capita daily water usage ranges from 80 to 300 liters in most sewered communities, although consumption in some U.S. and other communities is even higher than 500 liters The pH of wastewater generally ranges from 6.8 to 8.0, again depending on raw water quality.

[a] The major nitrogen compound in domestic waste is urea which is readily hydrolyzed to NH_3 and CO_2 by the enzyme urease present in sewage. Hence, NH_3 constitutes the major fraction of total nitrogen in domestic sewage.

5.3 Origin and characterictics of cotton textile waste waters

Textile mill operations consist of weaving, dyeing, printing and finishing. In particular, in cotton mills, raw cotton is carded, spun, spooled and warped, slashed (filled with starch), drawn, woven or knitted and finished.

Alternatively, after the raw cotton is converted to cloth it is de-sized, scoured to remove natural impurities, bleached to make them white, mercerized to give the fabric luster, strength and dye affinity, printed or dyed and finally sized again to make them more resistant to wear and smoother to touch.

Each of these processes involve many steps producing their respective wastes.

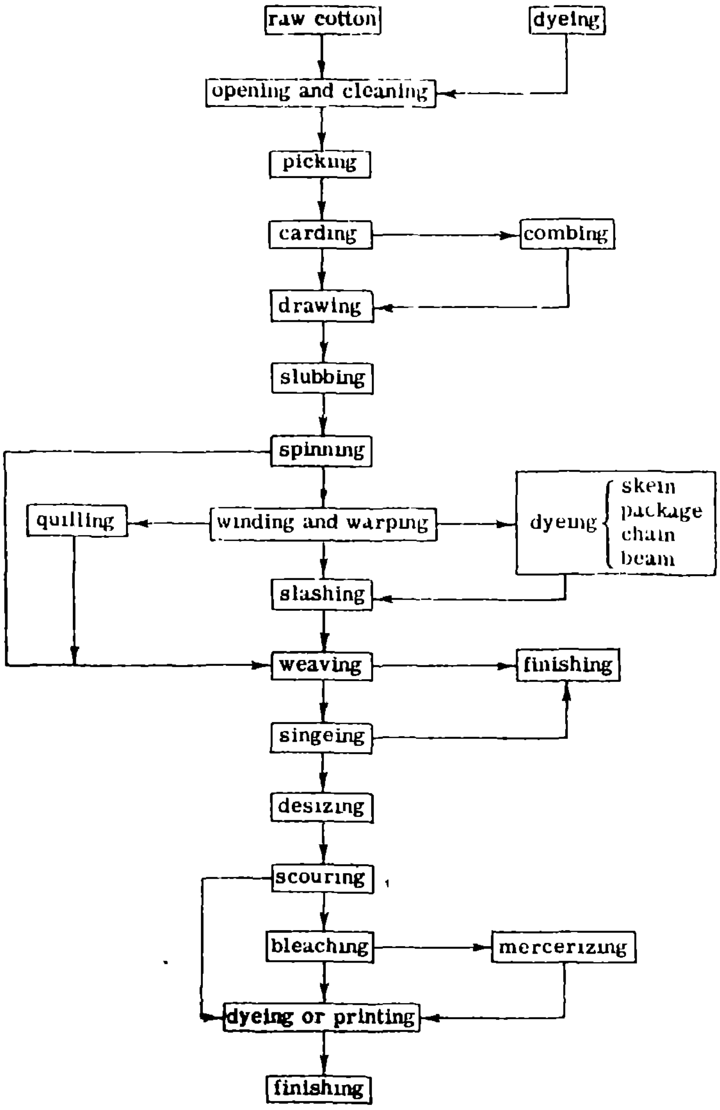


Figure 13.

Flow diagram: raw cotton to finished cloth. /12/

The sources of polluting compounds are the natural impurities extracted from the fibers and processing chemicals which are removed from the cloth and discharged as waste. The effluents may be either organic or inorganic, may contain valuable materials that are worth recovery, and they may be toxic to fish, vegetation or other biological organisms or inhibitory to the treatment processes used at sewage disposal works.

Many of the inorganic substances present in textile effluents influence COD, some increasing it, others depressing it. Some will affect BOD, suspended solids content and pH.

Some organic compounds will be difficult to destroy by biological oxidation process, others easy. Those that are difficult to destroy generally have a low BOD and are said to be biologically hard; those that are readily oxidized are termed soft and usually have a high BOD. /19/ But, most of the organic compounds used in or extracted during, textile processing are biodegradable to some degree. The process used for the purification of domestic sewage can, in the absence of toxic materials, be used for the treatment of textile effluents.

Still, some textile effluents may be deficient in nitrogen and phosphorous, and it is necessary to add nutrient material, usually ammonium sulphate, to restore the balance. This is why it is usually preferable to treat these effluents in admixture with domestic sewage, which will supply the required nitrogen and phosphorous.

Textile wastewaters are usually colored, highly alkaline, high in BOD and suspended solids and high in temperature.

The following flowchart and tables show the cotton textile process and finishing flow chart /18/ and typical characteristics of textile wastes. /19/

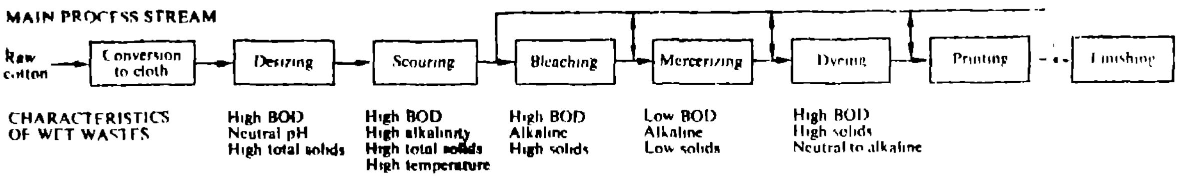


Figure 14. Flow diagram for a cotton textile process. /18/

Table 4. Pollutional loads contributed by the various textile processes (after Masselli and Burford). /18/

Department	**Process**	kg BOD/1000 kg cloth*	% of total
Desizing		53	35
Scouring	Either pressure kier, first scour	53	16
	pressure kier, second scour	8	1
	Or continuous scour	42	15
	Average	47	
	Subtotal (scouring)		32
Dyeing		0.5–32	15–30
Printing	Color-shop wastes	12	7
	Wash after printing, with soap	17–30	17–30
	Wash after printing, with detergent	7	7
	Subtotal (printing)		15–35
Bleaching	Hypochlorite bleach	8	3
	Peroxide bleach	3	1
Mercerizing		6	1
Total		125–250	

* Approximately 800 to 1000 kg of impurities are discharged in the waste per 1000 kg of cotton processed.

Table 5. Textile wastes - Typical characteristics. /9/

Source	Total water usage (l/kg)	pH	Total solids (mg/l)	Suspended solids (mg/l)	COD (mg/l)	BOD_5 (mg/l)
Cotton, woven fabrics	60–500	8–12	500–2000	50–250	200–100	100–500
Cotton/man-made woven fabrics	60–500	6–9	200–2000	50–200	100–1000	50–500
Man-made, knitted fabrics	50–600	4–8	100–1000	20–100	100–1000	50–250
Wool, woven fabrics	80–500	7–10	1000–5000	50–500	200–2000	100–1000

5.4 Origin and characteristics of tannery wastewaters

Tanning is the act of converting animal skins into leather. The dry matter of the skin is almost entirely protien of which 85 % is collagen. /18/ Tanning is done by means of chrome or vegetable tanning. The earlier is used for light leather and the latter for heavy leather products which are fuller, plumper and less affected by changes in humidity. The preliminary processes prepare the hide protein so that all undesirable impurities are removed, leaving the collagen in a receptive condition to absorb the tannin or chromium used in tanning.

Curing involves dehydration of the hide by drying it with salt or air inorder to stop proteolytic enzyme degradation. Fleshing removes the fatty tissues from the skin by mechanical means. Washing and soaking remove the dirt, salts, blood, manure and nonfibrous proteins and restore the moisture lost during preservation and storage. Unhairing is accomplished by the use of lime, with or without sodium sulphide; this makes the skins more attractive and more amenable to the removal of trace protein impurities. Lime splitting separates the skin into two layers; one is the more valuable grain layer; the other, the lower or flesh side, is called the "split". Bating prepares the hide for tanning by reducing the pH, reducing the swelling, peptizing the fibers, and removing the protein-degradation products. Bating is generally accomplished with ammonium salts and a mixture of commercially prepared enzymes. The bating bath renders the grain silky, slippery, smoother, and more porous, increases its width and diminishes its wrinkles. Pickling generally precede chrome tanning and involves treatment of the skin with salt and acid to prevent precipitation of the chromium salts on the skin fibers. Degreasing removes natural grease, thus preventing formation of metallic soaps and allowing the skin to be more evenly penetrated by tanning liquors. Briefly the following flow chart shows the processes.

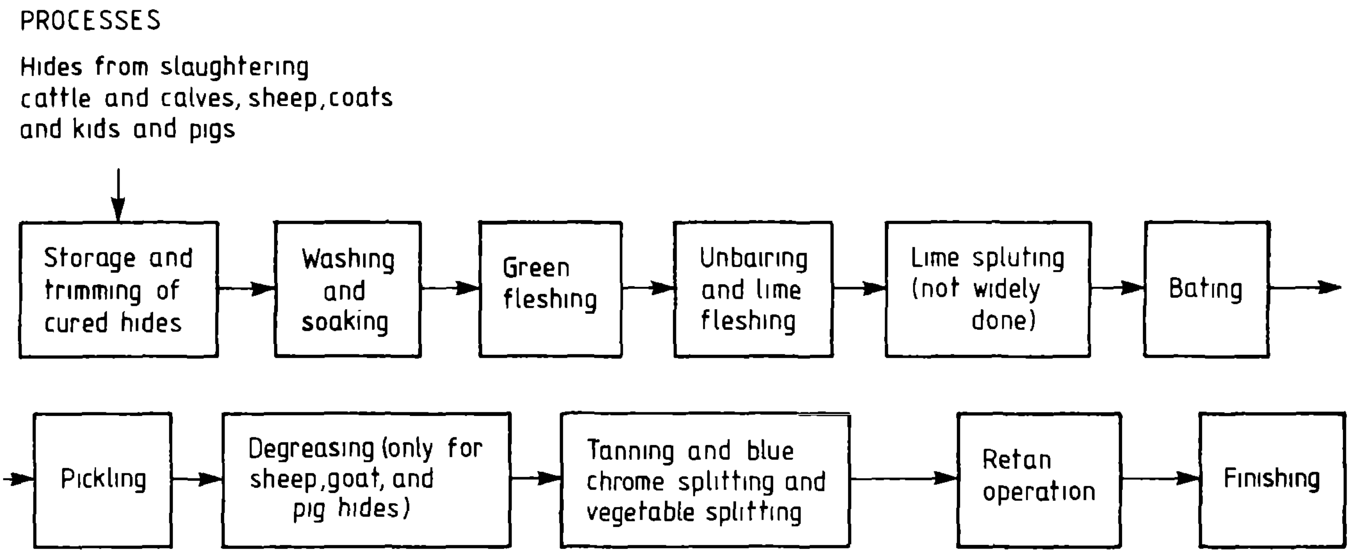


Fig 15. Flow diagram for a tannery process. /18/

As the raw material of the tanning industry is a natural product, its soluble impurities are generally readily biodegradable and represent a large part of the BOD load in the effluent. The process chemicals employed are a variety of inorganic and organic materials, affecting total solids, pH and COD. Of particular importance are the appreciable quantities of sulphide and of chromium (III) which may be present /9/ . Chromium averages to 30 - 70 mg/l /18/. Typical values of certain parameters are given on the next page.

Table 6. Tannery wastes - typical characteristics /9/.

Source	pH	Total solids mg/l	Suspended solids mg/l	BOD_5 mg/l	Sulphide (as S) mg/l
Pre-tanning	10-12	5000-20000	200-2000	1000-5000	500-2000
Vegetable tanning	3-5	5000-20000	200-1000	500-5000	-
Chrome tanning	3-6	2000-10000	50-5000	250-2000	-
Mixed: vegetable tannery	8-12	5000-20000	100-1000	500-5000	200-1000
Mixed: chrome tannery	7-11	2000-10000	50-500	250-2500	100-500

Wide fluctuation in the nature of tannery wastes, due to intermittent dump discharges, make these wastes difficult to treat, especially in combination with municipal sewage /18/.

The following tables show characteristics of tannery effluent from different raw materials.

Table 7. Cattleskin tannery survey (average composition of strong liquors) /12/

Process	l/day	Biochemical oxygen demand			Sodium chlor. mg/l	Total hardn. mg/l	Protein mg/l	Total solids mg/l	Volatile solids mg/l
		mg/l	kg/day	kg/ 1000 kg of hide					
Soak	276 683	2 200	607,8	15[a]	20 000	670	1 900	30 000	3 600
Unhair	102 952	15 500	1 596,7	40[a]	18 000	25 000	22 700	78 000	18 000
Relime	102 952	650	68	2[a]	3 500	25 000	-	20 300	2 500
Delime and bate	66 616	6 000	399,2	10[b]	<10	4 100	4 300	15 000	8 800
Pickle	37 093	2 900	108,9	3[b]	47 000	2 400	-	79 000	7 200
Chrome tan	32 172	6 500[c]	208,6	8[b]	26 000	1 800	-	93 000	13 000
Color and fat liq.									
First dump	19 303	2 000	38,6	3[d]	-	-	-	16 000	8 000
Second dump	19 303	2 200	43,1	3[d]	250	2 600	-	9 500	4 900
Total	657 076	-	3 070,9	-	-	-	-	-	-

Taken from Masselli et al with slight modifications.

[a] Based on wet salted hide.

[b] Based on fleshed split hide after relime.

[c] Estimated at 50 % of volatile solids concentration.

Table 8. Pigskin tannery survey (average composition of strong liquors) /12/

Process	l/d	mg/l	kg/d	kg/ 1000 kg of hide	Sodium chlor. mg/l	Total hardn. mg/l	Protein mg/l	Total solids mg/l	Volatile solids mg/l
Soak	11 355	2 400	27,2	17[a]	35 000	-	-	28 000	2 300
Unhair	15 140	14 000	211,8	70[b]	5 700	38 000	18 400	55 000	12 900
Delime and bate	15 140	4 400	66,7	23[b]	640	4 200	1 600	14 000	7 400
Pickle	2 649	4 200	11,3	9[b]	80 000	-	-	98 000	12 000
Degrease									
Kerosene layer	1 287	-	548,9	435+[d]	-	-	-	-	-
Brine layer	3 028	2 600	7,7	7	100 000	-	-	110 000	2 300
Vegetable tan	114	24 000	2,7	2[d]	-	-	-	93 000	25 000
Chrome tan	2 271	2 300[e]	5,4	5[d]	51 000	-	-	80 000	4 600
Color and fat liq.									
First dump	3 785	490	1,8	1[f]	410	-	-	3 950	890
Second dump	3 785	3 950	15	8[f]	135	-	-	3 980	3 030
Total	58 554	-	350	-	-	-	-	-	-

Taken from Masselli et al with slight modifications.

[a] Based on wet salted hide.

[b] Based on fleshed hide after soaking (30 % flesh removed)

[c] Calculated from kerosene (53 % BOD) only. Not included in total.

[d] Based on pickled hide.

[e] Estimated at 50 % of volatile solids concentration.

[f] Based on leather.

Table 9. Effluent from a sole leather tannery /12/

Waste	BOD			Sulfides			Dissolved solids			Total organic N			Sulfates		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
Slush wheel	2375	530	1272	50 0	17 8	34.5	12,608	4,560	8 295	74 2	44 8	60 6	269	230	248
16-hr Soak	400	125	332	16 3	13 4	14 6	16,109	2.707	9.912	34 5	26 6	30 1	250	230	238
6-hr Soak	400	110	243	12.4	2 4	8 7	7,455	2,080	3,837	53 2	40 6	44 3	257	222	240
Lime	3975	2225	3201	121 4	84 1	97.1	25,026	14,820	20,618	218 4	163 8	188 7	308	273	292
Wash wheel	700	335	475	–	–	–	1 333	1,021	1,186	92 4	65 8	78 4	240	222	230
Bate	185	130	151	–	–	–	1,212	1,150	1,174	226 9	196 0	210 0	230	212	222

All units in milligrams per liter.
Taken from Maskey (3).

6. COMBINED TREATMENT

6.1 General

Combined municipal and industrial waste treatment is the most desirable arrangement. It is often possible and advisable for an industry to discharge its waste directly to a municipal treatment plant, where a certain portion of the pollution can be removed.

A municipal sewage treatment plant, if designed and operated properly can handle almost any type and quantity of industrial waste. /18/

In many industrialized countries, more than 30 % of their municipal wastewater may consist of industrial wastes without any undue effect on their treatability./3/

Industrial wastes which may sometimes be more difficult to treat by themselves may, infact, become more treatable when mixed with domestic sewage. For example, because of lack of nitrogen in the system, there may be difficulty with wastes that are treated on their own at a textile works, but when treated with domestic sewage there is ample nitrogen for both. /16/

The presence of high amounts of toxic substances may render the mixed wastes less treatable and cause other problems as well. The desirability of admitting industrial wastes into public sewers with or without pretreatment must, therefore be considered carefully. Some industrial wastes may damage sewers and make their maintenance more difficult. The difficulties can be overcome by the enforcement of proper standards for the discharge of industrial waste to public sewers.

The other difficulty is human compatibility and understanding. The co-operation of industry and municipalities in the joint construction and operation of a municipal wastewater plant must be seriously considered.

At small sewerage works, trade effluent from just one factory may constitute a substantial increase in the flow and load to the works. It may not be possible to accept such an effluent without incurring heavy expenditure on sewerage and extensions at the treatment works./20/

Generally industrial wastewaters may be:

- non harmful at all to treatment, sewerage, sludge utilization etc.
- harmful to the treatment process
- harmful to the sewerage system
- harmful to sludge utilization
- useful to treatment processes

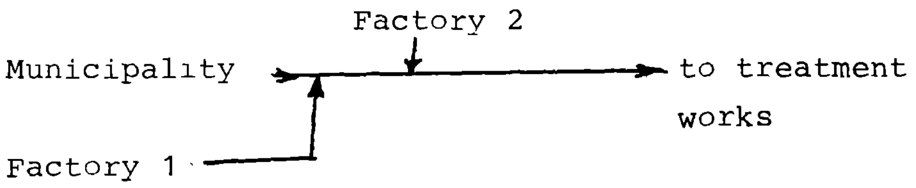
or a combination of some of the above when combined with domestic sewerage.

Depending on the conditions there are different technological solutions to the problem. These are:

a) joint treatment of raw industrial waste and domestic sewage
b) joint treatment of partially treated industrial waste and domestic sewage
c) discharge of completely treated waste to municipal sewer system.

The following three could be indicative on different alternatives for joint treatment

A.



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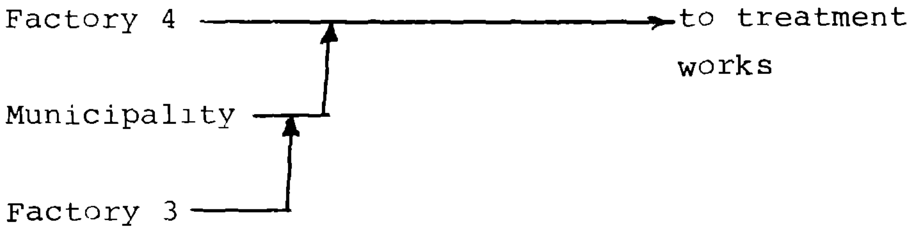
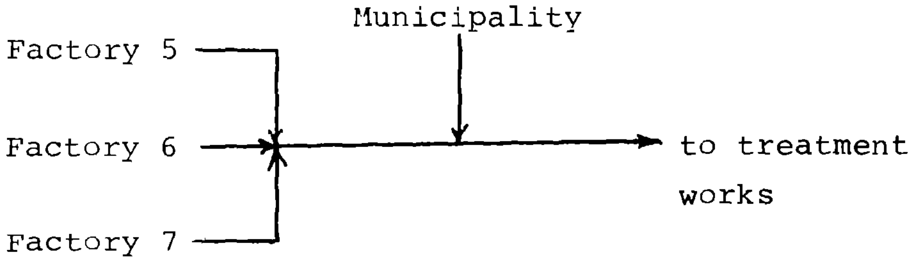


C.



6.2 Advantages of combined treatment

Some advantages of combined treatment are:

- construction cost is less to build one bigger treatment plant than two having the same overall capacity
- less operating cost (less rate per unit volume)
- less and better trained operators can be assigned
- operator has specific duty and responsibility
- land can easily be obtained by municipalities

- one wastewater can supply or get nutrients from others and both acidic and alkaline wastes from different sources can neutralize each other when combined
- reliable and uniform effluent quality for recieving water bodies (easier to control one treatment plant)
- municipality will have full control of rivers' resources and permit it to use the capacity of the river to the best advantage for the public at large
- besides providing nutrients, dilution with domestic sewage may also reduce any inhibitory effects the effluent might posses, possibly allowing the use of biological systems when alternative methods might otherwise be required. /20/

6.3 Objectives of trade effluent control

The most important objective of controlling industrial effluent is not mainly the recovery of costs via the charging system, but prevention of problems occuring in the sewerage system and with any of the treatment processes employed.

Generally the following could be guidelines as objectives /20/

I to protect the sewerage system, the sewerage treatment works and the personnel employed there in,

II to ensure that the mixed sewage can be effectively and economically treated by the processes employed at the sewage treatment works,

III to ensure that the products of that treatment, in the form of effluents or residues, have no unacceptable effects on water resources and the environment,

IV to insure that if, in times of storm, storm sewage reaches a river via a stormoverflow, its quality will be acceptable under those conditions, V to provide data upon which the design of future sewage treatment works can be based,

VI to ensure that the trader pays a fair charge for the reception, conveyance, treatment and disposal of his effluent.

6.4 Legal and managerial considerations

In order to come to an agreement for joint treatment various factors should be considered by both parties. Some of these are

- legal aspects depending on local regulations and laws
- economical aspects as described in section 6.5
- technological aspects as described in section 6.1.

The following conditions may be attached to consents to discharge

1) the sewer or sewers into which the discharge is to be made
2) composition of the trade effluent
3) maximum quantity of trade effluent which may be discharged on any one day
4) the highest hourly rate of discharge
5) period or periods of the day during which discharge may be made
6) elimination or reduction in concentration of any specified constituent
7) temperature of trade effluent at the time of discharge to the sewer
8) the payment of charges for reception and treatment of the effluent
9) provision and maintenance of an inspection chamber to enable samples to be taken
10) provision of maintenance of meters for measuring the volume and rate of discharge

11) provision and maintenance of apparatus for analyzing the effluent
12) keeping of certain records of meter readings etc.
13) the making of returns and giving of information to the authority concerning the volume, rate of discharge etc.

It would be advantageous to standardize quality conditions. However, it is the local conditions which dictate the permissible levels of certain constituents.

Amongst other things, consideration will be given to the following in setting quality conditions:

a) the dilution available in the sewerage system
b) the atmosphere in the sewers
c) the sewer material
d) type of treatment available
e) fate of various constituents at the treatment works
f) any tonic or inhibitory effect of the constituent
g) any build up of tonic materials in sludges, especially where those sludges are disposed of an agricultural land
h) any harmful effect caused by residues which pass to the receiving water course.

6.5 Industrial effluent charges

The question of what is a fair charge for handling industrial wastes in a municipal system is susceptible to much argument and discussion. What is right and fair for one city may be entirely unjust in another, not only for the industrial-plant owner but also for tax payers of the city. Such a vast number of factors enter into the determination of a charge for handling wastes that every municipality must accept the responsibility for working out its own formula. Thus no general rule or formula can be logically applied.

But one widely used formula is the Mogden-type formula which is expressed as /20/

$$\text{Charge per unit volume} = R + V + \frac{Ot}{Os}B + \frac{St}{Ss}S$$

where

R = one third of the amount determined by the Authority as the average cost to the Authority for the year of charge of receiving into its sewers (other than those used solely for surface water) and conveying 1 m^3 of sewage to the Authority's sewage treatment works

V = the amount determined by the Authority as the average cost for the year of charge of primary treatment and other volumetric treatment costs in the treatment of 1 m^3 of sewage at the Authority's sewage treatment works

Ot = the Chemical Oxygen Demand (COD) of the trade effluent in milligrams per litre after 1 h quiescent settlement

Os = the estimated average Chemical Oxygen Demand (COD) of settled sewage in milligrams per litre at the Authority's works as determined by the Authority for the purposes of the year of charge

B = the amount determined by the Authority as the average cost to the Authority for the year of charge of biological treatment of 1 m^3 of sewage at the Authority's sewage treatment works

St = the total Suspended Solids in the trade effluent in milligrams per litre at the pH of the trade effluent if within Consent conditions or otherwise at the minimum pH of the Consent conditions

Ss = the estimated average amount of Suspended Solids in milligrams per litre, determined on a shaken sample, in sewage received for treatment at the Authority's works as determined by the Authority for the purposes of the year of charge, and

S = the amount determined by the Authority as the average cost to the Authority for the year of charge, of primary sludge treatment and disposal of 1 m^3 of sewage at the Authority's sewage treatment works.

Some municipalities use the formula /20/

$$C = \frac{O_t - Os}{Os} + \frac{S_t - Ss}{Ss} S$$

where

C = total rate of charge per cubic meter and others as described before.

7. MATERIALS AND METHODS

7.1 Apparatus

The laboratory scale countinuous flow through reactor utilized in these studies can be seen in figure 16. The cell was constructed out of polyacril glass and is a modification which is assumed as capable of providing data for direct scale up. It consists of an aeration chamber and a sedimentation chamber separated by a baffle with a combined capacity of 9,5 l and 7,4 litres without the clarifier.

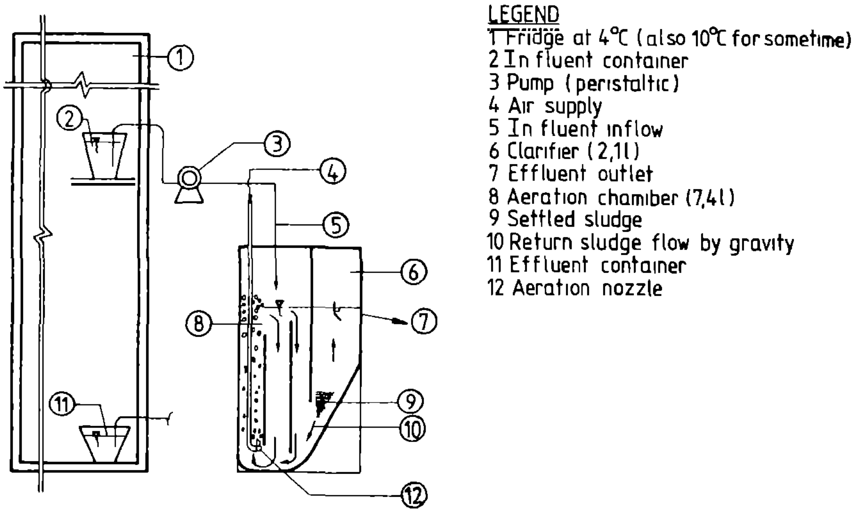


Fig 16. Activated sludge model used for the experiment.

7.2 Waste water collection and characteristics

7.2.1 Domestic waste water

Domestic waste water was collected from a manhole of a sewer collecting domestic waste water of Hervanta area. It was collected twice a week and kept in a refrigerator at 4 °C during use. It is roughly filtered when it is being collected. Characteristics of the waste water are shown in table 9.

7.2.2 Textile waste water

The waste water was collected from Lapinniemi cotton textile mill in Tampere once a week every Thursday. The production process is shown in figure 17. It is then stored in a refrigerator at 4°C while in use.

Characteristics of the waste water are shown in table 9.

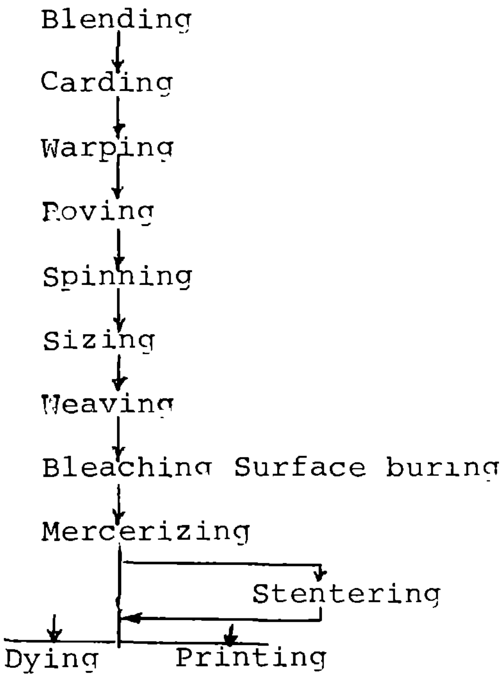


Fig 17. Lapinniemi production process.

The factory uses cotton and viscose rayon as raw material. It consumes 25000 m^3 of water per month working five days a week in two and three shifts. The raw water for the industrial use is pumped directly from a nearby lake without treatment, except water for social services which is taken from the city's water supply.

The waste water used to be discharged directly to a nearby lake, but it was joined to the city sewerage system 10 years ago. No pretreatment is made, except neutralization, before it joins the city sewer system.

7.2.3 Tannery waste water

Waste water was collected from Pirkanmaan Nahka Oy once a week every Thursday. The manufacturing process is roughly shown in figure 18. The waste water is stored at 4 °C during usage.

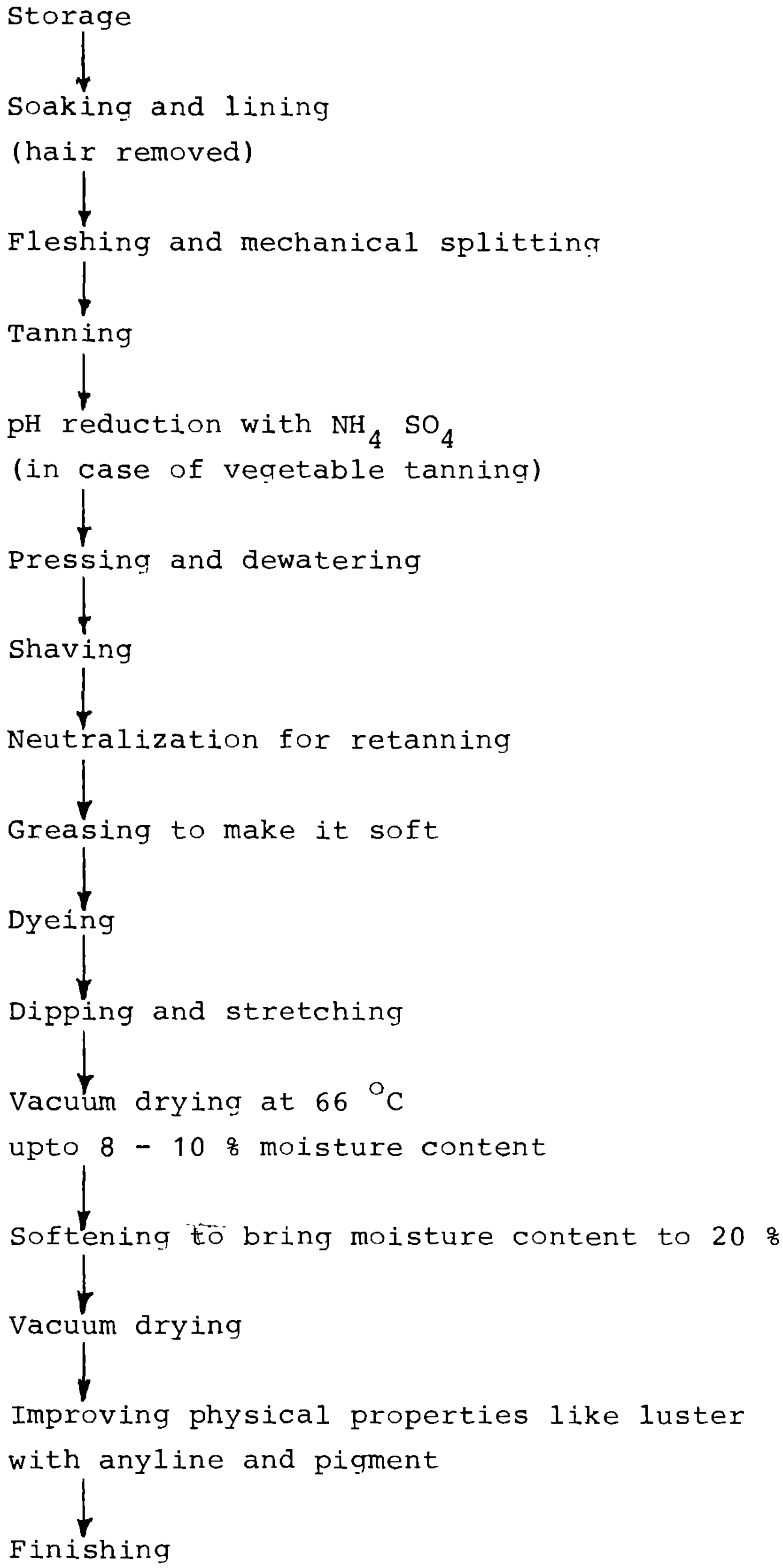
Typical characteristics of the waste water are shown in table 9.

Pirkanmaan Nahka Oy uses cow skin as raw hide, mainly from UK and Australia, at the rate of 25 tons per week.

Depending on the fashion, vegetable and chrome tanning are used in the proportions indicated below.

Chrome tanning	Vegetable tanning
90 %	10 %
40 %	60 %

The products are mainly used for shoes, belts and bags.



Storage

Soaking and lining
(hair removed)

Fleshing and mechanical splitting

Tanning

pH reduction with NH_4 SO_4
(in case of vegetable tanning)

Pressing and dewatering

Shaving

Neutralization for retanning

Greasing to make it soft

Dyeing

Dipping and stretching

Vacuum drying at 66 °C
upto 8 - 10 % moisture content

Softening to bring moisture content to 20 %

Vacuum drying

Improving physical properties like luster
with anyline and pigment

Finishing

Fig 18. Pirkanmaan Nahka Oy production process.

Table 9. Waste water characteristics.

Type of waste water	pH	SS mg/l	VSS mg/l	BOD_7 mg/l	COD_T mg/l	NH_4-N mg/l	Cr_T mg/l	P	Alkalinity m mol/l
Domestic	7... 8,5	70... 200	40... 150	200... 400	400... 650	35... 70		9... 15	3... 5
Textile	9... 12	0... 60	0... 40	150... 900	500... 1600	1... 7		1... 10	1... 30
Tannery	8... 11	400... 2000	300... 1100	1700... 3500	3000... 6600	120... 380	20... 140	1,5... 30	6... 30

7.3 Start-up

The experiment was started on 22nd September 1983 with one unit. The bio-sludge used was brought from Sahalahti waste water treatment plant treating, mainly, food industry waste water. The sludge was collected after the bio-filters before chemical addition. It had a suspended solids concentration of about 11500 mg/l and a volatile suspended solids concentration of about 10200 mg/l. It was diluted with distilled water to a concentration of 3000 mg/l suspended solids and 2500 mg/l volatile suspended solids respectively.

In order to get a rough idea of the loading to begin with, BOD_7 analyses was made for seven consecutive days for the domestic waste water before starting the experiment. This gave an average value of 350 mg/l. Thus the flow was adjusted to give a sludge load of about 0,2 $\frac{\text{kg}}{\text{kg MLVSS day}}$ at the start.

The second unit was started parallel to the first one with only domestic waste water feed for the first seven days. Then it was fed with a waste water combined from domestic and textile waste waters. This was done till 25.11.1983 and 29.11.1983 for reactor 1 and 2 respectively after which feeding tannery waste water started to both reactors.

Table 10 gives a summary of the programme of the experiment.

Table 10. Programme of the experiment.

Date		Reactor	Type of waste water	Respective proportions
from	to			%
22.9.83	25.11.83	1	Domestic	100
25.11.83	9.12.83		Tannery + domestic	10 : 90
9.12.83	30.12.83		Tannery + domestic	20 : 80
30.12.83	20.1.84		Tannery + domestic	30 : 70
29.9.83	7.10.83	2	Domestic	100
7.10.83	14.10.83		Textile + domestic	10 : 90
14.10.83	4.11.83		Textile + domestic	20 : 80
4.11.83	29.11.83		Textile + domestic	30 : 70
29.11.83	9.12.83		Tannery + textile + domestic	10 : 30 : 60
9.12.83	30.12.83		Tannery + textile + domestic	20 : 30 : 50
30.12.83	20.1.84		Tannery + textile + domestic	30 : 30 : 40
23.1.84	26.1.84		Oxygen uptake test was made.	

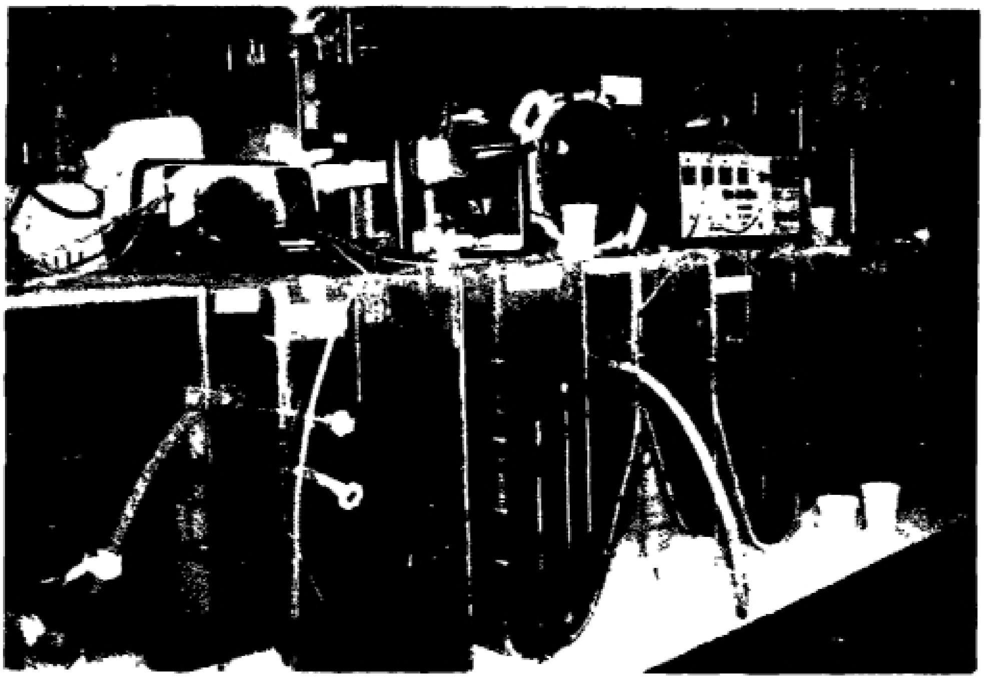


Fig 19. Arrangement in the laboratory.

7.4 Waste water feed and sludge recycle

Waste water during the whole experiment was fed from containers which were kept in a refrigerator at 4 °C, except for a month which was 10 °C for other reasons. From the container waste water was pumped with a desaga pump through silcon tubes. The pump could be adjusted to give different flow rates for a desired sludge loading.

Sludge recycle from the clarifier to the aeration unit was made by means of gravity and suction force due to flowing fluid.

7.5 Oxygen supply and mixing

Oxygen supply and mixing was made with bubble aerators. The aerators supply oxygen through silicon tubes attached to a nozzle made of polyacril glass having nine 1 mm tubes per nozzle.

During the experiment one aerator per unit was used until 30.12.1983 from which one aerator per unit was added for each reactor until the end of the experiment. This was made because of the drop in dissolved oxygen starting from 12.12.1983.

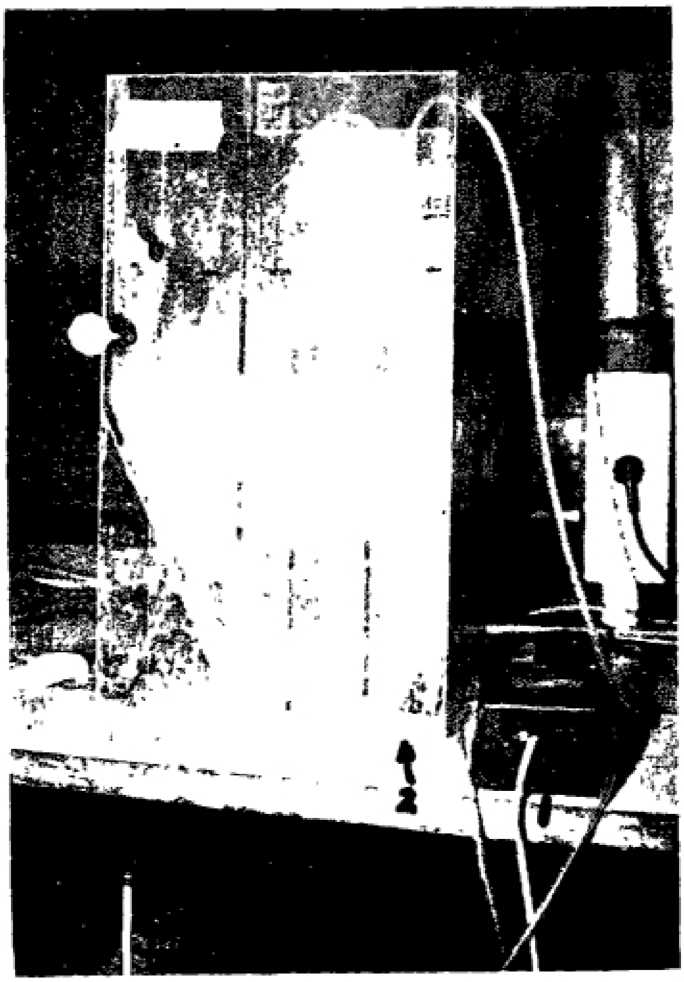


Fig 20. a) 1 bubble aerator used
2 nozzle placed in the reactor

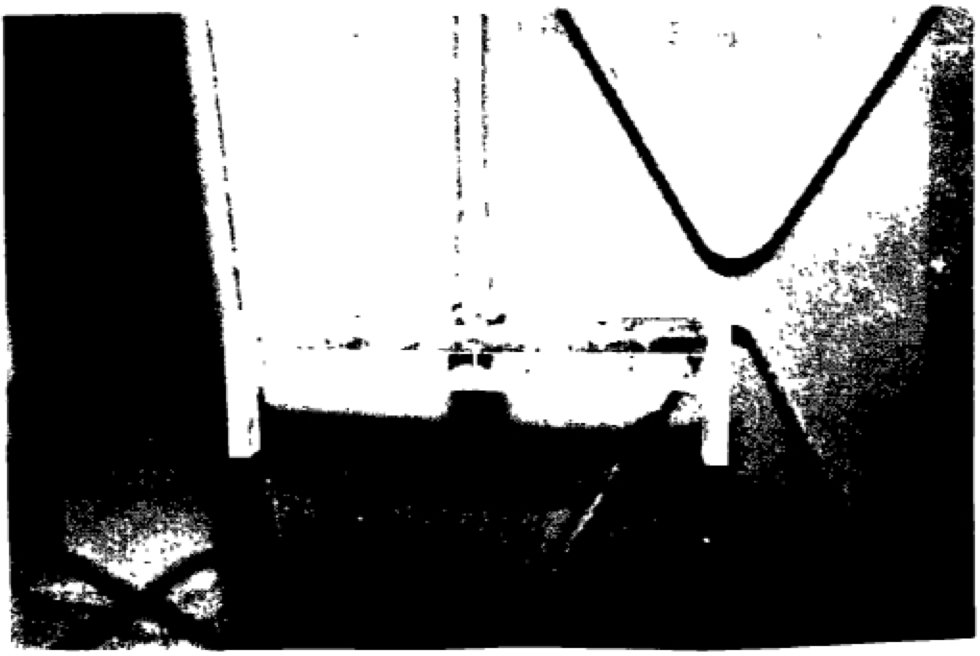


Fig 20. b) Nozzle

8. REACTOR CONTROL AND ANALYSES

8.1 Reactor control

A good control strategy is vital to the successful operation of an activated sludge process. Several methods have been proposed and used to control the activated sludge process. Three control methods currently in use are

- constant mixed liquor suspended solids level
- constant sludge load
- constant sludge age.

In this experimental study it was tried to control the process by keeping the sludge load within limits. Besides control was made on pH, temperature and dissolved oxygen.

8.1.1 Sludge loading

This is the main control parameter used during the experiment. There are three factors used to control this parameter.

a) MLSS or MLVSS concentration
b) Influent flow rate
c) Influent substrate concentration

In this experiment flow and MLVSS concentration were used for a check as in real practice an operator cannot usually have control on the incoming substrate concentration.

Depending on the influent COD result a rough estimate of the BOD_7 was everytime assumed. This was because there was not any correlation made between COD and BOD as the time allocated for the research was short to allow prior study of the waste water characteristics. As a result using the assumed BOD_7 the flow and MLVSS concentration were varied in order to fit the required range of sludge load.

Still, the sludge load, sometimes, has been out of the required range which was $0{,}2 - 0{,}4 \ \frac{\text{kg BOD}_7}{\text{kg MLVSS day}}$.

Higher values of sludge load were obtained mainly after tannery waste water feeding started. This is as a result of high BOD_7 value of tannery waste water.

Values are shown in the appendix including sludge load interms of MLSS concentration.

8.1.1.1 MLSS and MLVSS concentration

As described earlier these parameters, specially MLVSS, were controlled in order to control the sludge load. That is, when low influent BOD_7 values were expected from the COD results, the MLVSS concentration was checked and removed if required to bring the sludge load within limits.

Thus during the first part of the experiment sludge removal was not so much required until tannery waste water feed started. There after solids production increased so much so that sludge removal of 3 to 13 % of the activated sludge was reached. Sludge was removed directly from the aeration basin.

Typical MLSS and MLVSS concentrations are shown in the appendix.

8.1.1.2 Flow

The waste water feed rate has been also used in order to keep the sludge load within limits. But the rate of flow was not varied often since it was not required to change it now and then. Still in the later stages it was reduced as shown in the appendix.

8.1.2 pH and temperature

The pH in the aeration basin continuously dropped in both reactors until the 21.11.1983. The with the addition of 2 g $CaCo_3$ per day directly into the reactor it was kept between 6,5 and 7,3 in reactor 1 and 6,6 and 7,8 in reactor 2. When tannery waste water feed was started feeding $CaCo_3$ was interrupted assuming that tannery waste water having higher pH and alkalinity may do without it. But it was noticed in 20.12.1983 that the pH dropped to 5,52 and 5,98 in 1 and 2 respectively. Then again with 2 g $CaCo_3$ per day it was kept within the required range throughout the experiment. Possible reasons for pH dropped are discussed in section 9.2.

The temperature in the reactors has been between 21,5 - 22,5 ^{o}C throughout the experiment.

8.1.3 Dissolved oxygen

The dissolved oxygen concentration in both reactors has been from 1,3 - 4,5 mg/l, mostly about 2,5 mg/l, until 12.12.1983, when it dropped to about 0,4 mg/l in both cases. This is the time when both reactors were fed with 20 % tannery waste water. Thus, it is to be expected that oxygen requirement increases as influent loading increases. Flow was reduced in order to reduce the loading. But the dissolved oxygen did not recover until 31.12.1983 when one aerator for each reactor was added starting from 30.12.1983. Then the DO was kept within the range of 1,5 - 4 mg/l until the end of the experiment.

DO measurement was made with an oxygen meter YSI 57 and prob 5700.

8.1.4 Sludge age

In actual activated sludge treatment plants, the control of mean cell residence time (sludge age) has been practiced. The operator wastes activated sludge, usually from the return sludge flow, to maintain a desired concentration of mixed liquor suspended solids (MLSS). If, by this sludge wasting operation, the MLVSS concentration is kept constant, then the weight of waste sludge solids represents the net sludge growth in the system. It would be far more desirable, however, to know the mean cell residence time that is required to produce a desired degree of treatment, and to maintain a solids wasting rate that would produce this mean cell residence time. There are two obstacles to achieve this:

1) Unintentional wasting of sludge solids with the effluent.
2) The relationship between MLVSS and return sludge solids is not constant and cannot always be controlled closely by the rate of return sludge pumping since settleability of the activated sludge influences the ratio of MLVSS to return sludge VSS. Hence a return sludge wasting rate, established to produce a given mean cell residence at a low SVI will not be great anough to maintain this same mean cell residence at a higher SVI as return sludge solids concentration decreases when SVI increases.

In order to avoid this uncertainity, Garret wasted sludge directly from the mixed liquor when he had his experiment of activated sludge control by mean cell residence time /14/. By using this method a mean cell residence time of, say, ten days could be maintained by wasting one tenth of the aeration tank volume each day.

To operate a plant in the standard rate range, 7 to 20 per cent of activated sludge solids in the system must be wasted per day /14/.

In this particular laboratory scale experiment, no regular sludge removal was made during the first part of the experiment except sometimes when it exceeds the desirable MLSS concentration and sludge floating in the clarifier due to denitrification. Thus attention to sludge age was not so much given so as to present in this paper. But, as described in the previous section, due to higher growth rate, the solid concentration in the aeration basin was exceeding to much when tannery waste water feed started. As a result of consistent sludge removal proper attention was paid to sludge age in order to avoid too young sludge and its consequences. Therefore sludge age computation was made starting from 6.12.1983 until the end of the experiment using solids balance in the system. That is

$$\text{sludge age} = \frac{\text{total solids in the system (kg)}}{\text{solids wasted (kg/day) + eff. SS (kg/day)}}$$

The total solids in the system was computed by taking total mixed sample from the aeration basin and clarifier once a week and considering the average to be representative of the concentration for the week in between. Solids wasted are measured every day before damping it off and effluent suspended solids are measured twice a week so that the average of these two is used to compute the daily effluent SS for the week.

For example:

MLSS concentration of mixed sample of reactor 1

on 13.12.1983 = 3928 mg/l

on 20.12.1983 = 4208 mg/l

Average daily concentration for the week =

$$\frac{3928 + 4208}{2} = 4068 \text{ mg/l}$$

Volume of aeration basin + clarifier = 9,5 l

Weight of solids in the system $= 4068 \times 9,5 \times 10^{-6}$ kg
$= 38,646 \times 10^{-3}$ kg

Sludge wasted per day $= 1236,65 \times 10^{-6}$ kg (average of the week)

Effluent SS per day $= 226,8 \times 10^{-6}$ kg (average of the week)

Sludge age on 20.12.1983 $= \dfrac{38,646 \times 10^{-6}}{1,237 \times 10^{-3} + 0,227 \times 10^{-3}}$

$= 26,4$ days

This computation is too theoretical, but still can give some clue on the sludge age.

The results are plotted in figure 21 and tabulated in the appendix.

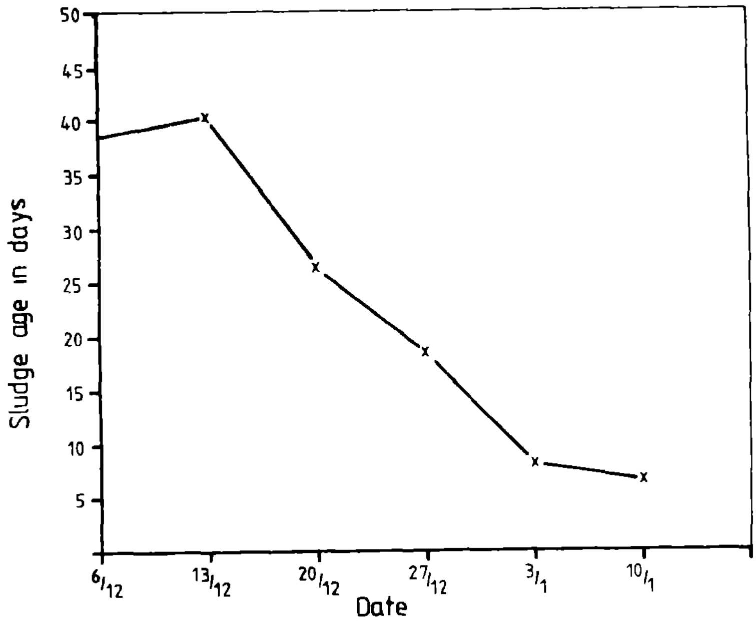


Fig 21. a) Sludge age (tan + dom).

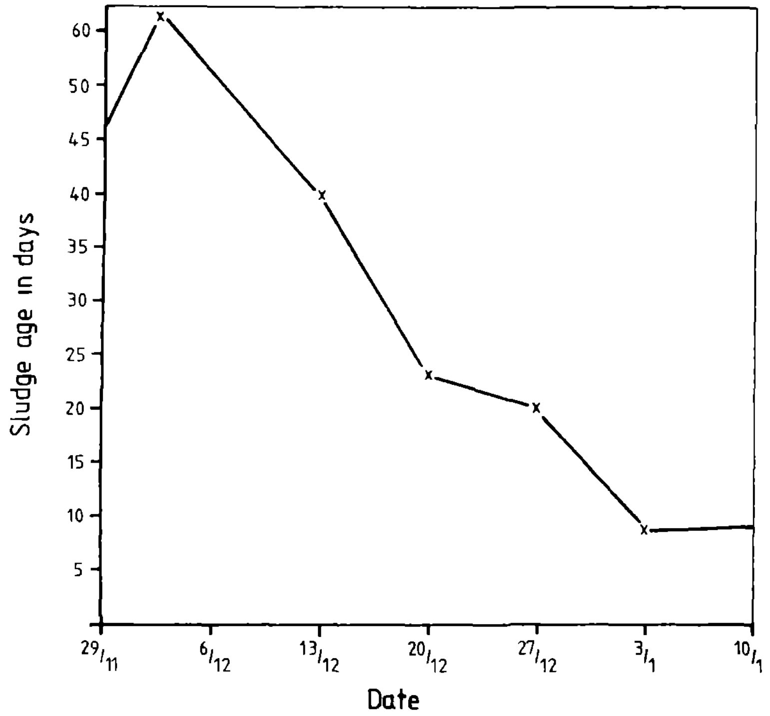


Fig 21. b) Sludge age (tan + tex + dom).

8.1.5 Sludge volume index

The 30 minute settling test is indicative of both the settlement rate and the concentration that can be produced in a final clarifier at a given MLSS concentration applied to the clarifier. In practice, optimum settling is indicated when the settled sludge after 30 minute settling time occupies approximately 200 ml (or 20 per cent) of the 1000 ml flask used in this determination, and when 75 % to 80 % of this settlement is reached in 4 to 5 minutes /21/. These factors are predicated on the actual characteristics of an average clarifier and are not arbitrarily chosen. If the 200 ml mark cannot be approached, solids in the mixed liquor must be reduced to the extent of the established SVI, otherwise excessive solids carry-over at the final tank weir is certain. Such a reduction will affect the BOD loading acceptance to the aeration basin.

If the SVI is excessively high, very little concentration will occur in the 30 minute test, and complete instability is indicated /21/. Such problems have been encountered during the last days of this experiment. These problems are discussed in detail under the section problems encountered.

The SVI values and some representative settleability graphs are presented in the appendices.

8.1.6 Hydraulic detention time

This parameter can be controlled either by varying the flow or volume of aeration basin. But in this experiment the volume of aeration basin was fixed and the flow was adjusted to fit the desired sludge load. Thus there was no possibility to fix a desired range for hydraulic detention time. As a result it has varied from 18 to 30 hours in each reactor.

8.2 Analysis

Influent and effluent analysis are made twice a week on Thursdays and Fridays, except for the influent industrial waste waters it is only once a week on Fridays. It is assumed that the industrial waste water characteristics will not change within a week when it is kept in a refrigerator at 4 °C.

Analysis was made for:

Test	Influent			Effluent			
	Dom	Tex	Tan	Dom	Tex+Dom	Tan+Dom	Tex+Tan+Dom
BOD_7 *	x	x	x	x	x	x	x
COD *	x	x	x	x	x	x	x
SS	x	x	x	x	x	x	x
VSS	x	x	x	x	x	x	x
Alkalinity	x	x	x	x	x	x	x
pH	x	x	x	x	x	x	x
NH_4-N	x	x	x	x	x	x	x
Chromium			x			x	x
P	x	x	x				

* These test were made on filtered samples for effluents except for NH_4-N it was made for both influent and effluent. Filtering was made with Whatman GF/A glass microfibre filters.

At the beginning, chromium was analyzed for total chromium and hexavalent chromium. But few results indicated that the influent constitutes negligible amount of Cr^{+6} and only total chromium was followed upto the end.

8.2.1 Method of analysis

NH_4-N	Standard methods for the examination of water and waste water Nesslerization method.
Alkalinity	The Finnish standard SFS 3005: Alkalinity and acidity in water. Potentiometric fitration.
BOD_7	The Finnish standard SFS 3019: Determination of biochemical oxygen demand (BOD) of water. Dilution method.

pH *	The Finnish standard SFS 3021: Determination of pH-value of water.
tot-P **	Folke Koroleff, Merentutkimuslaitos Helsinki 1969.
SS & VSS *	Water treatment handbook (Degrémont): Measurement of suspended solids No. 406 by filtration. (Ashless filter S8S 597, 105 °C/550 °C)
COD	Hach Chemical Company: The micro COD digestion procedure Oxidation with dichromate = $\mathrm{COD}_{\mathrm{Cr}}$
tot Cr	According to standard methods Sta VH73 and AA475.

* The same methods were used for determining these values in the aeration basin for reactor control.

** This was used in order to know if the waste waters were nutrient deficient.

9. OPERATIONAL PROBLEMS ENCOUNTERED

9.1 Foaming

This problem was faced as soon as the experiments were started. The foam was in the aeration basin. But it disappeared after some days without any corrective measure. In activated sludge plants foaming is actually a typical start-up problem /15/. It is most probably due to young sludge. Garrett /14/ showed that foam height increased as the mean cell residence time decreased. In this particular experiment the foam disappeared as the residence time increased.

9.2 pH drop

Some days after the start of the experiment the pH started to drop until it finally reached to 5,1 and 5,6 in reactors 1 and 2 respectively on 18.10.1983. This was mainly as a result of the beginning of nitrification.

Barritt /17/ has proposed that during nitrification a complex, cyclic reaction to be the cause of a continued drop in pH, without producing additional nitrates:

$$3HNO_2 \longrightarrow (H^+ + No_3^-) + 2NO + H_2O$$

and

$$2NO + H_2O + \tfrac{1}{2}O_2 \longrightarrow 2HNO_2$$

It could also be just because of the formation of CO_2 during start-up.

This problem has been corrected by means of adding 2 gms of $CaCo_3$ every day directly to the aeration basin.

9.3 MLSS and MLVSS concentration

The variation in MLSS and MLVSS concentration was not significant until beginning from 7.12.1983 when it abruptly increased much in both reactors. Possible reasons for this are high incoming substrate concentration, less sludge wastage rate and high sludge recycle rate. As there was no clear idea of the recycle rate, the cause for the rise in MLSS and MLVSS concentration was understood to be high incoming substrate concentration due to the tannery waste water and no significant sludge removal made earlier. Therefore as a measure for this sludge wastage rate was made consistently, and the amount was increased gradually. But this possibly brought another problem as discussed in a latter section. Anyway, with this measure, the concentration of MLSS and MLVSS was brought to the required range and fit a desired sludge load.

9.4 Dissolved oxygen concentration drop

When tannery waste water feed started the dissolved oxygen concentration dropped in both reactors as low as 0,25 - 0,3 mg/l. Two reasons were suspected. The first one is an obvious reason that the higher the substrate concentration the higher the oxygen requirement. The second one was the higher growth in micro-organisms population which is actually a result of the first.

With the addition of one aerator for each reactor and increase in the sludge wastage rate, the DO concentration recovered.

9.5 Rising sludge

This problem has been noticed now and then as the sludge in the clarifier rose to the surface, burst and spread over the surface. This happened mainly due to denitrification.

If aeration is sufficient for complete nitrification in the aeration tanks, problems may result in settling tanks. If the sludge inventory is too high or the DO level in the settling tank influent is not high enough, denitrification may result /4/.

Thus as nitrification was complete in these experiments, it is imperative to say that the sludge floating in the clarifier was due to denitrification.

9.6 Settleability

The 30 minute settleability test made once a week for the sludge in the aeration basin indicated that starting from 9.1.1984 the quality of the sludge has changed. That is poor settleability characteristics were noted. Also the sludge was fluffy with light foam on top of the aeration basin. Typical settleability curves are given from appendix 5 to 7.

In addition the sludge in the clarifier was not settling well, having high sludge blanket, indicating bulking characteristic.

The above problems can be caused by

- excessive organic loading,
- low sludge age particularly indicated by the foam and fluffy sludge,
- growth of filamentous organisms,
- pin point floc formation,
- in this particular case the drastic change in sludge removal to control MLSS and MLVSS has also created shock in the operation.

Thus in order to know the exact causes oxygen uptake rate tests and microscopic examination were made while in the meantime sludge wastage and flow were reduced.

The oxygen uptake rate tests gave values ranging from 40 to 60 mgO_2/h for both reactors which is acceptable whenever industrial component is involved /15/.

But the microscopic examinations gave the following:

Reactor I (tan + dom)

Observation:

- very few groups of live protozoa
- too many species of amaeba
- few species of filamentous and flagelite bacteria
- very many dead protozoa
- pin point flocs of very small size
- sludge was generally degrading.

Discussion

The presence of too many species of amaeba is an indication of low dissolved oxygen concentration which is actually the case as found on DO measurements. This low DO value might have also caused the death of protozoa together with the chromium in the waste water.

The reduction in the live population of protozoa causes internal peak organic load which gives actually higher sludge load than expected. As a result of this the settle-ability characteristic of the sludge changed from good to poor. Besides this the presence of pin point flocs and filamentous bacteria have also caused the change in sludge quality resulting bulking.

Even though some preliminary measures were taken as mentioned earlier, the experiment was stopped due to time limitations and the transfer of the laboratory to the new building before any change was noted to this effect.

Reactor II (tan + tex + dom)

Observation:

- various species of protozoa
- many species of filamentous bacteria
- species of flagellated sulfur bacteria.

Discussion

From the observations made the main cause of poor sludge settleability and bulking, in this case, is due to the presence of many species of filamentous bacteria. Because filamentous bacteria is known from previous works as well, to cause this problem. When compared to the quality of the sludge of reactor I, this was better even though both have same problems.

For the same reason as in reactor I the experiment was stopped before any change was noticed for the measures taken.

Recommendations

In order to prevent such problems good operational control schedule should be made and drastic day to day changes like in sludge wasting rate should be avoided.

For the problems faced in this experiment, and specially for similar problems in real plants, some of the following measures can be taken cautiously /4/

- gradual improvement in aeration
- pumping out half of the sludge under aeration and operate the plant to refill by itself
- chemical treatment
- increasing sludge age
- use flocculant or weighing agent to decrease SVI
- use disinfectant on return sludge.

10. RESULTS

10.1 Domestic waste water

10.1.1 Substrate removal

The BOD_7 and COD removal has been almost all the time above 90 % and 75 % respectively. This is demonstrated by the graphs of figures 22 and 23. This result has actually confirmed that this process is good in substrate removal as said by previous studies.

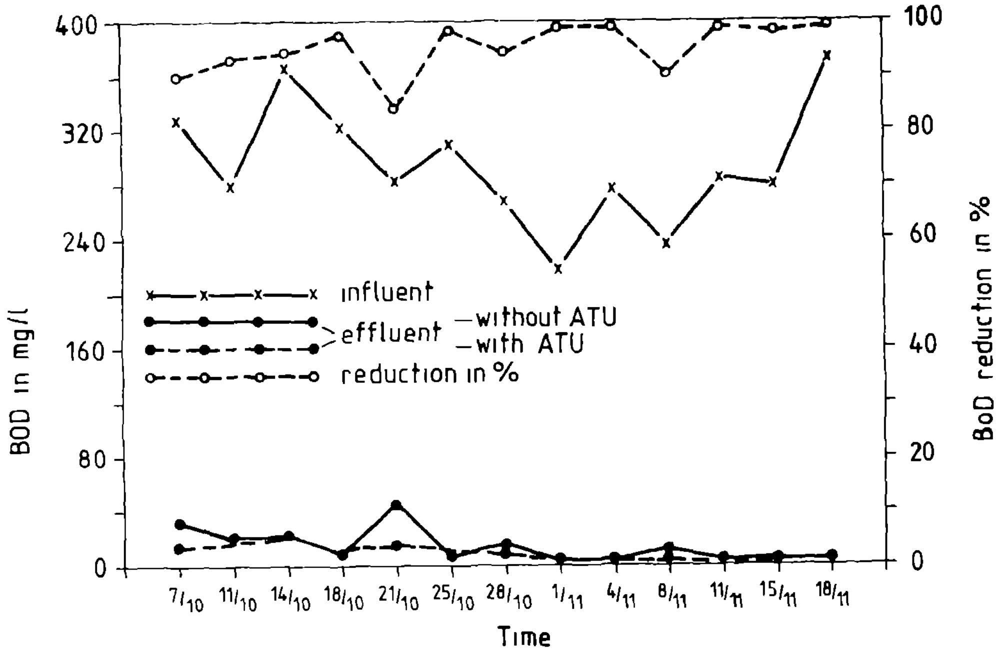


Fig 22. BOD removal for domestic sewage.

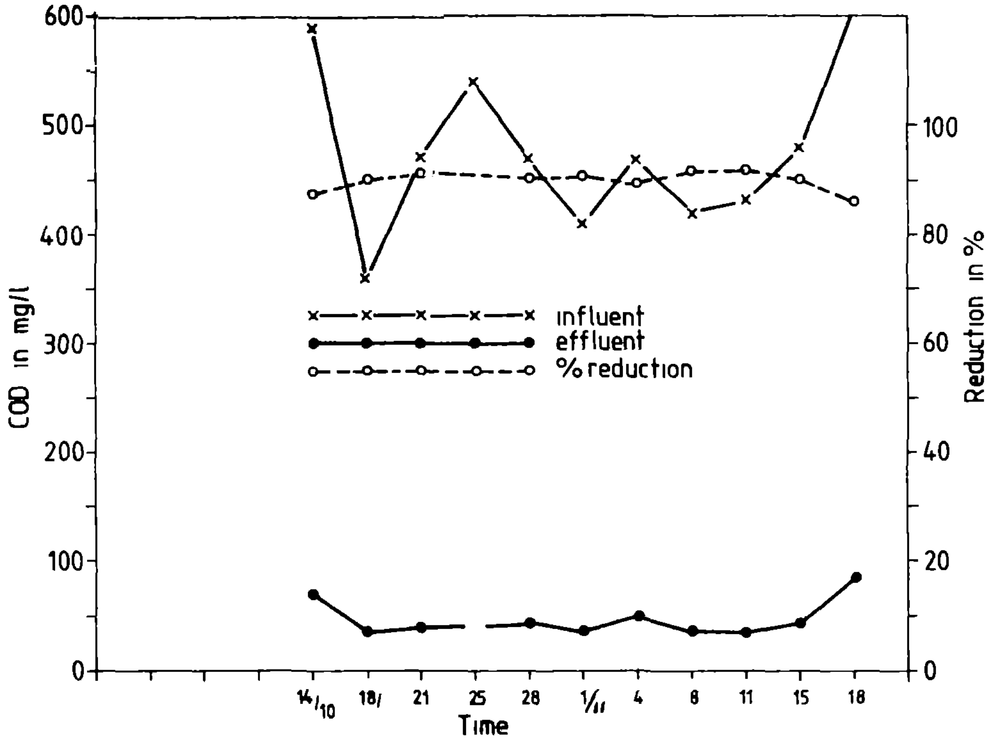


Fig 23. COD reduction of domestic sewage.

10.1.2 Nitrification

This was measured by the amount of NH$_4$-N removed; that is, the difference between influent and effluent NH$_4$-N in the system. Thus after about one month from start, nitrification started to be complete. This continued until the end of the experiment as can be seen in figure 24. It has been shown that activated sludge process with proper loading and temperature produces highly nitrified effluents when treats domestic sewage /1/. Because of high nitrification alkalinity has been consumed almost totally. Proper alkalinity level was maintained by adding CaCo$_3$.

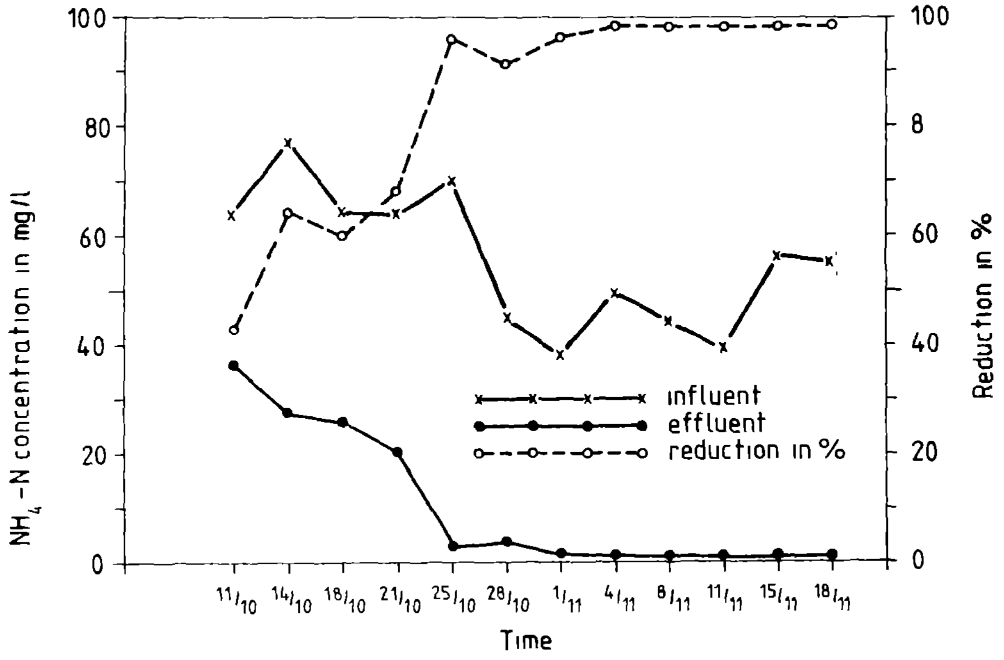


Fig 24. NH_4-N removal for domestic waste water.

10.2 Textile + domestic waste water

10.2.1 Substrate removal

This experiment has shown that the activated sludge process gives good effluent quality when domestic and textile waste water are combined upto the proportion indicated. As can be seen in figures 25 and 26 the BOD_7 and COD removal has been from 91 to 99 % and from 65 to 94 % respectively. The lower values at the beginning of the experiment could be as a result of adaptation period. That is the micro-organisms need time to acclamitize to the industrial waste water.

Prior investigations have also demonstrated that activated sludge treatment is very efficient for combined domestic and textile waste waters and removes upto 95 % of the BOD resulting in a clear stable effluent. Without pretreatment, one plant treating a mixture of 7 % municipal sewage and 93 % strong mill waste including sulfur dye wastes, has obtained a BOD removal efficiency ranging from 93 to 97 % with an influent BOD of 1400 mg/l, pH of 12,0 and Cr^{+6} of 25 mg/l. The effluent BOD was as low as 11 mg/l./12/

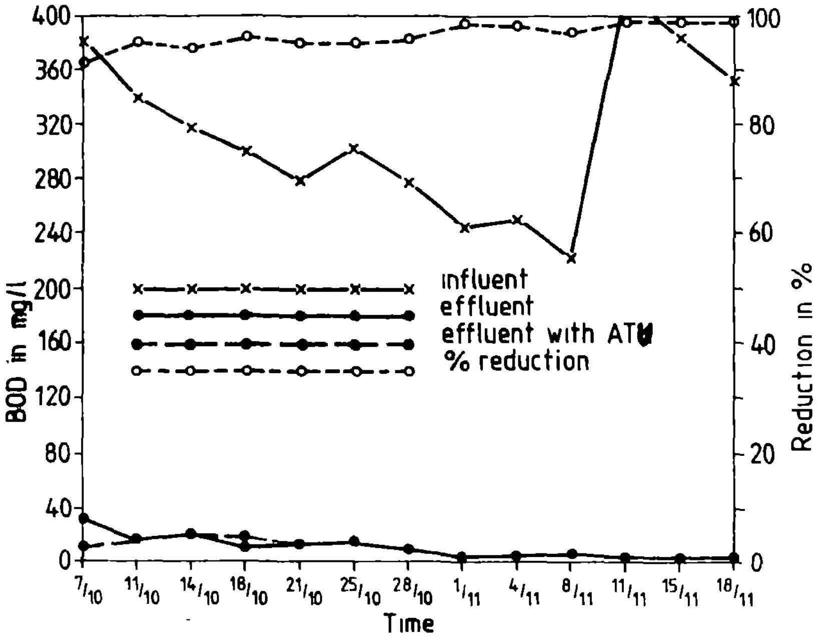


Fig 25. BOD removal (textile + domestic).

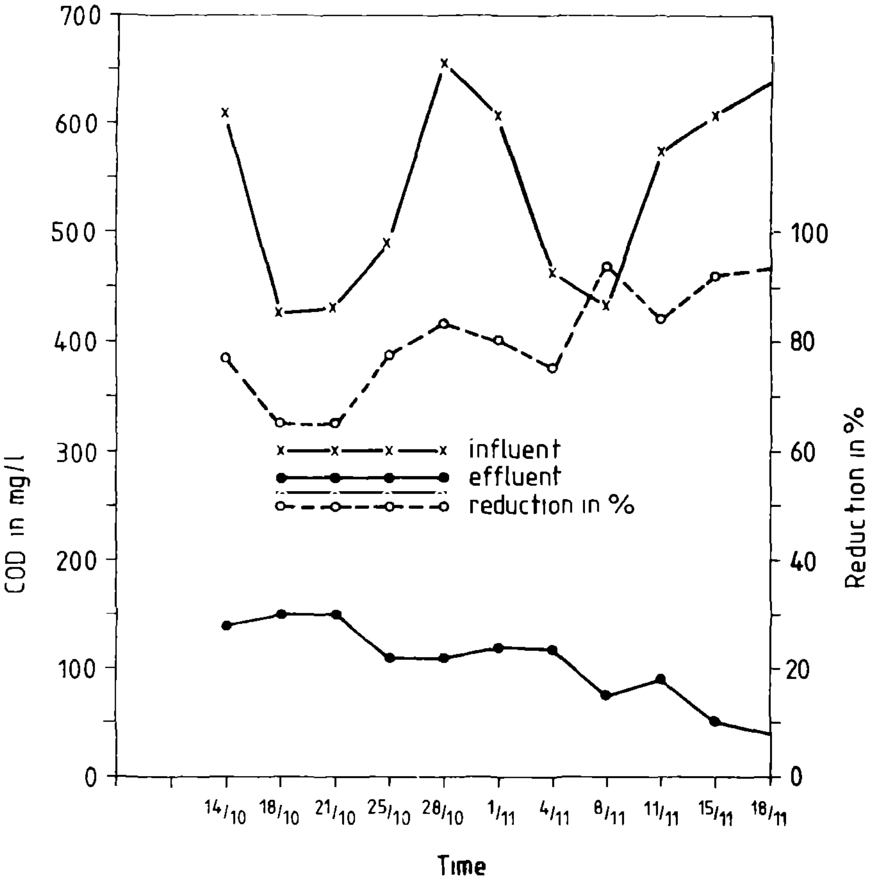


Fig 26. COD reduction (textile + domestic).

Thus when compared to previous works, this experiment has reaffirmed the result obtained.

10.2.2 Nitrification

In this experiment complete nitrification was attained when textile and domestic waste waters were combined and treated. This is shown in figure 27 where 90 to 97 % NH_4-N removal is obtained. The lower results during the first days are due to lag in starting nitrification for the obvious reason that nitrifying bacteria takes longer time to grow than normal activated sludge bacteria.

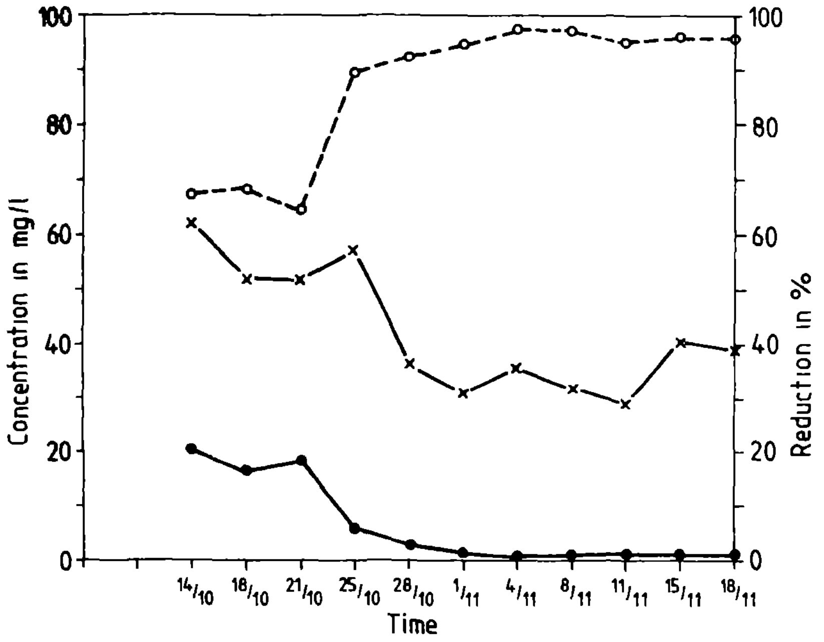


Fig 27. NH_4-N removal (textile + domestic).

10.3 Tannery + domestic waste water

10.3.1 Substrate removal

The BOD and COD removal efficiencies have been from 93 to 99 % and 88 to 95 % respectively. Laboratory pilot studies have demonstrated that the conventional activated sludge treatment process is capable of reducing the BOD of the combined waste from 65 to 85 %, depending primarily upon the organic loading /18/. Previous works by BLMRA and others /7/ have shown that substantial amount of tannery waste liquors can be mixed with domestic sewage without creating difficulty in the subsequent biological treatment. It is generally agreed that chromates can interfere with sewage treatment. However, Tanaka et al /7/ obtained a 96 % reduction in BOD in a plant treating tannery wastes with BOD of 620 mg/l and 52 mg/l of chromium.

Thus, the results obtained in this experiment confirm what has been made earlier. Higher efficiencies obtained could be as a result of soluble effluent BOD and COD values used in this experiment.

Results are shown in figures 28, 29 and the appendix 3.

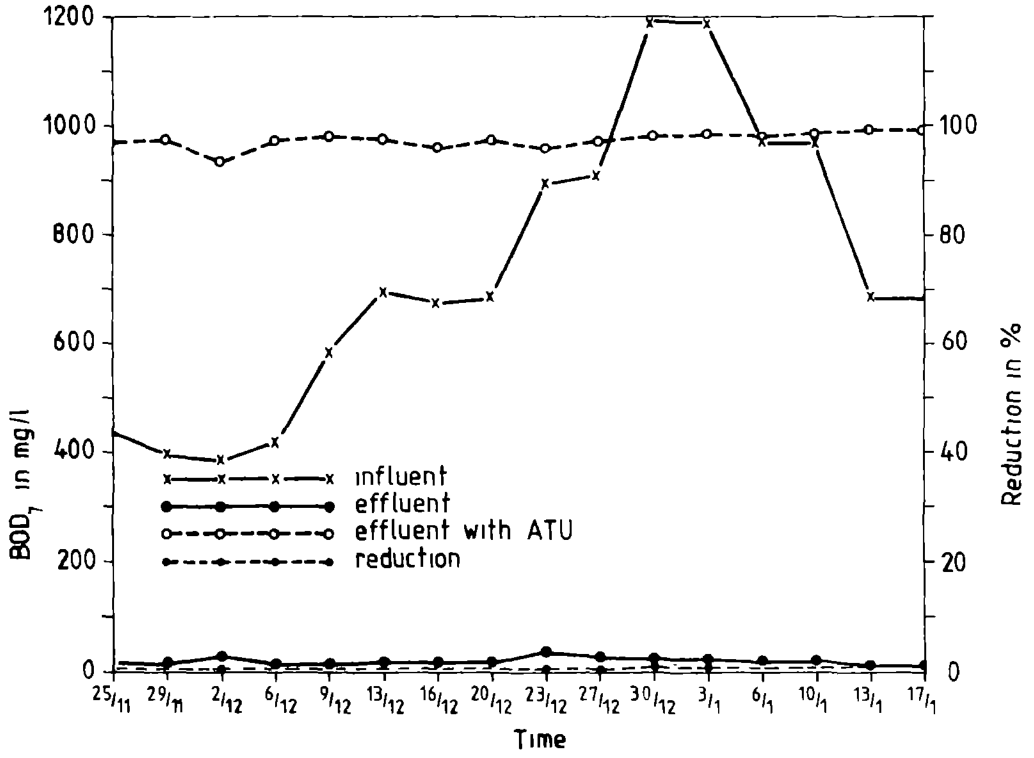


Fig 28. BOD removal (tannery + domestic).

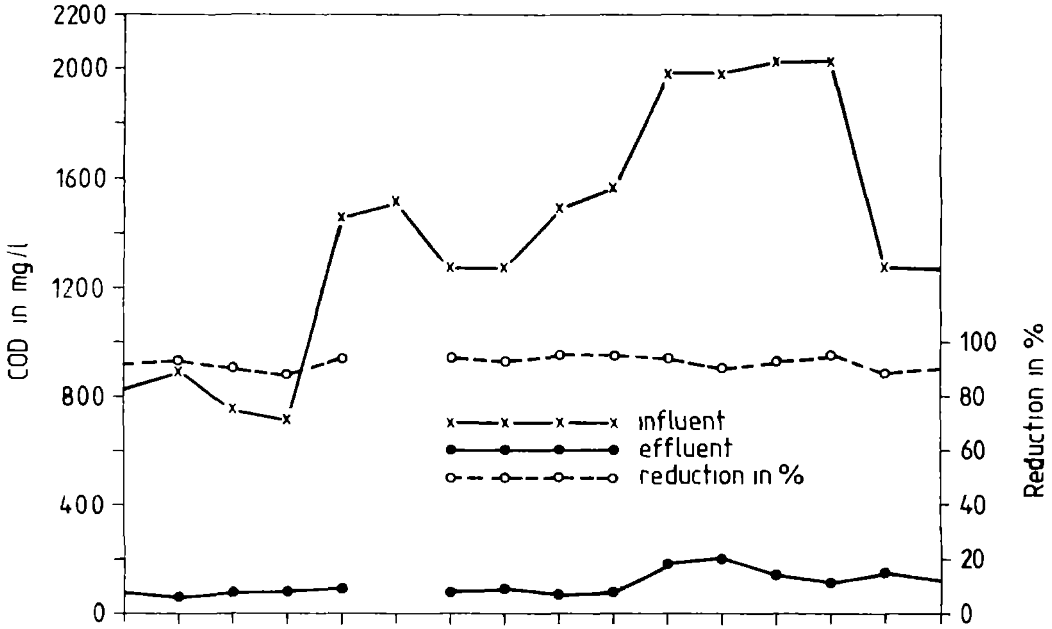


Fig 29. COD removal (tannery + domestic).

10.3.2 Nitrification

This experiment has demonstrated that nitrification ceases for some time but subsequently recoveres. When tannery waste water feed started to the reactor having complete nitrification, it was found that build-up of NH_4-N in the effluent was noticed increasing constantly for one month. Then it started to recover and during the last days nitrification was almost complete as shown in figure 30.

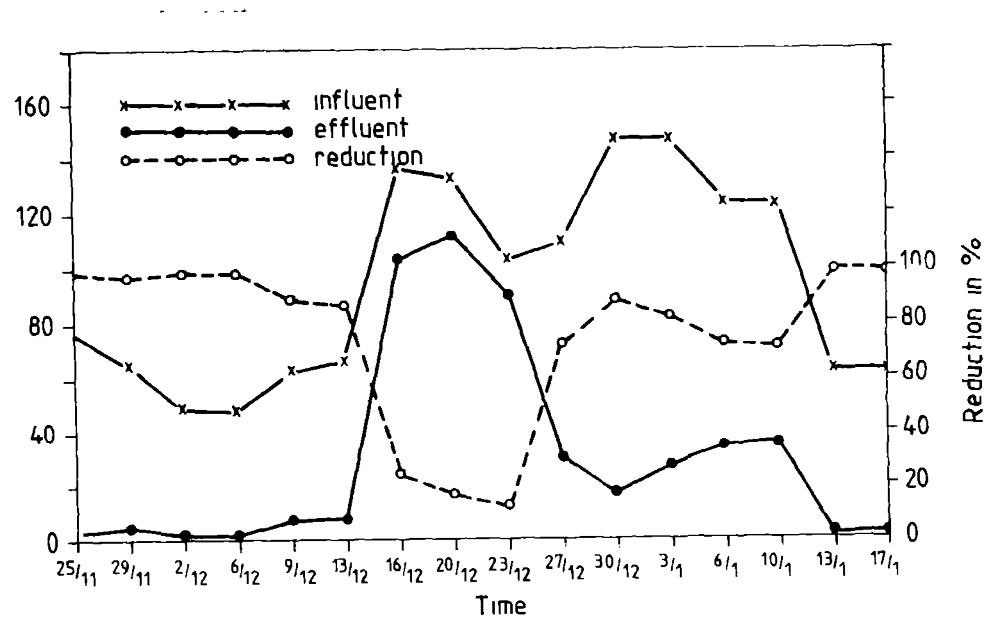


Fig 30. NH_4-N removal (tannery + domestic).

This temporary effect may be due to the effect of chromium present in tannery waste water. Because previous works made on the effect of chromium on activated sludge give evidence of this fact as well, for example, Ingols /7/ stated that 100 mg/l of Cr^{+6} or 200 mg/l of Cr^{+3} depressed the activity of nitrifying bacteria in an activated sludge plant. Jenkins and Hewitt /7/ found that 1,0 mg/l of chromate reduced nitrification slightly and resulted in some build up of ammonia in the effluent. Moore et al /7/ also found that nitrification was first inhibited but recovered after 10 days.

In this experiment concentration of total chromium in the influent has been as low as 4,5 mg/l and as high as 57,9 mg/l. No specific concentration value can be given from this experiment. Because the inhibition and recovery times do not correspond to a rise or a fall of influent concentration and there was no aim to find the relationship between chromium concentration and inhibition.

Still the result is in accordance with previous experiments showing that nitrification inhibition could be noticed during the first days when tannery waste water is treated with activated sludge process.

10.3.3 Chromium removal

The influent concentration of chromium has been varying between 4,5 and 57,9 mg/l. Whatever the concentration was in the influent the effluent consistently showed its chromium concentration to be 0,02 to 0,3 mg/l. The reduction was mostly above 99 %. This was mainly because the chromium in the waste water mainly settles as sludge. It was also tested a couple of times that the influent contains less than 0,1 mg/l Cr^{+6}. The result is shown in figure 31 and appendix 3.

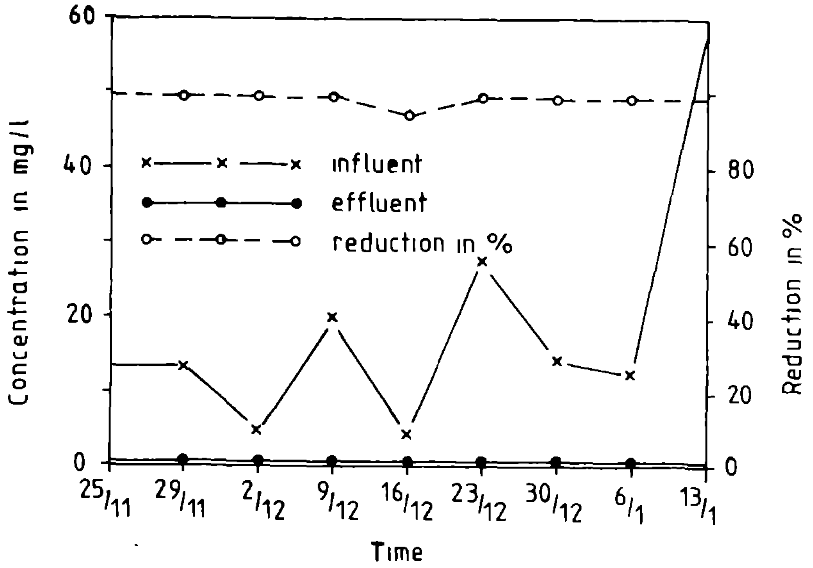


Fig 31. Chromium removal (tannery + domestic)

10.4 Tannery + textile + domestic waste water

10.4.1 Substrate removal

The BOD and COD removal efficiency has been from 96 - 99 % and 80 - 98 % respectively. This result shows that textile and tannery waste waters can be treated well when both are mixed with domestic sewage. The effluent BOD value was mostly lower than 30 mg/l as shown in figure 32. Values are given in appendix 4.

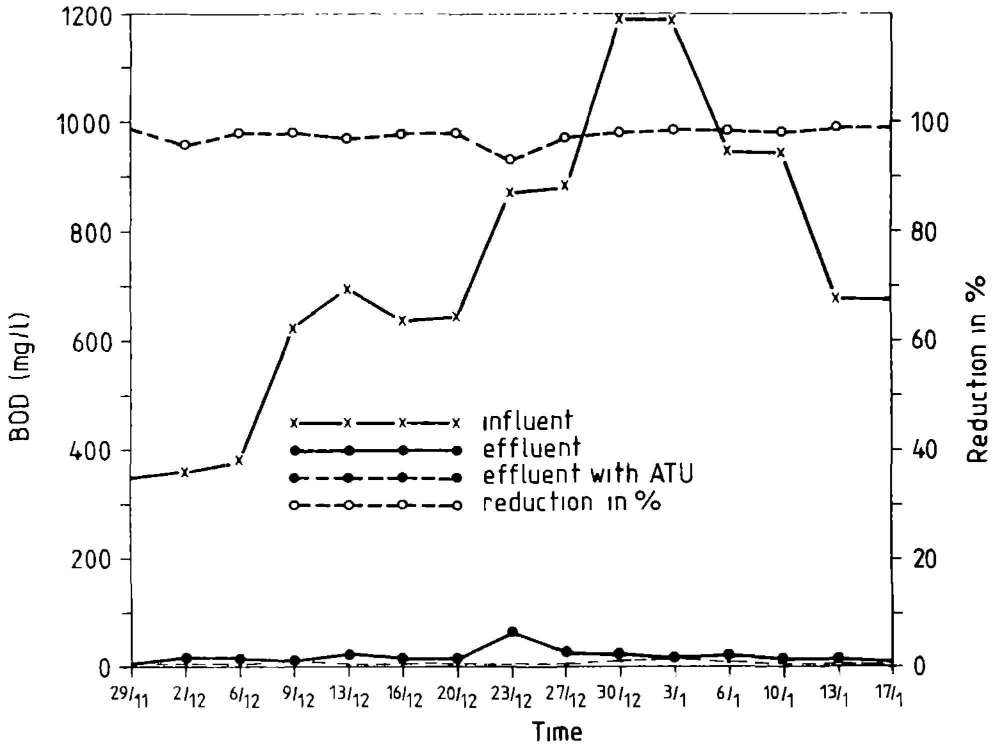


Fig 32. BOD removal (tannery + textile + domestic).

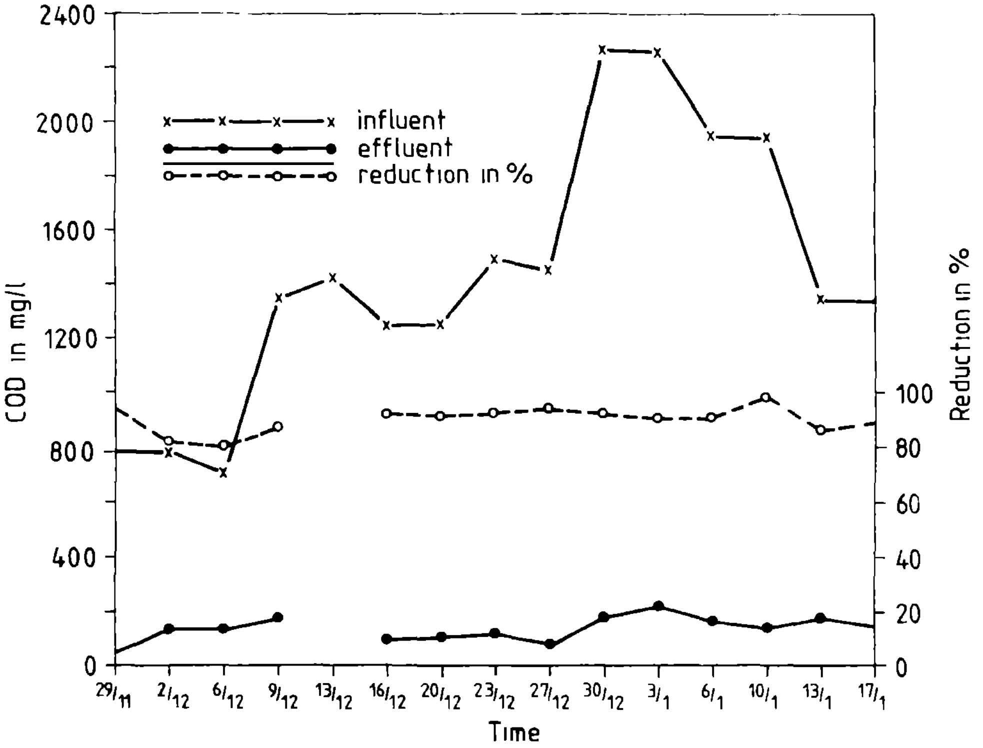


Fig 33. COD removal (tannery + textile + domestic).

10.4.2 Nitrification

Nitrification was quite similar as with tannery and domestic. That is, nitrification ceased for some time and recovered again. This is better demonstrated in figure 34.

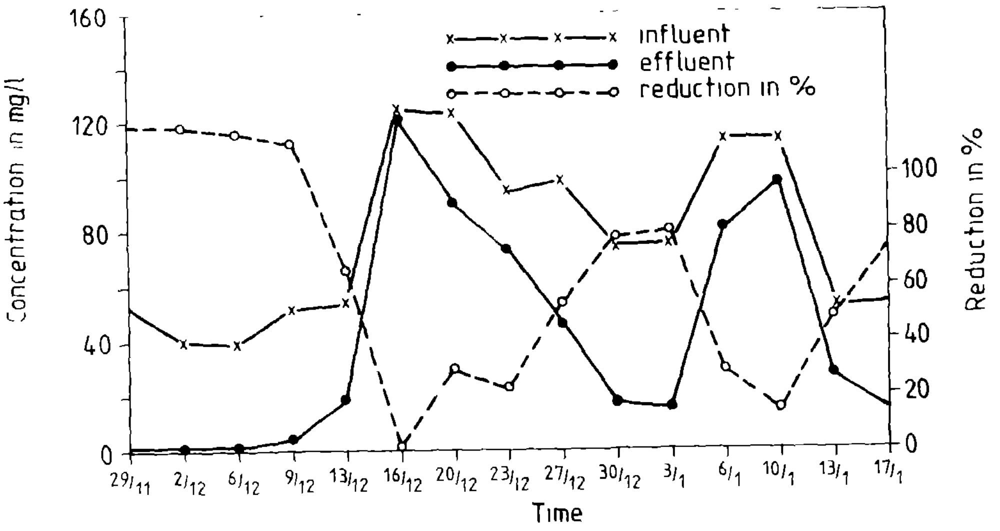


Fig 34. NH_4-N removal (tannery + textile + domestic).

Since this has not occurred when textile and domestic waste waters were fed alone, it can be said that this is as a result of the tannery waste water.

10.4.3 Chromium removal

The influent and effluent concentrations were 4,5 to 57,9 and 0,02 to 0,3 mg/l respectively. The same resoning goes to this part of the experiment as well, as the textile waste water is assumed not to contain chromium at all. However the result is shown in figure 35 and appendix 4.

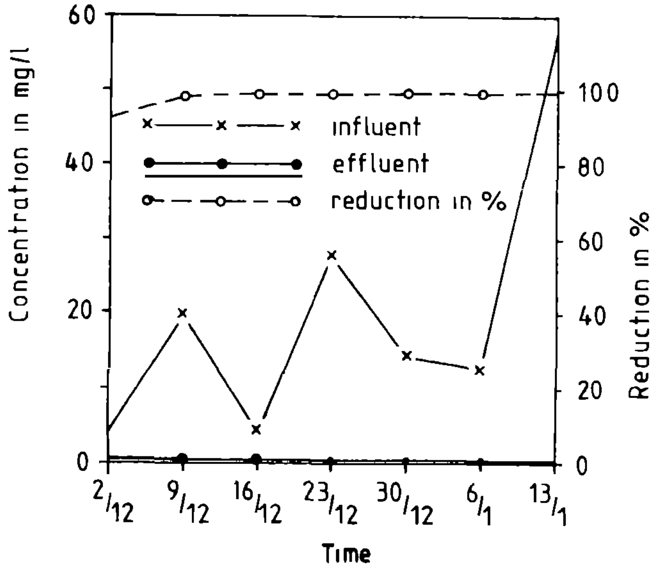


Fig 35. Chromium removal (tannery + textile + domestic).

10.5 Comparison of results

10.5.1 Substrate removal

The results obtained for both tannery and textile waste waters were satisfactory. In terms of effluent BOD_7 and COD concentrations, tannery waste water seems to give a higher value when compared to that of textile + domestic. This is because of the very high BOD concentration of the tannery waste water resulting higher loading for the system. Still the effluent BOD concentrations were less than 30 mg/l in most of the cases.

Good removal efficiency is obtained as a result of the pollutant characteristics. That is both tannery and textile waste waters contain pollutants which are mainly biodegradable. Hence bio-oxidation occurred to a good extent giving the results presented.

No inhibition was noticed upto the proportions reached.

10.5.2 Nitrification

As mentioned earlier complete nitrification was obtained with both textile and tannery waste waters. But during the first few days nitrification has ceased in the case of tannery waste water both with domestic and combination of textile and domestic. This trend of inhibition and recovery was mainly because of chromium which needed adaptation. Adaptation could be

I Social

- Different bacteria get predominating instead of old ones. Thus until the new ones are enough populated for the substrate amount temporary inhibition could be noticed.

II Genetic

- New mutants with new enzymes can take over old ones and until they are enough to take care of the whole substrate temporary inhibition can be noticed. That is active sites of old bacteria may be blocked by metals like in this case by chromium and thus resulting the new mutants to take over.

Thus the main cause in this experiment is due to chromium which requires genetic adaptation as described.

Otherwise both waste waters, textile and tannery upto the proportions indicated did not give problems against nitrification. Still if we compare the stability of the results, the ones without tannery waste water have been more consistent and stable.

10.5.3 Suspended solids removal

The suspended solids removal efficiency has been very much variable in all cases. Thus the results were not reliable enough to make any substantial conclusion from this experiment. For example, it has been 33 to 98 % in case of domestic, 5,7 to 100 % in textile, 75 to 100 % in tannery and domestic and 56 to 99 % in case of textile, tannery and domestic. Hence it is clear from the above that the results were not quite stable in all cases. The range in the last two cases looks narrower because of the high suspended solids concentration in tannery waste water which brought the percentage to be higher.

No specific reason could be given for such a result, except the effect of the size and shape of the model in general and the clarifier in particular.

Tabular results are presented **from** appendix 1 to 4.

10.5.4 pH

The influent pH values have been variable depending on the type and combination of waste waters made. However variable have been the influent pH values, the effluent have been stable enough, in the neutral and desired range.

Still pH drop upto 5,6 was obtained in the effluent when treating domestic sewage alone. Even though it has not been as low as this, pH drop was noticed in the other reactor treating combined domestic and textile waste water at the same time. This was due to the start of nitrification in both cases and with the addition of $CaCo_3$ the effluent pH recovered again.

Otherwise the results concerning pH have been satisfactory in all cases.

11. OXYGEN UPTAKE RATE TEST

11.1 Aim

The aim of this part of the experiment was to know which waste water, textile or tannery, is more toxic to activated sludge micro-organisms and to what extent. Besides it is meant to get an idea of the inhibitory nature of the respective waste waters.

11.2 Apparatus and methods

11.2.1 Apparatus

The apparatus used comprises:

a) Oxygen meter YSI57 with probe 5700
b) Recorder Honeywell
   chart speed scale 0,5 - 20 cm/min
   span 1 - 100 mv
c) Magnetic stirrer Heidolph MR-80
   RPM 60 - 1100, 220 V
d) Conical flask, 250 ml Na_2SO_3 for removing O_2
   in the probe for calibration
e) Test vessel
f) Aerator with stone diffusers
g) Sample aerating bottle

The arrangement is shown in figure 36.

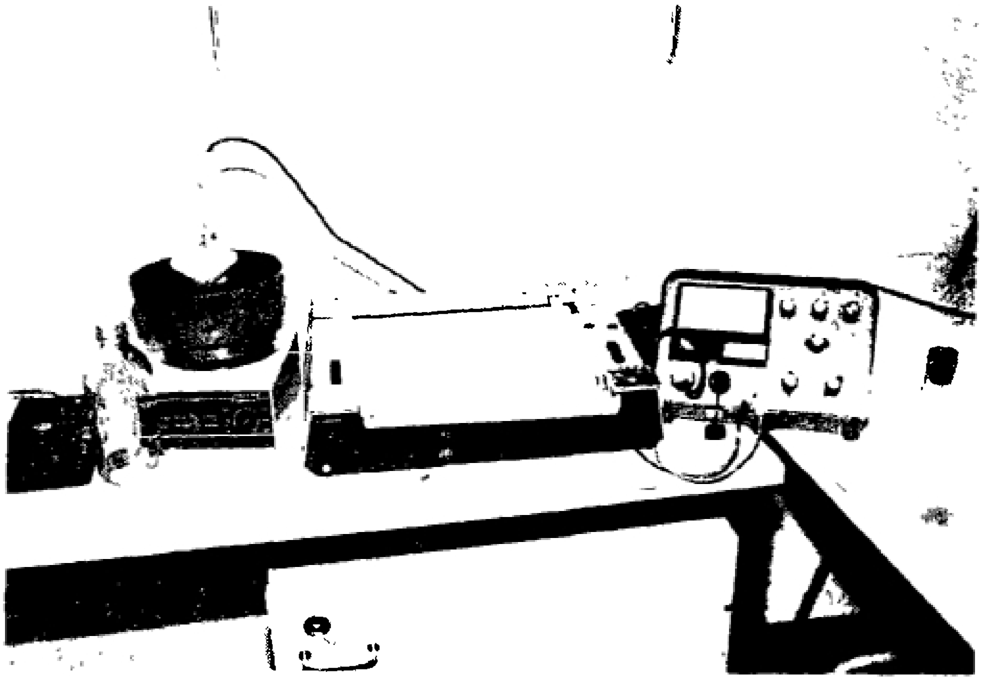


Fig 36. OUR test apparatus.

11.2.2 Methods

The respective waste waters and the biosludge were continuously and separately aerated from which the desired amount is taken at a time. That is, 250 ml of the waste water with the respective proportion is prepared. Then it is mixed with 250 ml biosludge after which it is continuously aerated for 10 - 15 minutes before the measurement is made. With such a procedure two tests were made for each proportion (10:90 to 90:10).

The biosludge used was brought from Sahalahti waste water treatment plant treating mainly food industry wastes. The industrial and domestic waste waters were collected every day from the same sources used for the main part of experiment as described earlier.

The characteristics of the waste waters collected every day was as follows.

	Textile waste waters					Tannery waste waters				
Date	BOD	COD	SS	VSS	pH	BOD	COD	SS	VSS	pH
24.1.84	444	1200	39	21	12,0	-	-	-	-	-
25.1.84	173	200	29	26	9,7	2365	5600	612	224	11,9
26.1.84	117	500	21	12	11,0	1430	3400	908	380	9,2

11.3 Results and discussion

The results from this experiment have indicated that, depending on the strength of the waste waters, both textile and tannery waste waters can be inhibitory to biological treatment process. This can be seen from the shapes of the graphs in figure 37 as the waste waters from textile and tannery showed inhibitory characteristic on 24.1.1984 and 25.1.1984 respectively. If we look for the results of the other days it is clear from the same graph that both did not indicate any inhibitory characteristic. When this is compared to the strength of the waste waters of the specific days, as presented earlier, those waste waters which showed inhibition are stronger than those which did not indicate inhibition. Thus it can be said that these industrial waste waters comprise more inhibitory chemicals as they get stronger.

Otherwise, under normal conditions, the higher the substrate concentration the higher the oxygen uptake rate for a domestic sewage. This was explained by Duggan and Cleasby /12/ as follows:

There are two components to oxygen uptake; exogenous and endogenous respiration. Exogenous respiration fluctuates with influent loading, but the endogenous respiration typical of the effluent side of an aeration basin, is much slower.

12. CONCLUSIONS

The results obtained in this experiment are important. They can be used to form certain conclusions, subject to caution, or may form the basis for further research in this area. Therefore, based on the results and data analysis presented, the following conclusions are made.

1. Irrespective of the type and combinations made, good effluent quality can be obtained upto the proportion of 30 industrial to 70 domestic. No problems of inhibition with respect of treatability can be found.

2. Complete nitrification can be obtained, for all combinations, and upto the proportions indicated above with proper control of sludge age and other parameters. Temporary inhibition during the first days of feeding tannery waste water should not be taken as a serious problem.

3. Good effluent pH values can be obtained with proper attention to the additional alkalinity which may be needed.

4. Chromium mainly in trivalent form and upto a concentration of 60 mg/l does not affect the process except temporary inhibition on nitrification.

5. Textile and tannery waste waters have proved to be inhibitory in some occasions. More precise tests are necessary if the respective industrial waste waters exceed 30 % or 60 % when they are combined.

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APPENDIX 1

Date	INFLUENT AND EFFLUENT RESULTS																					REACTOR CONTROL								
	Waste water		BOD_7				COD			SS			VSS		NH_4-N			Alkalinity		pH		MLVSS	MLSS	flow	sludge load		sludge age	SVI	pH	DO
	Type	Respective proportion %	inf mg/l	eff mg/l	with ATU	red %	inf mg/l	eff mg/l	% red %	inf mg/l	eff mg/l	red %	inf mg/l	eff mg/l	inf mg/l	eff mg/l	% red %	inf mmol/l	eff mmol/l	inf	eff	mg/l	mg/l	l/h	kg BOD / kg MLVSS d	kg BOD / kg MLSS d	days	ml/g		mg/l
7 10 83	Dom		327	33	13	89,9	-	-	-	149	53	64,4	123	44	-	-	-	5,6	0,5	8,8	6,9	1580	2000	0,41	0,28	0,23		42,5	6,2	-
11 10 83	Dom		278	20	-	92,8	-	-	-	129	33	74,4	118	27	64	36,4	43,1	4,7	0,5	8,5	6,7	924	1172	0,41	0,4	0,32		187,7	6,1	2,5 - 3,5
14 10 83	Dom		366	22	22	94	590	70	88,1	140	21	85	114	17	77	27,8	63,9	5,1	0,2	8,5	6,2	785	1030	0,41	0,62	0,47		136	5,8	3 - 3,5
18 10 83	Dom		322	8	13	97,5	360	35	90,4	107	16	85	86	11	64,5	26	59,7	4,8	<0,1	8,4	5,6	1284	1543	0,41	0,33	0,28		-	5,1	4
21 10.83	Dom		281	45	15	8-	470	40	91,5	121	2	98,3	100	0	64	20,4	68,1	4,8	0,2	8,6	6,1	1172	1400	0,41	0,32	0,27		162	4,9	2
25 10 83	Dom		314	6	20	98,1	540	-	-	125	25	80	99	19	70	3,0	95,7	4,8	0,2	8,2	6,3	1634	1700	0,41	0,26	0,25		-	6,3	4 - 4,2
28.10 83	Dom		257	15	5	94,2	470	45	90,4	78	22	84,6	70	16	45	4,0	91,1	3,9	0,8	8,2	7	1820	2424	0,41	0,19	0,14		99	-	-
1 11 83	Dom		217	3	3	98,6	410	37	91	97	11	88,7	85	0	38	1,5	96	3,8	-	8,3	-	2365	3000	0,41	0,12	0,1		-	6,8	-
4 11.83	Dom		276	3	3	98,9	470	50	89,4	55	9	83,6	32	5	49,5	1,0	98	-	0,8	-	7	2408	3419	0,41	0,15	0,11		64,4	-	3 - 4
8 11 83	Dom		236	12	5	94,9	420	35	91,7	74	49	33,8	53	34	44	1,0	97,7	4,3	0,5	7,9	6,7	1928	2588	0,41	0,16	0,12		68,6	6,7	3,5 - 4
11 11 83	Dom		324	3	2	99,1	430	35	91,9	119	19	84	96	14	39	0,8	97,9	3,8	0,5	7,6	6,7	1824	3351	0,41	0,24	0,16		-	-	-
15.11.83	Dom		280	4	2	98,6	480	45	90,6	86	30	65,1	58	18	56	0,9	98,4	4,6	0,7	7,9	7	2235	3708	0,41	0,17	0,1		67,4	6,6	3,5 - 4
18.11.83	Dom		373	3	2	99,2	610	85	86,1	102	24	76,5	77	15	55	1,0	98,2	4,6	0,5	8,2	6,7	2100	3000	0,41	0,24	0,17		77,9	6,7	2,2 - 3,8

APPENDIX 2

Date	INFLUENT AND EFFLUENT RESULTS																					REACTOR CONTROL								
	Waste water		BOD_7				COD			SS			VSS		NH_4-N			Alkalinity		pH		MLVSS	MLSS	flow	sludge load		sludge age	SVI	pH	DO
	Type	Respective proportion %	inf mg/l	eff mg/l	with ATU	red %	inf mg/l	eff mg/l	% red %	inf mg/l	eff mg/l	red %	inf mg/l	eff mg/l	inf mg/l	eff mg/l	% red %	inf mmol/l	eff mmol/l	inf	eff	mg/l	mg/l	l/h	kg BOD / kg MLVSS d	kg BOD / kg MLSS d	days	ml/g		mg/l
7 10 83	Tex+ Dom	10 90	384,1	33	12	91,4	-	-	-	142,8	29	79,7	113,6	25	-	-	- -	-	-	-		1167	1492	0,42	0,45	0,35		-	7,9	-
11 10 83	"	10 90	340	16	-	95,3	-	-	-	124,8	26	79,2	109,1	20	-	-	-	-	-	-		1167	1492	0,42	0,40	0,31		255,4	6,8	-
14 10 83	"	20 80	337,8	20	20	94,1	613	140	77	117,6	29	75,3	106	22	62,4	20,3	67,5	6,5	2,6	9,3	7,6	1893	1992	0,42	0,25	0,23		150,6	6,4	1,2 - 2,5
18 10 83	"	20 80	302,6	12	13	96	428	150	64,9	91,2	13	85,7	80,8	8	52,4	16,6	68,3	6,2	0,6	9,3	6,8	1800	2343	0,42	0,23	0,18		-	5,6	1,2
21 10 83	"	20 80	279,8	13	13	95,4	436	150	65,6	100	10	90	82	3	52	18,4	64,6	4,0	0,5	9,1	6,6	2020	2400	0,42	0,19	0,16		145	6	1,2
25 10 83	"	20 80	306	15	18	95,1	492	110	77,6	103,2	27	73,8	81,2	19	57	6	89,5	4,0	0,4	9,1	6,6	1800	2628	0,42	0,23	0,16		-	-	1,2 - 1,5
28 10 83	"	20 80	277,4	10	10	96,4	656	110	83,2	74	26	64,8	62,4	21	36,7	2,8	92,4	7,4	2,9	9,9	7,9	1643	2628	0,42	0,23	0,15		87,5	6,3	-
1 11.83	"	20 80	245,4	3	5	98,8	608	120	80,2	89	12	86,5	68	0	31	1,6	94,8	7,4	-	9,9	-	2000	3940	0,42	0,17	0,09		-	7,4	-
4 11 83	"	30 70	252,6	5	5	97,6	464	115	75,2	40	0	100	22,4	0	35,7	0,9	97,5	-	5,4	11,4	8	2000	3527	0,42	0,17	0,1		71	7,4	4 - 4,5
8 11 83	"	30 70	224,6	6	6	97,3	429	75	94,2	53	50	5,7	48,5	-	31,9	1,2	96,2	-	5,4	11	8,3	1988	3424	0,42	0,16	0,09		87,9	-	3,5 - 4
11 11 83	"	30 70	417,3	3	3	99,3	574	90	84,3	99	20	79,8	78,6	-	28,8	1,4	95,1	[illegible]	2,1	8,6	7,6	1888	4004	0,42	0,3	0,14		-	-	-
15 11 83	"	30 70	386,5	3	2	99,2	609	50	91,8	76,1	26	65,7	42,1	17	40,7	1,5	96,3	4,1	1,4	9	7,5	2143	5200	0,42	0,25	0,1		122	7	2,5 - 3,5
18 11 83	"	30 70	355,9	3	3	99,2	640	40	93,4	78	25	67,9	55,4	13	38,8	1,5	96,1	5,7	1,4	9,1	7,3	2250	5050	0,42	0,22	0,1		75	7	-

Influent concentrations are computed according to the proportions of the respective waste water

APPENDIX 3

Date	INFLUENT AND EFFLUENT RESULTS: Waste water		BOD7				COD			SS			VSS		NH4-N			Chromium (total)			Alkalinity		pH		REACTOR CONTROL: MLVSS	MLSS	flow	sludge load		sludge age	SVI	pH	DO
	Type	Respective proportion %	inf mg/l	eff mg/l	with ATU	red %	inf mg/l	eff mg/l	red %	inf mg/l	eff mg/l	red %	inf mg/l	eff mg/l	inf mg/l	eff mg/l	red %	inf mg/l	eff mg/l	red	inf mmol/l	eff mmol/l	inf	eff	mg/l	mg/l	1/h	kg BOD / kg MLVSS h	kg BOD / kg MLSS h	days	ml/g		mg/l
25 11 83	Tan+ Dom	10 90	458	13	5	97	836	70	91,6	162	12	92,6	99,2	5	76	1,5	98	13,6	0,03	99,8	2,7	1,1	-	7,2	2223	3400	0,41	0,27	0,18	-	88,2	-	3-4
29 11 83	"	10 90	399	10	6	97,5	899	60	93,3	185	44	76,2	125,3	36	65	2,3	96,5	13,6	0,04	[illegible]	5,6	0,6	-	7	3124	4216	0,41	0,17	0,13	-	90,8	6,6	-
2 12 83	"	10 90	385	24	7	93,8	759	75	90,1	226	30	86,7	168,1	19	49	0,8	98,4	4,9	0,07	98,5	3,8	1	-	7,2	2946	3736	0,41	0,17	0,14	-	86	-	-
6 12 83	"	10 90	417	10	6	97,6	714	80	88,8	149	0	100	105,1	0	48	0,8	98,3	4,9	-	-	3,5	1,1	7	7,1	3876	5095	0,41	0,14	0,11	38,5	-	6,7	1-1,5
9 12 83	"	20 80	580	12	4	98	1456	90	93,8	453	39	91,4	248,4	22	63	6,7	89,[illegible]	19,7	0,05	99,[illegible]	7	2,3	-	7,5	3716	4622	0,35	0,18	0,14	-	-	-	-
13 12 83	"	20 80	695	15	10	97,8	1512	-	-	514	25	95,1	306	8	66	8,3	87,4	19,7	-	-	6,4	1,9	9	7,[illegible]	4359	5500	0,35	0,18	0,15	40,[illegible]	116	6,9	0,25-0,3
16 12 83	"	20 80	674	15	[illegible]	96,3	1272	80	93,7	166	41	75,3	127,6	21	136	104	24	4,5	0,26	[illegible]	4,6	0,4	8,6	6,7	[illegible]801	4581	0,35	0,20	0,17	-	-	6,4	0,3-0,75
20 12 83	"	20-80	681	17	6	97,5	1272	90	93	151	15	90,1	110,8	5	133	112	16	4,5	-	-	4,6	1,2	8,4	7,1	4177	5130	0 35	0,16	0,15	26,4	79,3	5,5	0,5-0,6
23 12 83	"	20 80	894	34	6	96,2	1480	75	95	403	22	94,5	234,4	8	103	91	12	27,8	0,02	99,9	8,8	2,2	9,2	7,5	4203	5189	0,35	0,24	0,20	-	-	6,5	0,5
27 12 83	"	20 80	908	27	7	97	1560	80	95	418	28	93,3	240,8	12	109	30,5	72	27,8	-	-	9,1	2,1	9,1	7,4	4384	5851	0,35	0,24	0,18	18,7	98,2	7,3	0,3-0,5
30 12 83	"	30 70	1195	20	14	98	1980	180	93,4	455	53	88,3	223,2	22	147	17	88	14,2	0,07	99,5	11,1	2	-	7,3	4340	5468	0,35	0,31	0,25	-	-	7,4	0,3
3 1 84	"	30 70	1195	18	12	98,5	1980	200	89,9	455	48	89,5	223,2	14	147	27	81,6	14,2	-	-	11,1	2,2	-	7,3	3816	4959	0,35	0,36	0,27	8	183,2	7,1	-
6 1 84	"	30 70	970	16	7	98,4	2030	140	93,1	410	42	89,8	274	21	123	34	72,3	12,8	0,09	99,3	9,5	1,3	9,6	7,3	3404	4100	0,35	0,32	0,27	-	-	-	-
10 1 84	"	30 70	970	15	12	98,4	2030	110	94,6	410	55	86,6	274	37	123	35,6	71	12,8	-	-	9,5	2,4	9,6	7,5	2400	2900	0,25	0,34	0,28	6,5	348,8	6,5	3
13 1 84	"	30 70	970	7	7	99,3	1277	150	88,2	355	45	87,3	236	22	62	0,5	99,2	57,9	0,28	99,5	4,3	1,5	7,6	7,4	2650	3000	0,25	0,30	0,26	-	326	6,5	2,75-3
17 1 84	"	30 70	970	5	5	99,5	1277	130	89,8	355	28	92,1	236	5	62	0,7	98,9	57,9	-	-	4,3	0,5	-	6,9	2600	3172	0,25	0,30	0,25	-	316,5	-	4

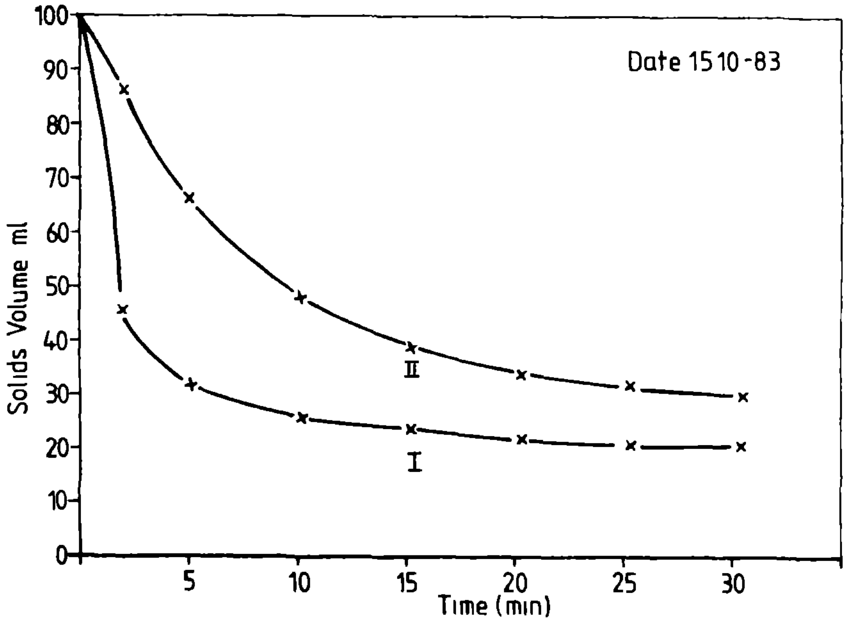
Influent concentrations are computed according to proportions of the respective waste water

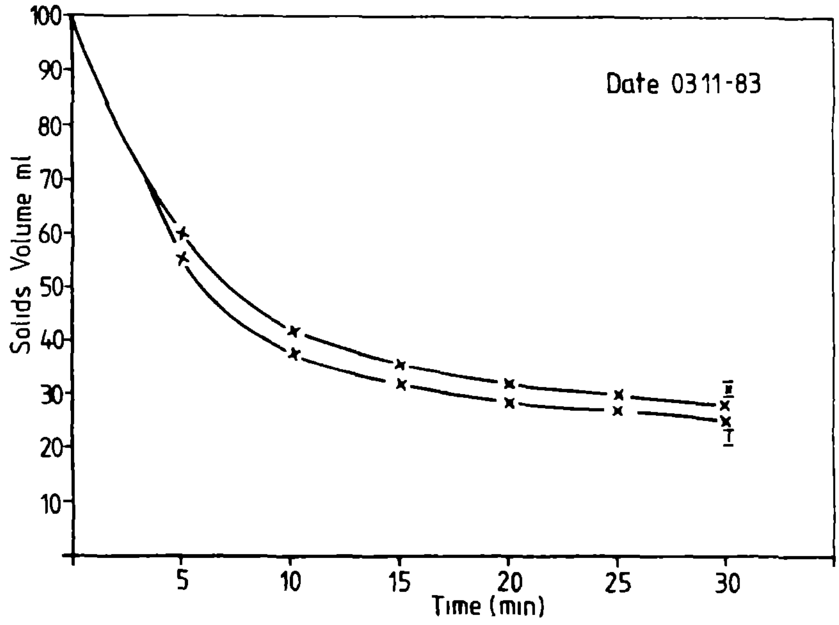
APPENDIX 4

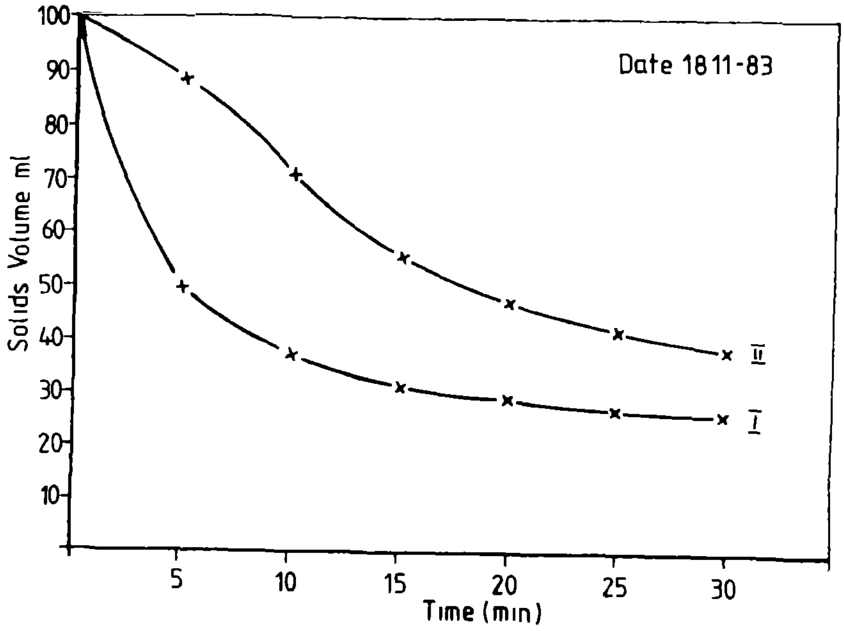
Date	INFLUENT AND EFFLUENT RESULTS: Waste water		BOD7				COD			SS			VSS		NH4-N			Chromium (total)			Alkalinity			pH		REACTOR CONTROL: MLVSS	MLSS	flow	sludge load		sludge age	SVI	pH	DO
	Type	Respective proportion %	inf mg/l	eff mg/l	with ATU	red %	inf mg/l	eff mg/l	red %	inf mg/l	eff mg/l	red %	inf mg/l	eff mg/l	inf mg/l	eff mg/l	red %	inf mg/l	eff mg/l	red %	inf mmol/l	eff mmol/l	red %	inf	eff	mg/l	mg/l	1/h	kg BOD / kg MLVSS h	kg BOD / kg MLSS h	days	ml/g		mg/l
29,11 83	Tan+ Tex+ Dom	10 30 60	350	3	4	99	782	50	94	185	59	68	102	52	52	0,9	98	13,6			4,7	0,7	[illegible]	-	7,1	2120	4016	0,42	0,22	0,12	46	37,3	6,5	1,3
2 12 83	"	10 30 60	360	15	11	96	786	140	82	205	72	65	127	49	40	0,8	98	4,9	0,35	92,8	12	3,7	69,2	-	7,8	2784	3176	0,42	0,18	0,15	-	48,9	-	-
6 12,83	"	10 30 60	380	9	6	98	701	140	80	153	21	86	102,7	0	39	1,5	96	4,9	-	-	11,8	2,6	78	9,4	7,5	2400	4243	0,42	0 22	0,12	64	-	7,4	2,6
9 12 83	"	20:30 50	623	10	10	98	1351	180	87	445	5	99	238,8	0	52	4,1	92	19,7	0,4	98	14,8	6,3	57,4	-	8,1	2986	4365	0,35	0,24	0,16	-	-	-	-
13 12 83	"	20 30 50	694	22	6	97	1423	-	-	483	70	85,5	281	42	54	18,7	65,3	19,7	-	-	14,5	10,9	24,8	11,3	8,2	3501	5361	0,35	0,23	0,15	40	77,9	7,9	0,2
16 12 83	"	20 30 50	637	12	6	98	1250	100	92	148	65	56	115	42	124	122	1,6	4,5	0,05	98,8	5,1	5,8	-	9	7,9	3527	5231	0,35	0,21	0,15	-	-	7,8	0,2
20 12 83	"	20 30 50	642	11	5	98	1250	110	91	140	41	71	104,5	25	123	90	26,8	4,5	-	-	5,1	1,1	78,4	8,7	7,3	3496	4624	0,35	0,21	0,16	23	180,4	6,9	0,4
23 12 83	"	20 30 50	869	62	9	93	1490	120	92	392	38	90	221,8	19	94	73	22,3	27,8	0,15	99,5	11 4	8,9	33,6	11,1	8	3484	5008	0,35	0,28	0,20	-	-	6,9	0,2
27.12 83	"	20 30 50	880	27	7	97	1449	80	94	401	29	93	225,8	14	98	46	53	27,8	-	-	13,6	2,1	84,6	10,7	8	4081	6800	0,35	0,25	0,15	20	161,3	7,7	0,2
30.12 83	"	30 30 40	1188	20	14	98,3	2264	180	92	440	48	89	208,8	18	75	17	77,3	14,2	0,1	99,9	12 2	4,2	65,6	-	7,9	3943	6696	0,35	0,34	0,20	-	-	7,5	0,2
3.1.84	"	30 30:40	1188	15	14	98,7	2264	220	90,3	440	50	88,6	208,8	14	75	15,4	79,5	14,2	-	-	12,2	3	73,8	-	7,6	3804	5868	0,35	0,35	0,23	8,7	146,6	7,5	-
6.1 84	"	30 30 40	944	14	10	98,5	1944	170	91,2	384	44	88,5	249,4	27	113	81	28,3	12,8	0,1	99,9	8 8	4,4	50	9,7	7,6	3146	4500	0,35	0,34	0,24	-	-	-	-
10 1 84	"	30 30:40	944	15	8	98,4	1944	140	97,9	384	47	87,8	249,4	27	113	97	14,2	12,8	-	-	8 8	5,6	36,4	9,7	7,7	2196	3269	0,25	0,36	0,24	9	301,4	-	4-4,5
13.1 84	"	30 30 40	944	10	9	98,9	1340	180	86,6	342	42	87,7	224,3	6	52,1	27	48,2	57,9	0,16	99,7	[illegible]	2,7	33,2	8,3	7,8	2146	3108	0,25	0,36	0,25	-	331,4	-	4-5
17.1 84	"	30 30 40	944	8	7	99,1	1340	150	88,8	342	1159	-	224,3	874	52,1	13,9	73,3	57,9	-	-	4	2,6	35,6	-	7,8	2272	2724	0,25	0,34	0,28	-	352,4	-	2,5-3

Influent concentrations are computed according to proportions of the respective waste water

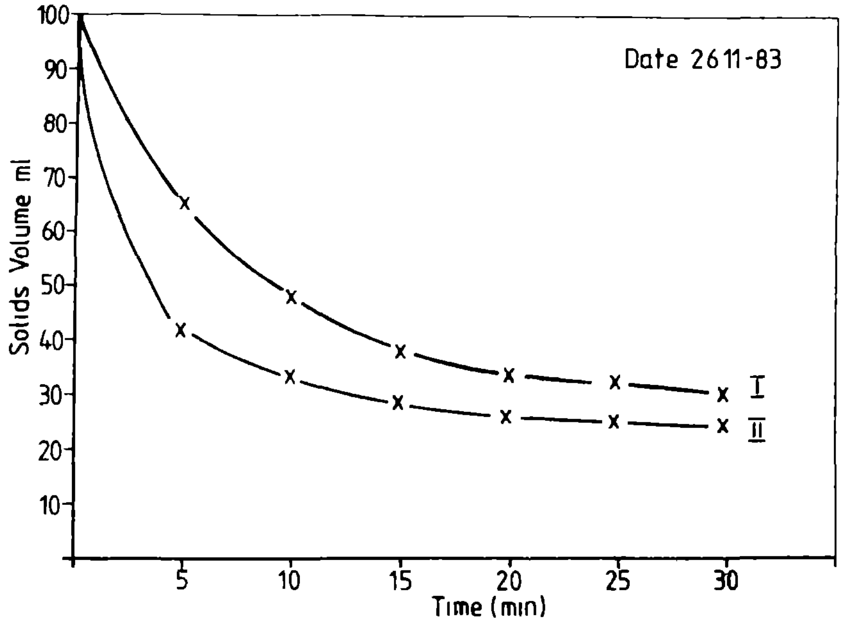
APPENDIX 5

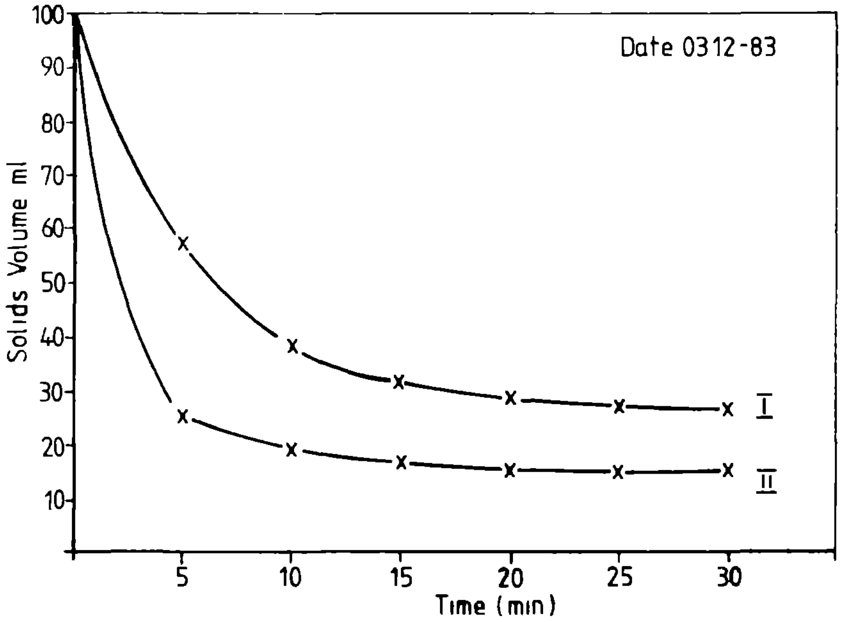

Date 1510-83
Solids Volume ml
Time (min)
0
10
20
30
40
50
60
70
80
90
100
5
10
15
20
25
30
I
II

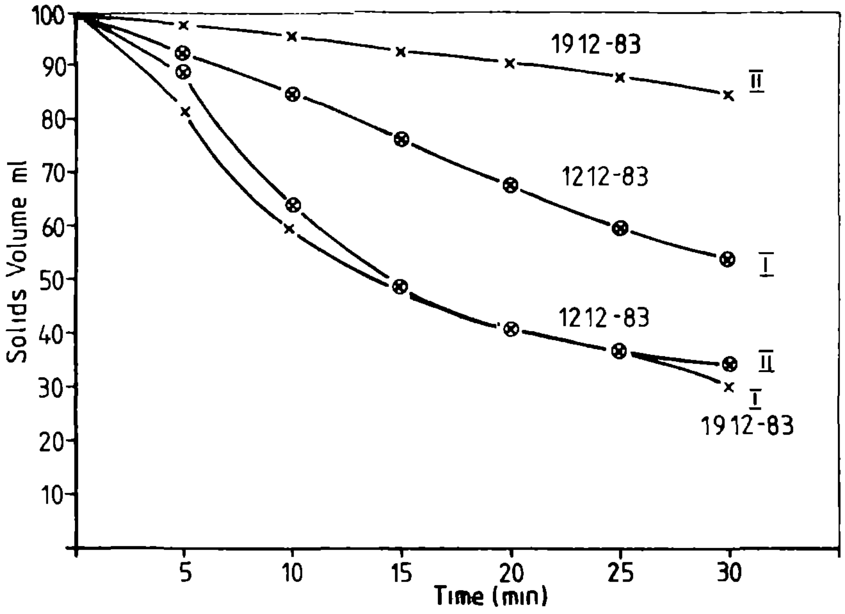

Date 0311-83
Solids Volume ml
Time (min)
10
20
30
40
50
60
70
80
90
100
5
10
15
20
25
30
I
II


Date 1811-83
Solids Volume ml
Time (min)
10
20
30
40
50
60
70
80
90
100
5
10
15
20
25
30
I
II

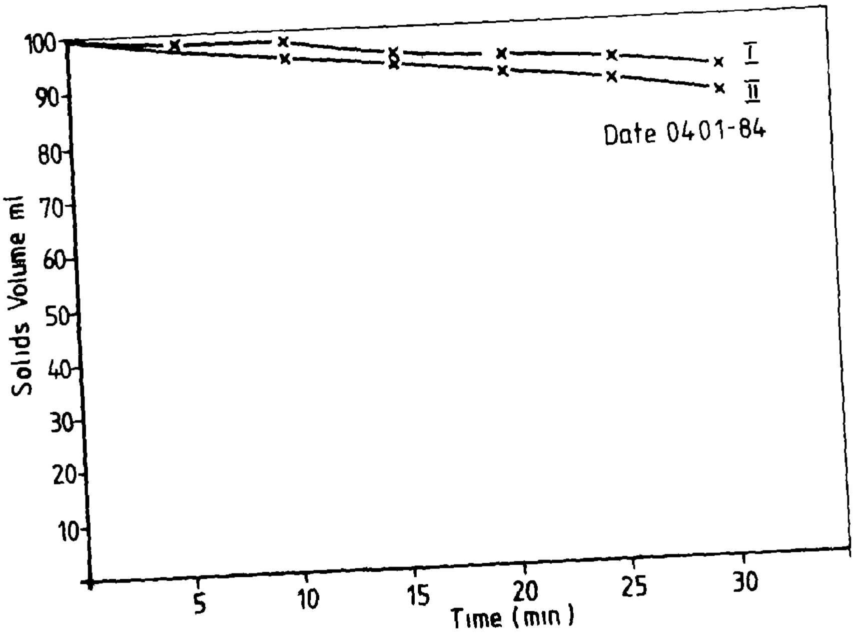
APPENDIX 6


Date 2611-83
Solids Volume ml
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
Time (min)
I
II

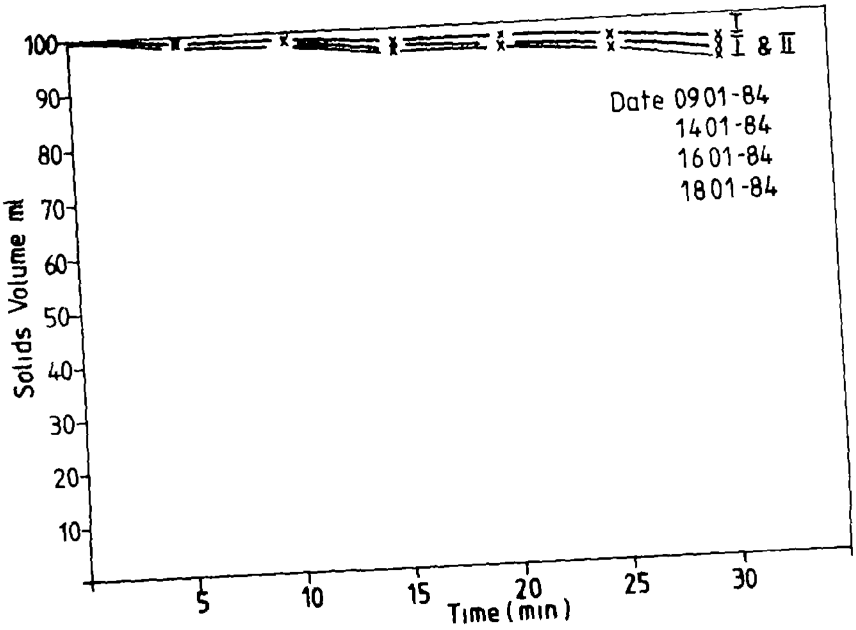

Date 0312-83
Solids Volume ml
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
Time (min)
I
II


1912-83
II
1212-83
I
1212-83
II
I
1912-83
Solids Volume ml
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
30
Time (min)

APPENDIX 7



Date 0401-84



Date 0901-84
1401-84
1601-84
1801-84