AN INVESTIGATION INTO BIOLOGICAL
TREATMENT OF FRUIT
CANNERY WASTES

by

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A Thesis submitted in partial fulfilment of the
requirements for the Degree of Master of Science
in the Faculty of Engineering, University of
Cape Town.

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September, 1975

DECLARATION OF CANDIDATE

I, Ian Law, hereby declare that this thesis is my own work and that it has not been submitted for a degree at another university.

Signed by candidate

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ACKNOWLEDGEMENTS

I wish to express my gratitude to the following :

Professor G.v.R. Marais, Water Resources and Public Health Engineering, University of Cape Town, under whose guidance and supervision this research was conducted. His advice throughout this work is very much appreciated.

Mr. R.F. Beverton, laboratory technician in the Department of Civil Engineering, whose expertise in constructing the apparatus made the laboratory scale experiments possible.

Mr. T. Lakay, of the laboratory staff, who carried out all the analytical work on the disc system as a form of 'secondary' treatment.

Mr. G. Steenveld who carried out the experimental work on the disc system as a form of 'roughing treatment' for cannery wastes.

Mrs. G. Frost who patiently typed the script, and Mr. C. Basson who produced the manuscript.

My Brother-in-Law Hugh, and his girlfriend Shealagh, who performed the arduous task of producing the photographs.

Finally, my wife for her patience and encouragement throughout this work.

CHAPTER 1

INTRODUCTION.

The production of canned fruits and vegetables in the Republic of South Africa is an important factor in the country's export trade. South Africa exported goods valued at R2 016m in 1972, of which R69m was accounted for by canned fruits and vegetables. (Bulletin of Statistics 1974 and Stats 1974).

The major fruit and vegetable growing areas are in the Western Cape and the canneries are situated in those towns in close proximity to both the farms and railheads.

The wastewaters generated by the numerous canneries vary greatly in composition - being dependent upon the particular fruit or vegetable being processed. The wastes generally have high BOD or COD concentrations (mainly due to sugars and starches) and low concentrations of the nutrients, nitrogen and phosphorus.

In many towns the seasonal 'pollution' load from the canneries can exceed by several times the municipal load. Usually the municipal waste water treatment facilities are inadequate to handle the seasonal peak loads. This, in conjunction with the nutrient deficient nature of the cannery wastes, results in poor treatment efficiencies being recorded at the purification works.

The city of Paarl (population 70 000) is situated on the banks of the Berg River in the Western Cape. This river is the most important river in the area, used extensively by riparian farmers. Strict control of all effluent discharges into the river is maintained by the State.

Paarl has separate sewers for industrial and domestic waste waters. At the sewage works the industrial effluent and domestic sewage undergo separate grit removal and settlement prior to mixing and treatment on biological filters. After settlement in humus tanks the total flow is directed to maturation ponds, the final effluent discharging into the Berg River.

The main contributors to the industrial waste flow are two fruit canneries, H. Jones and Company and Langeberg Ko-operasie, and a textile factory, Berg River Textiles. The waste flow from Berg River Textiles is fairly constant throughout the year; in contrast, the waste flow from the two canneries is highly seasonal. January to the end of April of each year constitutes the period of high seasonal activities for the canneries with canned peaches, apricots and pears being produced. The waste discharged during this period is approximately three-quarters of their annual discharge.

The variation in flow of both industrial and domestic wastes during 1973 is shown in Fig. 1.

Fig. 2 shows the variations in strength (measured in terms of Permanganate Value and Chemical Oxygen Demand (PV and COD)) of the industrial and domestic wastes over the same period.

Figs. 3 and 4 show the 'pollution load' (as kg COD. day^{-1} and kg PV. day^{-1} respectively) of the industrial and domestic wastes after primary settlement during 1973. Fig. 4 shows that the design capacity of the biological filters was exceeded during the months of February and March, with the peak loading in February exceeding the capacity by approximately 100 per cent.

It is of interest to note that the 'population equivalent (based on the PV) of the industrial wastes, after primary settlement, for the month of February was 1 200 000 people (c.f. Paarl's population 70 000).

The canneries' contribution to the total industrial load arriving at the sewage works during the canning season has been estimated as 89 per cent based on PV, and 91 per cent based on COD (Abbott,1973).

The performance of the biological filters during 1973 is shown in Figs. 5 and 6 - in terms of PV and COD respectively. The poor COD removals obtained during the canning season, as opposed to the high PV removals obtained over the same period, would indicate that the PV is a misleading parameter with which to monitor the filters' performance.

A record of the performance of the maturation ponds in terms of COD is not available. However it has been established that with an influent loading of 500 kg PV. day^{-1} the ponds produce an effluent with a PV very close to the 10 mg l^{-1} standard laid down by the Department of Water Affairs.

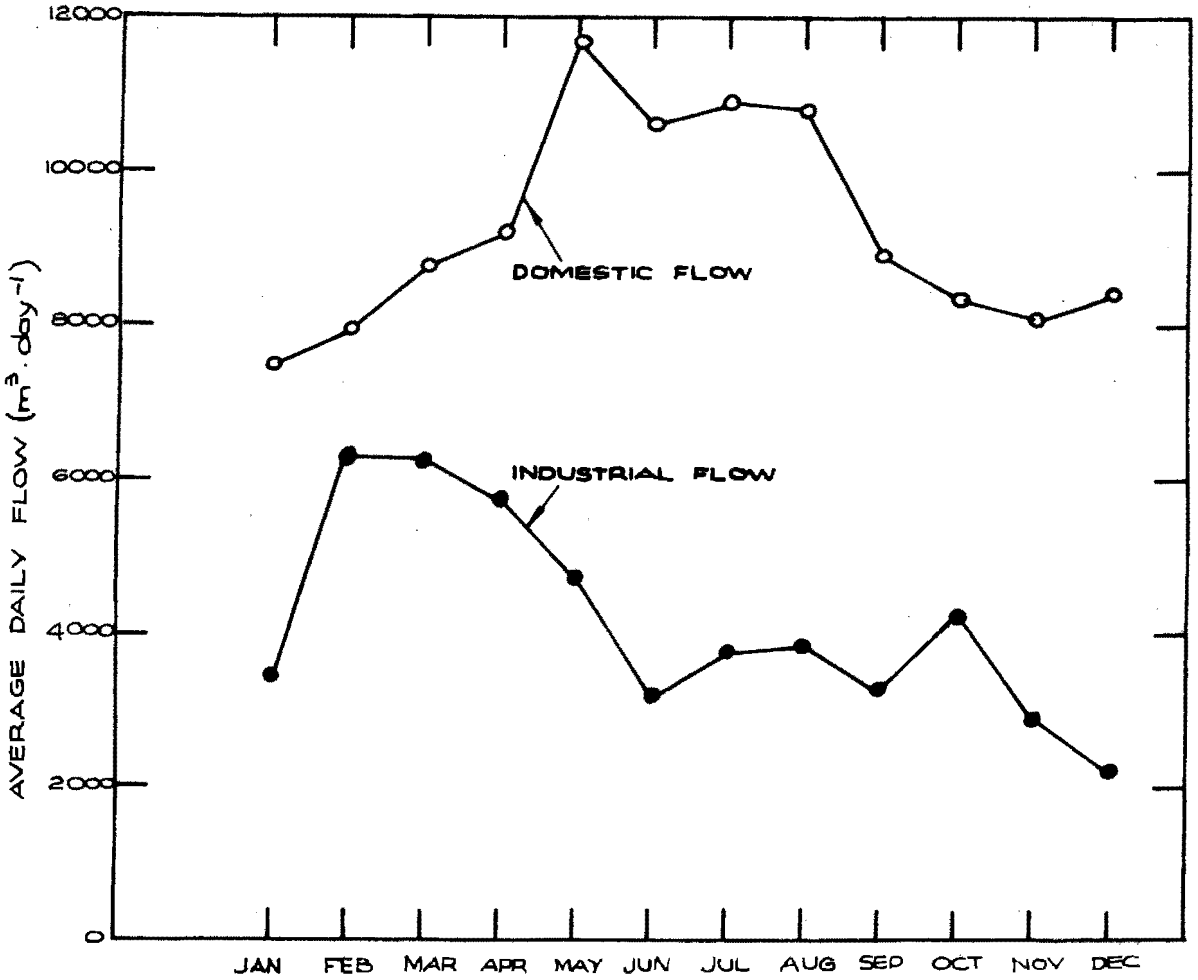


FIGURE 1: AVERAGE DAILY FLOWS FOR 1973

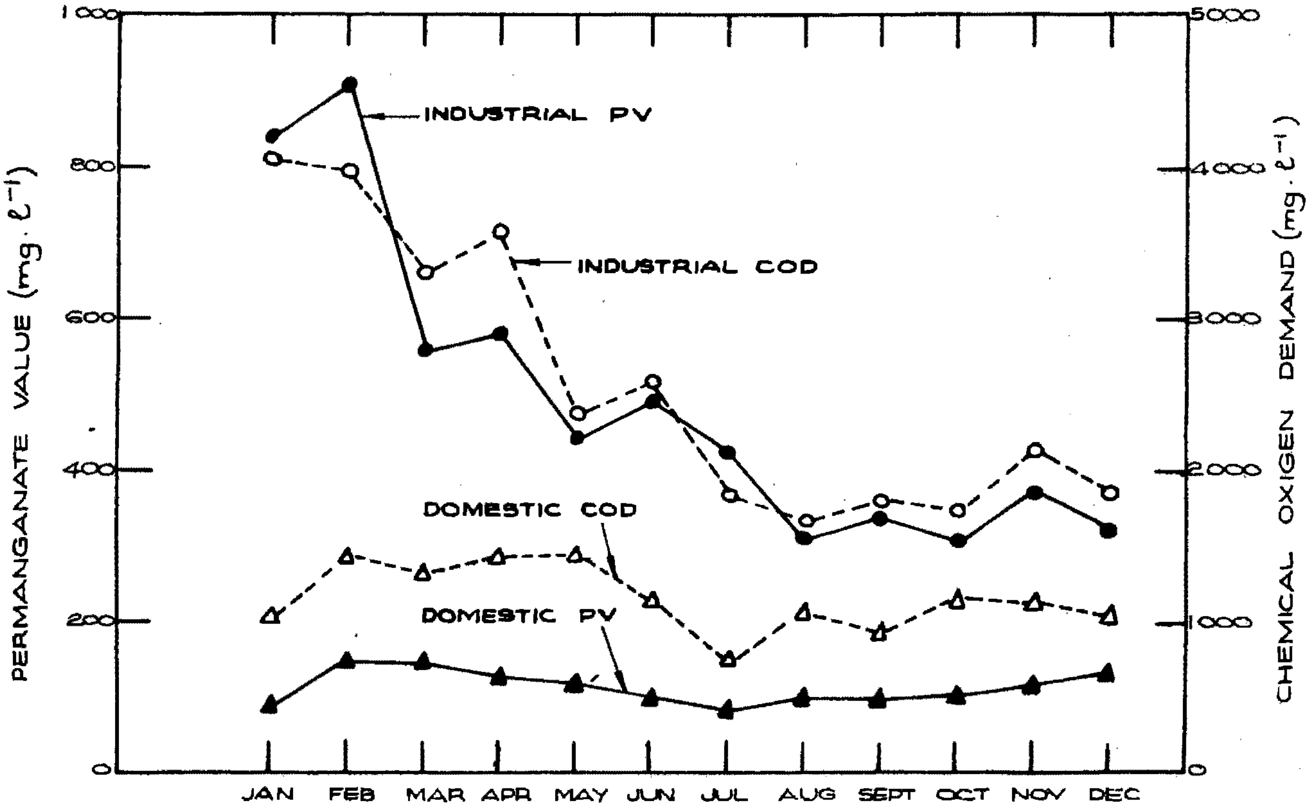


FIGURE 2: STRENGTH OF WASTES DURING 1973

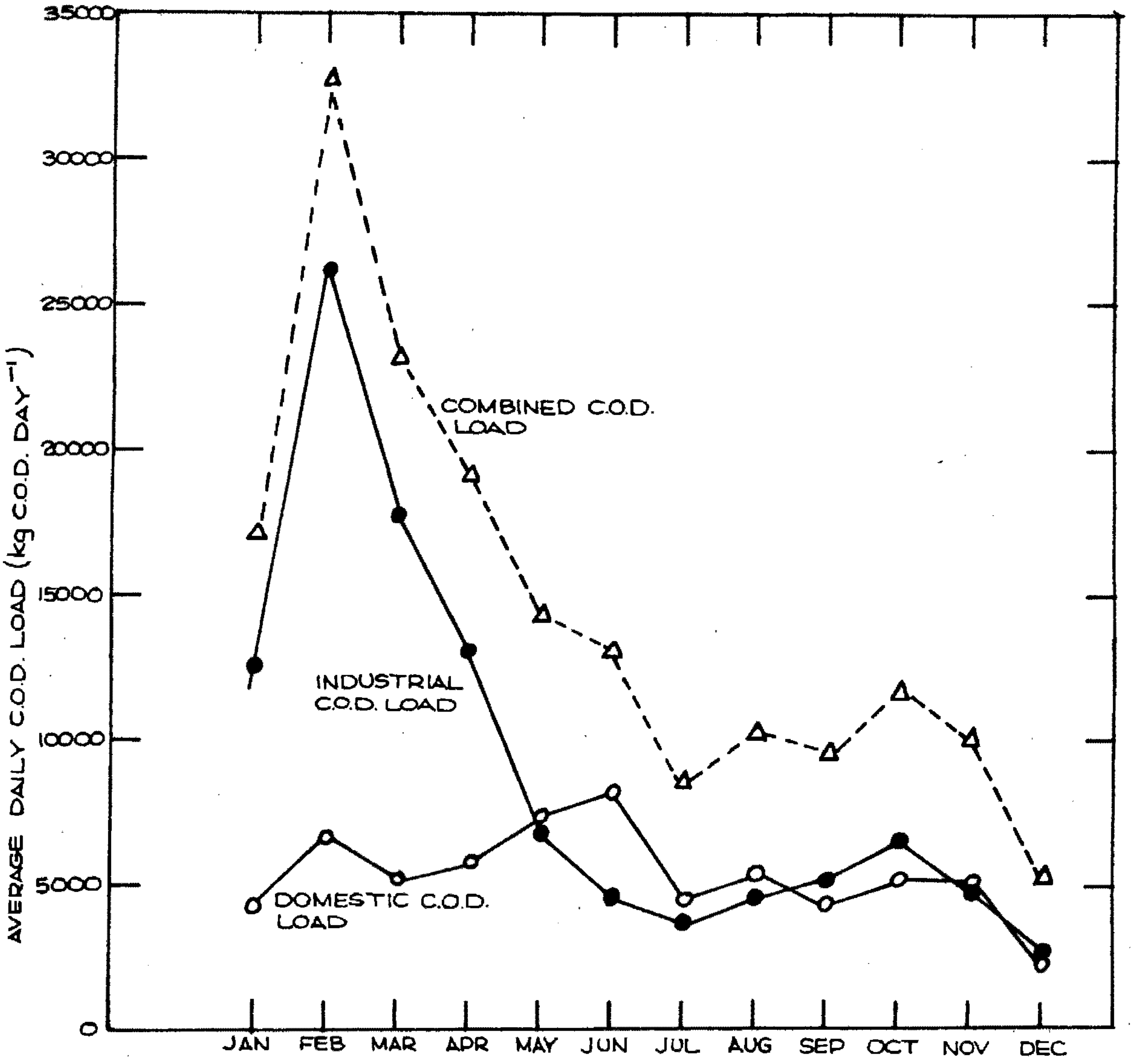


FIGURE. 3: AVERAGE DAILY COD. LOAD (kg COD. day^{-1})

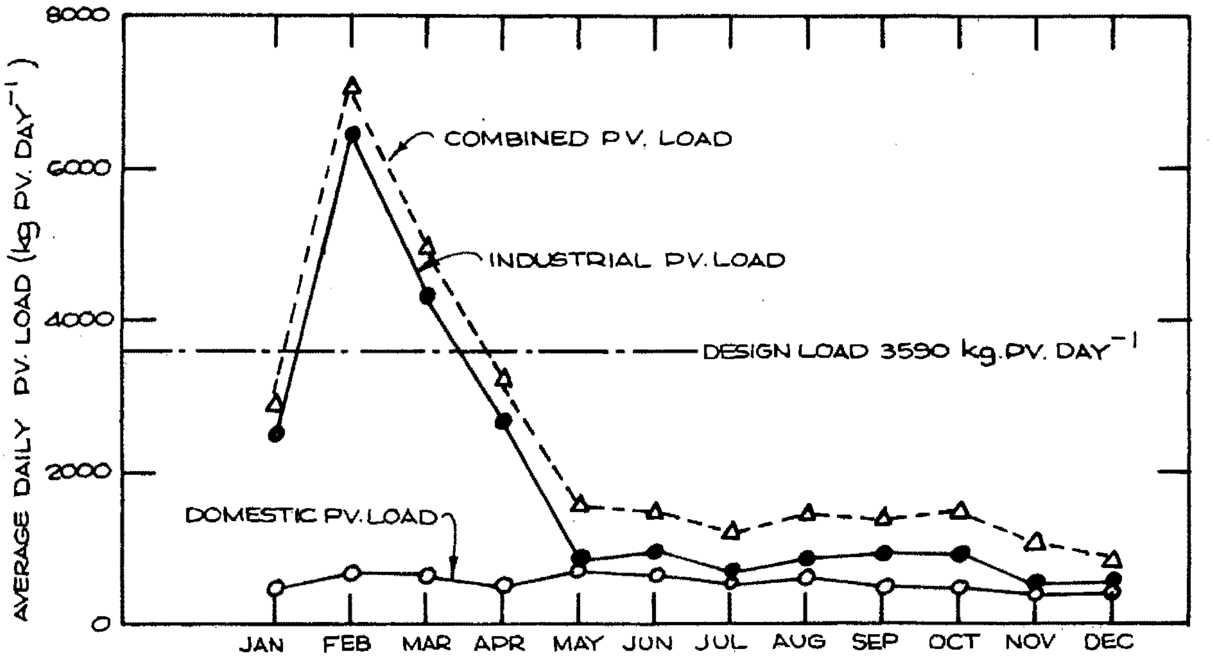


FIGURE 4: AVERAGE DAILY PV. LOAD (kg PV. day^{-1})

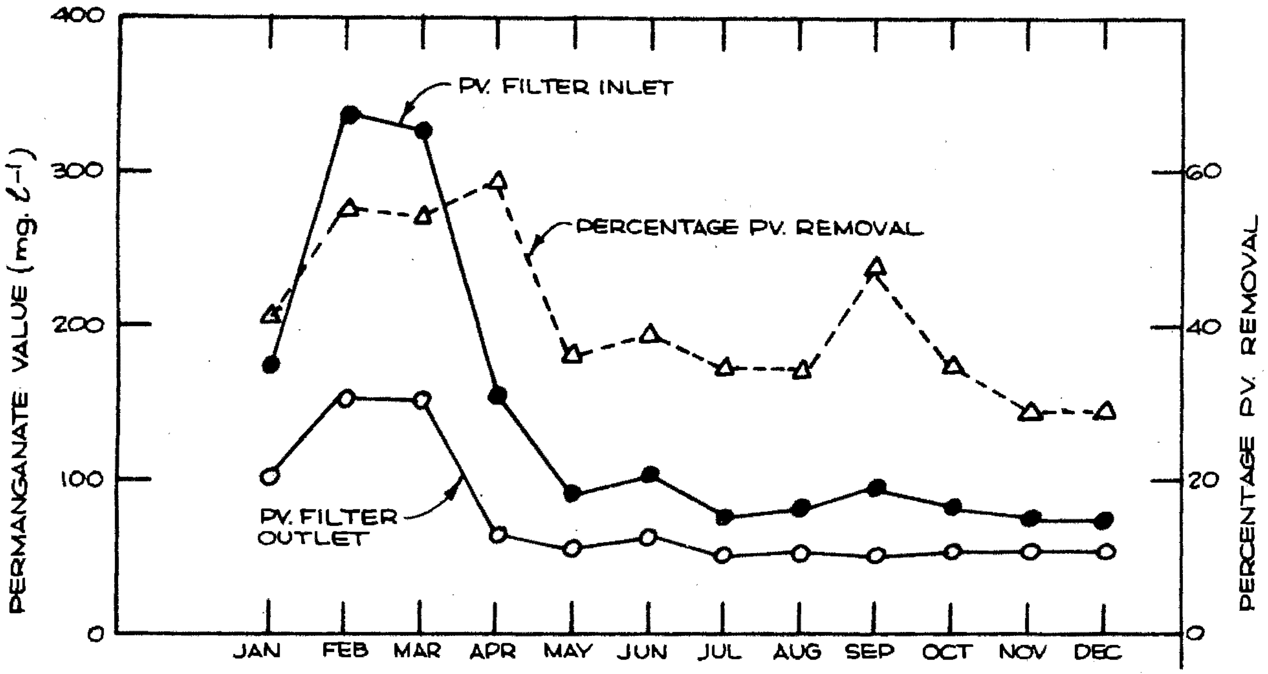


FIGURE 5: BIOLOGICAL FILTERS' PERFORMANCE DURING 1973– BASED ON P.V.

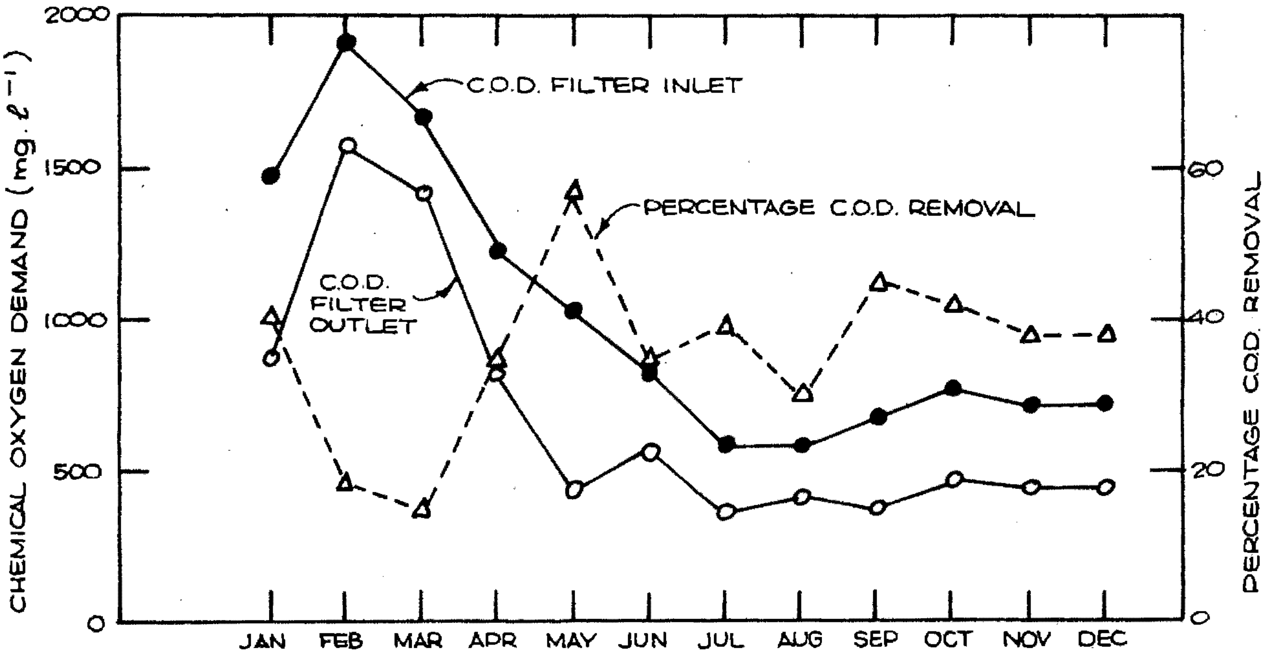


FIGURE 6: BIOLOGICAL FILTERS' PERFORMANCE DURING 1973– BASED ON COD.

During the 1973 season the loading on the ponds was consistently greater than 500 kg PV. day^{-1} – with a peak value of 1 600 kg PV. day^{-1} being recorded in February. This overload of approximately 220 per cent resulted in a substandard effluent being produced.

In order to deal with the seasonal load it was concluded (Ninham Shand and Partners report, September, 1973) that instead of providing additional primary treatment, secondary treatment of the effluent from the existing works would be the most feasible and economical. Three alternative forms of secondary treatment were proposed :-

(i) Secondary biological filtration
(ii) Activated sludge treatment
(iii) Biological disc treatment.

This thesis deals with the investigations into (i) the activated sludge, rotating biological disc and secondary biological filtration as forms of secondary treatment, and (ii) the biological disc system as a form of 'roughing' treatment for the industrial waste.

CHAPTER 2

LITERATURE REVIEW.

TREATMENT OF CANNERY WASTES

Cannery wastes have been treated by screening, chemical precipitation, lagooning, spray irrigation, biological filtration and activated sludge.

Screening

Screening is an essential part of cannery waste treatment, being designed to remove large solids prior to further treatment or discharge to the municipal sewers. Screening removes only a small fraction of the waste BOD. (Nemorow, 1971).

Mechanically operated screens (mesh size varying from 12 to 30) of either the rotating or vibrating type are used, with surface area averages of 0,1 m^2 per 700 l. of wastes per hour (Koziorowski et al,1971).

Typical 'screening' production figures are reported as 40 to 50 pounds per 1 000 gallons of waste water (i.e. 4 to 5 kg. m^{-3} of waste) with moisture contents of between 70 and 95 per cent (Nemerow, 1971).

The 'screenings' are disposted of in various ways; spread on the ground, used for land fill, dried and incinerated or used to supplement animal feed.

Chemical Precipitation

Chemical preceipitation is used to remove colloidal suspended matter, the largest concentrations of which occur in wastes from the processing of leguminous vegetables, mainly peas (Koziorowski et al,1971). It has been applied effectively to treat apple, tomato and cherry wastes (Nemerow, 1971). Ferric salts or aluminate and lime have produced 40 to 50 per cent BOD reductions, with dosages of 500 to 1 000 mg. l^{-1} of lime plus 100 to 800 mg. l^{-1} of ferric sulphate or alum (Nemerow,1971).

The quantity of sludge produced is 10 - 15 per cent of the volume of waste treated, and is reported to dry easily on drying beds (Koziorowski et al, 1971). Area requirements for the drying beds have been reported as 1 m^2. m^{-3} of waste flow (Eldridge,1942).

Stabilisation Ponds (lagoons)

Only when adequate land is available is stabilisation pond treatment practical and economical. Both anaerobic and aerobic lagoons have extensive application in the treatment of screened cannery wastes in Australia (Parker, 1966). Anaerobic lagoons loaded at 600 lb BOD. $acre^{-1}$. day^{-1} (670 kg BOD. $hectare^{-1}$. day^{-1}) and followed by aerobic lagoons loaded at 50 lb BOD. $acre^{-1}$. day^{-1} (60 kg BOD. $hectare^{-1}$. day^{-1}) are reported to effect 70 - 80 per cent BOD reductions.

Eckenfelder (1971) reported the optimum BOD loading for anaerobic lagoons as 390 lb BOD. $acre^{-1}$. day^{-1} (440 kg BOD. $hectare^{-1}$. day^{-1}) and for aerobic/facultative lagoons as 140 lb BOD. $acre^{-1}$.day^{-1} (160 kg BOD. $hectare^{-1}$. day^{-1}).

Lagoons aerated by means of surface aerators have been used extensively to treat food cannery wastes in America (Eckenfelder,1971). Two types of aerated lagoons are commonly used (Mohanrao,1973) :

(1) Completely aerobic lagoons requiring a power imput of 0,1 hp. 1 000 gal^{-1} of basin volume (0,02 kW. m^{-3}), and

(2) Facultative lagoons requiring 0,01 - 0,02 hp. 1 000 gal^{-1} of basin volume (0,002 - 0,003 kW. m^{-3}).

The power requirement for completely aerobic lagoons is based on mixing requirements, whereas that for facultative lagoons is based on the oxygen requirements.

The lower power input in a facultative lagoon results in mixing velocities being insufficient to keep the solids in suspension. Solids settle to the bottom where they undergo anaerobic decomposition. The aerators maintain an aerobic 'strip' above the anaerobic zone, thus preventing odour release.

Depths of both types of lagoons are governed by the choice of aerator. The lagoons should be deep enough to prevent scour of the bottom. Width and lengths of the lagoons are governed by the aerator spacings required for the particular application.

Eckenfelder(1971), Lisanti and Balakrishnam (1974) and Mohanrao (1973) all report 90 - 95 per cent BOD reductions on screened cannery wastes.

Spray Irrigation

Spray Irrigation is an economical and unobjectionable method of treatment. The feasibility of employing this method is influenced by several factors (Luley, 1973) :

(i) slope of terrain,
(ii) characteristics and extent of soil surface cover including vegetation,
(iii) characteristics of the earth layers in the upper part of the soil profile,
(iv) depth of the groundwater table,
(v) quantity of the waste effluent,
(vi) salinity of the waste [Luley (1963) states that no apparent adverse effect on crops will be noticed if the total salinity does not exceed 0,15 per cent].
(vii) pathogenicity of the waste.

Luley states that flat terrain and permeable soils are accepted as ideal for spray irrigation. High BOD reductions are obtained as the waste percolates through the vegetation and soil. The waste must be applied at rates which do not result in run-off or ponding on the land. Good reductions are obtained by spraying 12 - 18 mm daily, or 75 - 100 mm over an 8 hour period every 7 days. The rate of irrigation may be increased up to 10 times when spraying woodlands (Koziorowski <u>et al</u>, 1971).

Typical spray irrigation application rates employed in America are shown in Table 1.

A spray run-off system has been developed for sloping terrain and impermeable soils (Luley, 1963). Extensive tests carried out in America (Law <u>et al</u>, 1970) indicated that 61 per cent of the waste applied to the slopes returned to surface streams as run-off. This run-off was reported as having undergone 92 - 99 per cent reduction in BOD, 83 - 90 per cent reduction in total nitrogen and 50 - 60 per cent reduction in total phosphorus.

TABLE 1 : Spray Irrigation performance (After Eckenfelder 1958)

Product	Pump rate, gpm	Total area sprayed, acres	Rate of application, gpm/acre	Average application, in./day	Average loading	
					lb BOD/ acre/day	lb suspended solids/ acre/day
Tomatoes	1000 500	5.63 6.4	178 86	2.96 0.70	413 155	364 139
Corn	350	2.28	153.5	3.35	864	500
Asparagus & beans	253	0.9	282	3.5	22.5	356
Tomatoes, corn and lima beans	430	9.18	43.8	0.375	40.5	14.7
Lima beans	430	6.65	65	0.375	65	46
Cherries	216	2.24	96.5	3.61	807	654

Biological Filtration

In all biological treatment processes the cannery wastes are found to be deficient in the essential nutrients, nitrogen and phosphorus; to attain the correct balance they are usually mixed with domestic sewage.

In biological filtration of cannery wastes, the filters are normally of the high rate variety, being loaded at 0,5 to 2,0 lb BOD.Yd^{-3}. day^{-1} (295 to 1 180 gBOD.$m^{-3}day^{-1}$). BOD removal rates of 90 - 95 per cent have been reported in America (Nemerow, 1971).

The high rate filters at Paarl sewage works are loaded at rates of up to 1 000 g PV.m^{-3}.day^{-1}, 3 500 g BOD.m^{-3}.day^{-1} and 6 000 g COD.m^{-3}.day^{-1}. Removal efficiencies of 70 per cent based on PV, 30 per cent based on BOD and 25 per cent based on COD have been reported (Abbott, 1973). The COD:N:P ratio in the combined flow to filters during the canning season approximates 100:1,4:0,3. Nutrient deficiency is indicated when compared with the ratio of 100 COD:5,2 N:0,86 P, accepted by Marais (1975).

Activated Sludge

Investigations into the use of activated sludge to treat cannery wastes were initiated in the United States around 1950, and since then a few pilot and full scale plants have been built. (Eckenfelder *et al*, 1969).

Two trends are apparent in this method of treatment :

(i) treatment of cannery wastes alone, and

(ii) treatment of a mixture of cannery wastes and domestic sewage.

Irrespective of whether the cannery wastes were treated alone or mixed with domestic sewage it was found necessary to add a nitrogen and phosphorus source.

Nemerow (1971) investigating the conventional activated sludge process to treat cannery wastes alone obtained 90 to 95 per ent BOD reduction on an influent BOD of 1 500 $mg.l^{-1}$. (Hydraulic retention times of between 3 and 5 hours and BOD loadings of 1,7 to 2,5 kg $BOD.kg\ MLSS^{-1}.day^{-1}$). However, no data is reported on the settleability of the mixed liquor in the final settling tank.

Eckenfelder and Grich (1969), using pilot plant data, designed a full scale activated sludge plant to treat cannery wastes. They employed a high rate 'Contact Stabilization Process'. This process differs from the conventional activated sludge process in that the sludge drawn off from the final settling tank undergoes a period of aeration in a separate tank prior to being pumped back to the aeration tank. Table 2 indicates the performance of the process.

From Table 2, the following points are of interest :

(i) The biodegradable portion of the waste adsorbs very readily onto the sludge. This is indicated by the relatively high percentage BOD reductions achieved in the very short aeration retention times.

(ii) Peach canning wastes are apparently not as readily treatable as other cannery wastes. The percentage BOD reductions for the peach waste in both the full scale plant and pilot plant are considerably lower than for the other wastes.

Eckenfelder reported on the settleability of the mixed liquor. The sludge from the peach waste plant was dark brown in colour with a sludge volume Index (SVI) of 600 - 700 $ml.g^{-1}$. (A well settling sludge has an SVI of approximately 150 or less). It would seem therefore that from a practical point of view the peach waste mixed liquor was completely unsettleable.

TABLE 2 : PERFORMANCE OF HIGH RATE "CONTACT" ACTIVATED SLUDGE PROCESS

Waste	Det. Time (min)		Raw BOD (ppm)	% BOD Red	BOD Ldg. (lb/day/lb sludge)		O_2 Utiliz. (lb/hr/1000gal)		Suspended Solids	
	Aer.	Stab.			Aer.	Aer. & Stab.	Aer.	Aer. & Stab.	Aer.	Stab.
FULL SCALE PLANT										
Tomato	48	96	412	85.0	2.82	1.08	1.05	2.05	2250	3600
Peach & Tomato	39	78	740	58.0	3.82	1.44	0.96	2.56	3600	5900
Tomato & Apple	60	120	492	89.7	2.42	0.87	1.52	3.04	2500	4400
Apple	285	—	630	81.6	2.56	—	3.38	—	2500	—
PILOT PLANT										
Tomato	21	100	450	84.0	12.4	1.29	—	—	2500	4500
Peach	30	140	2240	64.3	36.0	4.00	—	—	3000	5000
Apple	50	240	1040	77.0	14.6	1.86	—	—	2500	3500

Esvelt and Hart (1970) conducted an investigation into the treatment of screened fruit cannery wastes. An aerated lagoon and an activated sludge plant were operated in parallel. Table 3 indicates the results obtained :-

TABLE 3 : PERFORMANCE OF AERATED LAGOON AND ACTIVATED SLUDGE PROCESS (after Esvelt and Hart, 1970)

	Screened Waste			Effluent		
	Flow ($m^3.d^{-1}$)	BOD ($mg.l^{-1}$)	COD ($mg.l^{-1}$)	BOD ($mg.l^{-1}$)	COD ($mg.l^{-1}$)	SS ($mg.l^{-1}$)
AERATED LAGOON						
Pear processing	6 730	2 080	2 870	460	1 050	640
Peach processing	9 180	860	1 510	115	710	520
ACTIVATED SLUDGE						
Peach processing	9 180	860	1 510	20	120	66
Pear processing	8 500	1 600	2 290	9	55	15
Apple processing	1 950	1 190	1 500	5	28	11

From their paper the following further information is of interest :

(i) The activated sludge process effected a 90 per cent COD reduction at loadings of less than 0,4 kg COD. kg $MLVSS^{-1}.day^{-1}$.

(ii) The aerated lagoon system effected a 60 - 70 per cent BOD reduction with a hydraulic residence time of 4 days.

(iii) The effluent from the aerated lagoon consistently contained high concentrations (400 - 700 $mg.l^{-1}$) of suspended solids.

(iv) The excess activated sludge had a volatile content of 90 per cent and settled very poorly. SVI values ranged from 400 - 290 $ml.g^{-1}$ as the loading was reduced from 0,26 - 0,04 kg $COD.kg^{-1}$ $MLVSS.day^{-1}$. Filamentous organisms were responsible for the high SVI values.

In the treatment of a mixture of cannery waste and domestic sewage, Norgaard, Hicks and Reinsch (1967) performed pilot plant studies at San Jose, California. They investigated both anaerobic digestion and activated sludge treatment. In the activated sludge studies, several modifications to the process were investigated :

(i) Aerated lagoon treatment with final sedimentation but without return of sludge.

(ii) Preliminary aeration of the raw waste prior to treatment in a "Contact stabilization" plant.

(iii) Primary sedimentation followed by treatment as in (ii) above.

(iv) Conventional activated sludge treatment of the raw waste.

(v) Treatment as in (iv) above with occasional use of sludge reaeration in an attempt to control bulking and to improve settleability.

A plot of BOD loadings versus BOD removal efficiency is shown in Fig. 7 for all the modifications. The plots indicate that at the loadings investigated, conventional activated sludge treatment gave the highest BOD removals (see the curves marked "Activated Sludge"). However, comparing the activated sludge plots, the peach-pear waste again showed significantly poorer results than the tomato-pear waste. This corroborates the findings of Eckenfelder that peach waste appears to be less amenable to treatment than other cannery wastes.

As a result of the studies above, Norgaard <u>et al</u> concentrated their efforts on the conventional activated sludge treatment of the cannery wastes. From their paper the following further information is of interest :

(i) The effect of load on the efficiency of the process is illustrated in Fig.8. The figure shows a plot of efficiency versus sludge loading rate (lb BOD.100 lb $MLSS^{-1}.day^{-1}$.). Below a loading of 50 lb BOD.100lbM$LSS^{-1}.day^{-1}$ the efficiency of the plant was practically steady at 95 per cent. Above this loading the efficiency reduced progressively.

(ii) SVI values ranged from 170 to 670 $ml.g^{-1}$. Filamentous organisms were found to be responsible for the bulking sludge.

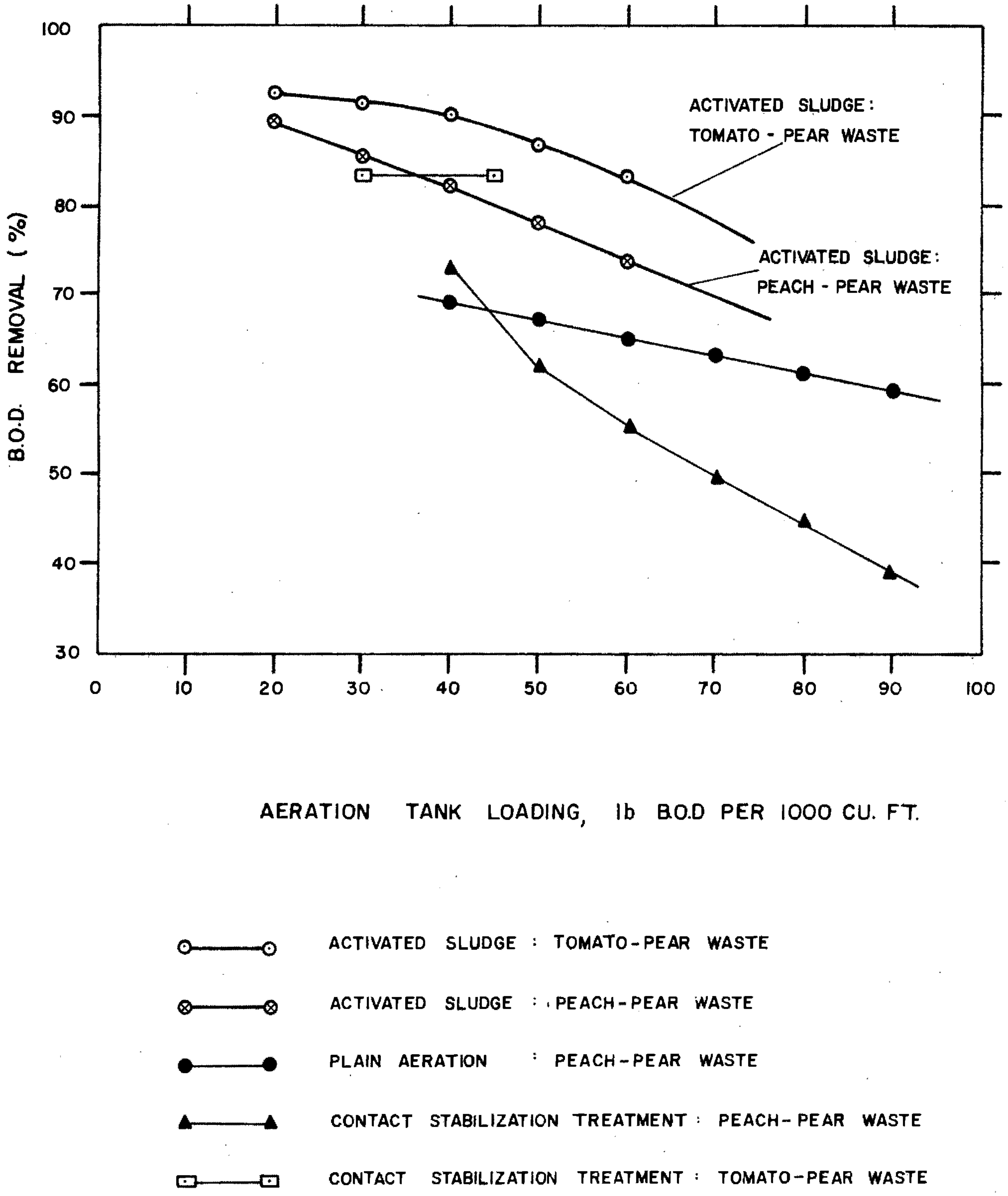


FIG. 7: PERFORMANCE OF THE ACTIVATED SLUDGE MODIFICATIONS

(iii) Sludge ages employed throughout the investigations varied from 1 to 4 days.

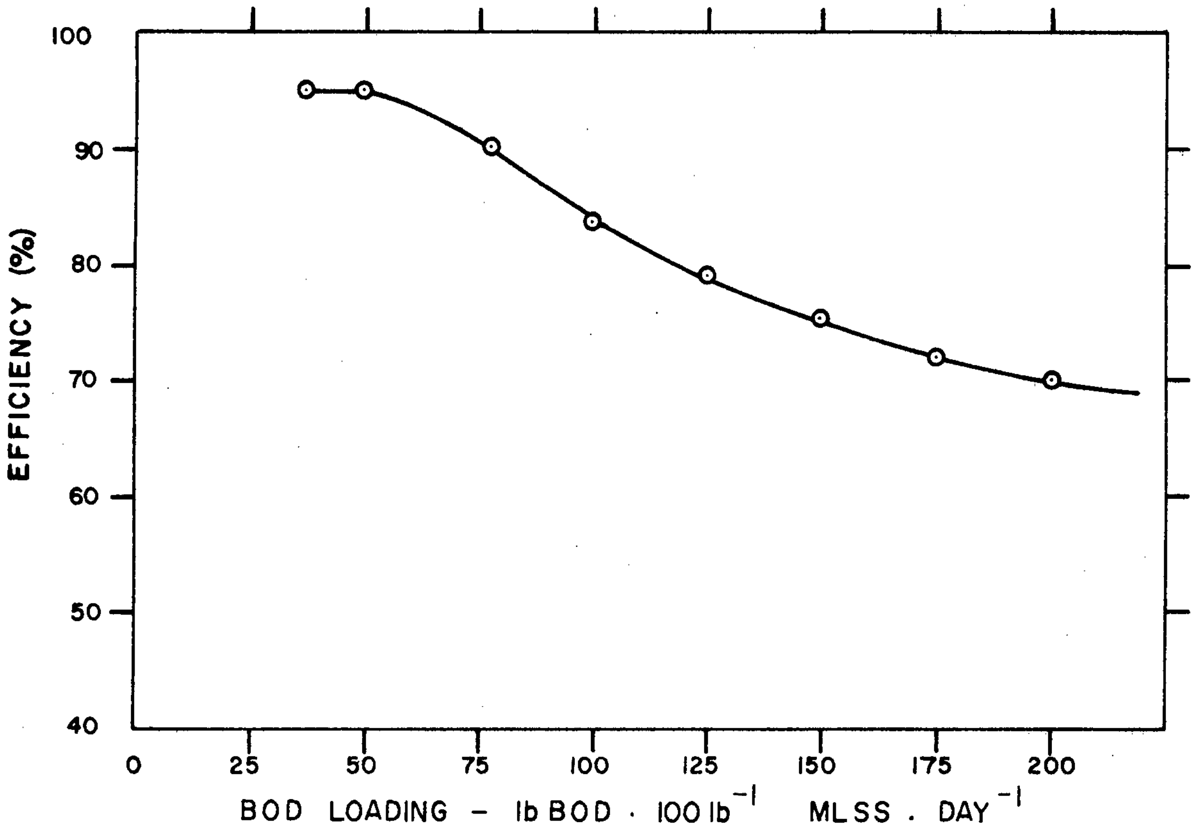


FIG. 8 : EFFICIENCY IN TERMS OF BOD LOADING

It is clear from the results that the sludge in general was of poor settleability. The sludge ages were very short; unfortunately from the data it is not possible to ascertain whether poor settleability was encountered at the shortest or the longest sludge ages. At the short sludge ages employed, the sludge wasted will be very active and additional treatment of the sludge would be required.

From the literature survey, the following conclusions can be made :

(i) The poor BOD and COD removals, as opposed to the high PV removal, obtained over the filters at the Paarl sewage works indicates that the PV can be very misleading.

(ii) Cannery wastes are amendable to treatment by the activated sludge process.

(iii) The conventional activated sludge system is preferable to the 'contact' system.

(iv) Loading rates must be lower than 0,5 kg BOD.kg $MLSS^{-1}.day^{-1}$ to attain high BOD removals, i.e. sludge ages of more than 3 days.

(v) Sludge bulking is an ever present problem, probably due to a deficiency of nitrogen and phosphorus in the waste. Generally SVI values greater than 170 $ml.g^{-1}$ can be expected.

(vi) Peach wastes have a marked adverse effect on the performance of the plant.

No literature could be found on the use of the activated sludge process as a form of "secondary" treatment for a mixture of cannery wastes and domestic sewage. It is possible that once the waste has undergone primary biological treatement that the problems encountered in the treatement of the raw waste may be less in evidence. Long sludge ages may also reduce the problem of bulking of the sludge as the nutrient demand is less.

NUTRIENT BALANCE AND ADDITION

For optimum microbial growth certain nutrient elements, notably nitrogen and phosphorus are required - nitrogen, to form cell protein and phosphorus, an important constituent of the energy reactions within the cell. While domestic sewage contains an excess of nitrogen and phosphorus, many industrial wastes particuarly cannery wastes are deficient in these nutrients. To attain a nutritional balance, it is common practice to mix industrial wastes and domestic sewage prior to biological treatment. A deficiency of these elements leads to a reduction in the BOD (or COD) removal efficiency and gives rise to sludges with poor settling and filtration characteristics.

There are two common parameters in terms of which nutrient balance or deficiency is evaluated :

(i) Nitrogen and Phosphorus content of volatile portion of sludge

A healthy activated sludge contains approximately 12 per cent nitrogen and 2 per cent phosphorus in its volatile fraction. (Helmers et al, 1952). However, these values can decrease; Helmers et al found that the percentage nitrogen decreases as the amount of available N per unit of BOD (COD) decreases. They suggested that a minimum of 7 per cent nitrogen should be present in the volatile fraction of the sludge to maintain desirable qualities. Thus a check of the nutrient content of the volatile portion of the sludge will indicate whether there is in fact a nutrient deficiency in the system.

(ii) BOD:N:P ratio

According to Watson (1971), for optimum microbial growth, the BOD:N:P in the liquid phase of the influent should be 100:5:1. No mention was made of the effect of sludge age or whether the ratio referred to synthesis requirements only.

Haltrich (1965) showed that the BOD:N:P ratio required for optimum purification was dependent upon the BOD loading, i.e. the sludge age. Haltrich further showed that the ratio of 100:5:1 was the optimum for a sludge age of 5 days. The nitrogen and phosphorus requirements increased as the sludge age decreased.

Sachs and Sheets (1967), using a Warburg Constant-Volume Respirometer indicated that the BOD:N:P ratio varied from 100:2,9:0,27 to 100:0,95:0,25 as the sludge 'aged'. According to Marais (1975), assuming a yield of 0,43 mg VSS.mg^{-1}COD removal, the ratio of COD:N:P for synthesis only approximates to 100:5,2:0,86 (using the N and P contents of the sludge as 12 and 2 per cent respectively). Assuming COD $\approx$ 1,8BOD, the corresponding BOD:N:P: ratio approximates to 100:9,4:1,5.

Marais further showed that the N and P requirements are reduced as the sludge age increase, i.e. as the nett sludge generated decreases.

The nutrient requirements for a given sludge age may be calculated from Eqs.8 and 9.

Fig. 9 shows the effect of sludge age on the nutrient requirements. It

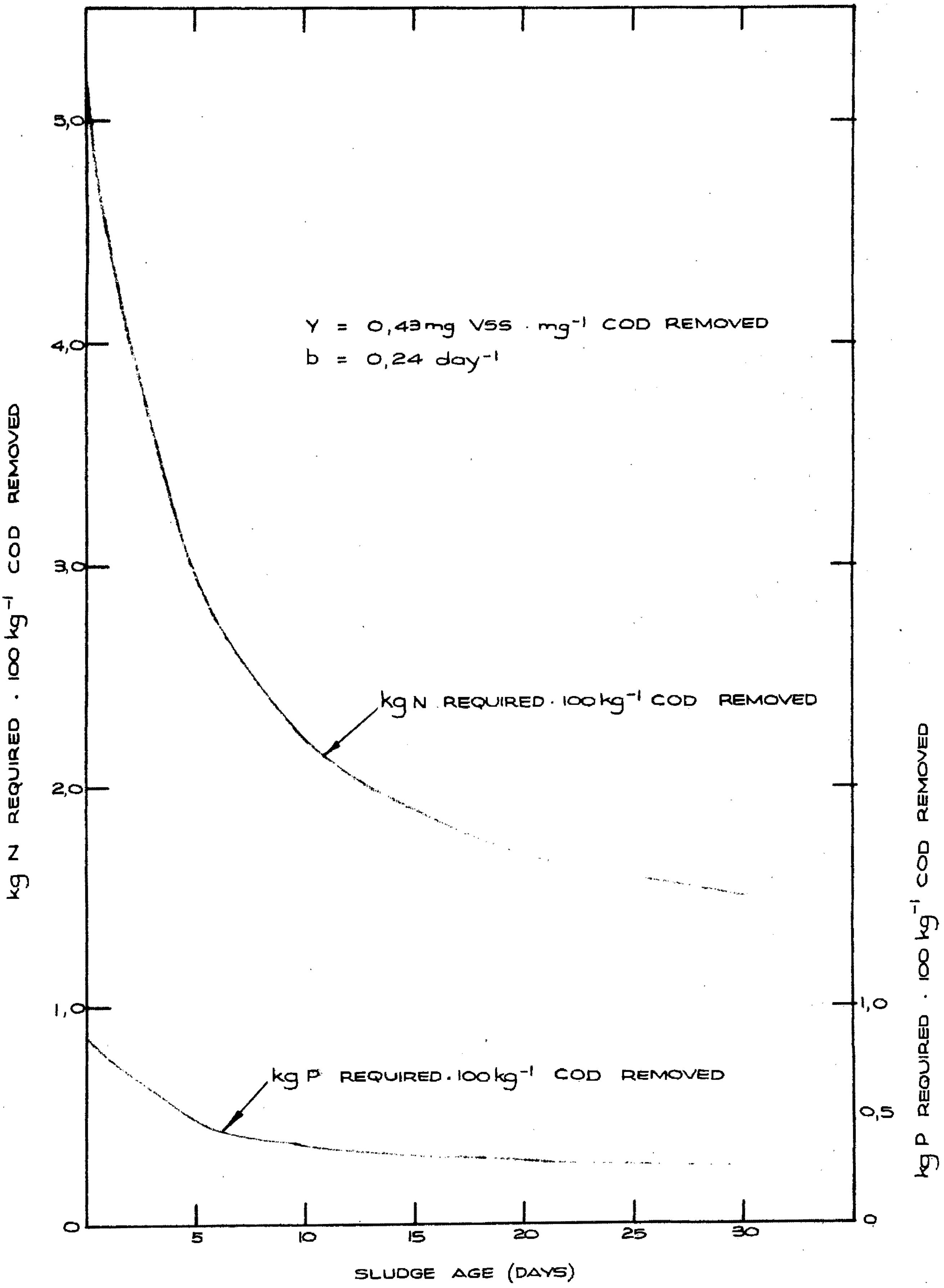


FIGURE 9: EFFECT OF SLUDGE AGE ON NUTRIENT REQUIREMENTS

is evident that both the N and P requirements are reduced by approximately 65 per cent as the sludge age is increased from 1 to 30 days.

Availability of Nitrogen and Phosphorus

Nitrogen :

Nitrogen in the inorganic form (NH_4^+) is 100 per cent available, whereas organic nitrogen is only partially available for sludge growth (Watson, 1971).

The availability of organic nitrogen varies from 20 per cent with some industrial wastes up to 77 per cent with domestic sewage (Helmers et al, 1952). Watson found that supplementary nitrogen should preferably be in the ammonium form, e.g. ammonium sulphate.

Urea, an organic nitrogen compound, is widely used as a nitrogen source. In the light of Watson's findings, a comparison between urea and ammonium sulphate should be of considerable practical value especially as the costs are very similar.

Phosphorus :

Phosphorus in the ortho-phosphate form (PO_4) is approximately 100 per cent available (Watson 1971). Supplementary phosphorus should take this form.

THEORY OF COMPLETELY MIXED ACTIVATED SLUDGE (CMAS) SYSTEMS

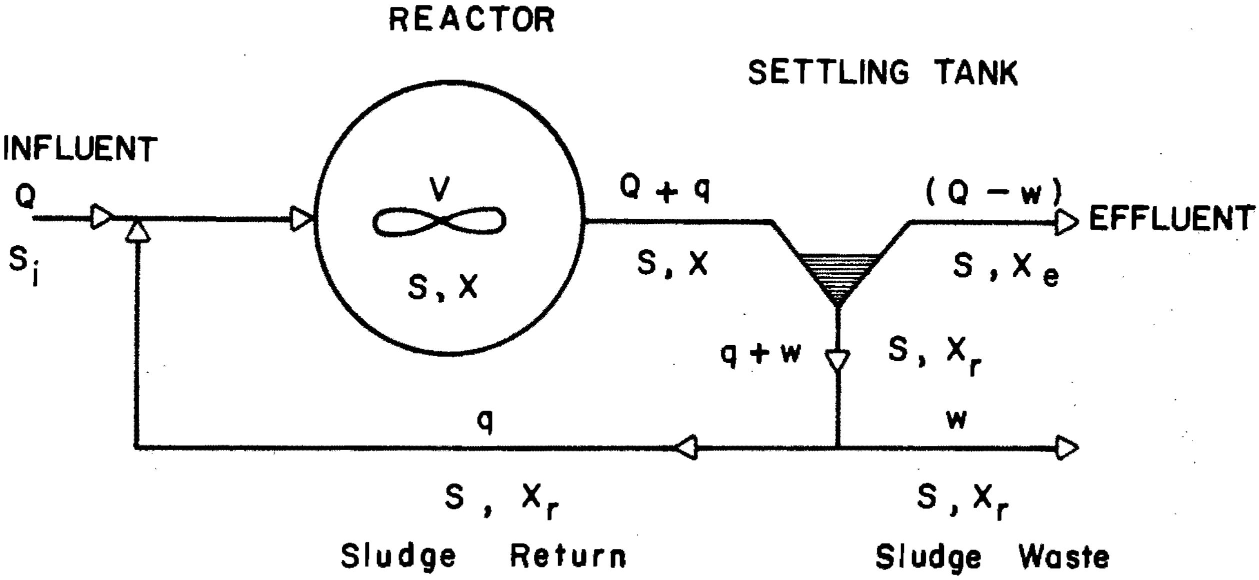
A typical layout of a CMAS system is shown in Fig. 10.

Marais (1973) performed material balances on the systems and derived equations relevant to the activated sludge system.

(a) SLUDGE COMPOSITION :

The mixed liquor suspended solids (MLSS) in a CMAS reactor consists of a volatile fraction, known as the Mixed Liquor Volatile Suspended Solids (MLVSS) and an Inert Inorganic Fraction.

The volatile mass in the reactor, Xv, consits of various fractions, i.e.



Q : INFLOW (l/day)

Si : INFLUENT SUBTRATE (mg/l)

V : VOLUME OF REACTOR (l)

S : SOLUBLE SUBSTRATE IN EFFLUENT AND IN REACTOR (mg/l)

X : SOLIDS CONCENTRATION IN REACTOR (mg/l)

Xe : SOLIDS IN SETTLING TANK EFFLUENT (mg/l)

Xr : SOLIDS CONCENTRATION IN RETURN SLUDGE (mg/l)

q : RECYCLE FLOW (l/day)

w : WASTE SLUDGE FLOW (l/day)

FIG.10 : COMPLETELY MIXED ACTIVATED SLUDGE PROCESS WITH RECYCLING

$$Xv = Xav + Xe + Xio \qquad (1)$$

where Xav = active mass, measured as VSS

Xe = endogenous mass, measured as VSS

Xio = inert organic mass, measured as VSS

The MLSS (Xt) is usually expressed as :

$$Xt = Xv/B \qquad (2)$$

where B = Volatile fraction (Xv/Xt)

The equations for the individual fractions are :

(i) Active Mass, Xav

$$Xav = \frac{Y.(Si-S)}{1+b.Rs} \cdot \frac{Rs}{R} \qquad (3)$$

where Y = Yield constant (mgVSS/mg COD removed)

b = Endogenous mass loss rate constant (day^{-1})

Rs = Sludge Age (days) defined by : $\frac{\text{Mass of sludge in reactor}}{\text{Mass wasted/day}}$

(The other symbols are explained in Fig. 10).

(ii) Endogenous Mass, Xe

$$Xe = 0{,}2b.Xav.Rs/R \qquad (4)$$

(iii) Inert Organic Mass, Xio

$$Xio = Xioi.Rs/R \qquad (5)$$

where Xio is the influent inert organic concentration.

(b) SLUDGE MASS

The waste to be investigated has undergone primary settlement, biological filtration and secondary settlement. The organic solids in this waste are assumed to be completely solubilized and utilised as substrate by the organisms in the activated sludge.

Eq.(1) then reduces to :

$$Xv = MLVSS = Xav + Xe$$

Substituting Eqs. (3) and (4), this reduces to :

$$Xv = \frac{Y.(Si - S).Rs}{1+b.Rs\ R}(1+0{,}2b.Rs) \qquad (6)$$

Assuming that the volatile fraction (i.e. Xv/Xt) = B, the MLSS is :-

$$Xt = \frac{Y.(Si - S).Rs}{B \quad 1+b.Rs \quad R}(1+0,2bRs) \qquad (7)$$

(c) NUTRIENT REQUIREMENTS

The required nitrogen and phosphorus concentrations in the influent are clearly related to the N and P contents of the sludge wasted to maintain a certain sludge age.

i.e. $$Q.\Delta N = \frac{fn.Xv.V}{Rs} \quad \text{and} \quad Q.\Delta P = \frac{fp.Xv.V}{Rs}$$

where fn, fp are the fractions of N and P with respect to the volatile portion of the wasted sludge, and ΔN, ΔP, are the changes in N and P concentrations ($mg.l^{-1}$). Substituting Eq.6 for Xv, and simplifying :

$$\Delta N = \frac{fn.Y.(Si - S).(1 + 0,2\ bRs)}{1 + bRs} \qquad (8)$$

$$\Delta P = \frac{fp.Y.(Si - S).(1 + 0,2\ bRs)}{1 + bRs} \qquad (9)$$

(d) OXYGEN DEMAND

Oxygen is required by the organisms to synthesise new cell material and to endogenously respire. The total oxygen demand is the sum of the "carbonaceous" oxygen demand :

$$O_2 mg.l^{-1}.day^{-1} = \frac{Si-S}{R} - 1,42\ \frac{Xv}{Rs} \qquad (10)$$

and the "nitrification" oxygen demand :

$$O_2\ mg.l^{-1}.day^{-1} = 4,6\ \left[\frac{(Ni-Ne)}{R} - 0,12\ \frac{Xv}{Rs}\right] \qquad (11)$$

where Ni = NH_3-N in influent ($mg.l^{-1}$)
Ne = NH_3-N in effluent ($mg.l^{-1}$)

i.e. $$O_2\ Total, mg.l^{-1}.day^{-1} = \frac{Si-S}{R} - 1,42\ \frac{Xv}{Rs} + 4,6\left[\frac{(Ni-Ne)}{R} - 0,12\frac{Xv}{Rs}\right] \qquad (12)$$

where nitrification is absent, the total oxygen demand is represented by Eq. (10).

(e) EFFLUENT QUALITY

The Chemical Oxygen Demand (COD) in the effluent from an activated sludge works consists of three fractions :

(i) Soluble Unbiodegradable, Sub.

A fraction of the influent COD is unbiodegradable, the magnitude of the fraction depending on the constituents contributing towards the COD. A Textile waste is approximately 50 per cent unbiodegradable (Marais et al, 1974) while domestic sewage is 10 per cent (Marais, 1973).

i.e. $$\text{Sub} = f.\text{Si} \qquad (13)$$

(ii) Soluble ummetabolized, S.

This fraction is dependent on the sludge age (Marais, 1973).

i.e. $$\frac{1}{Rs} = Y.K.S.-b \qquad (14)$$

where K = substrate conversion rate ($mg. l^{-1}.day^{-1}$)

(iii) Effluent suspended solids COD.

1 mg VSS is equivalent to 1,42 mg COD (Marais, 1973). The COD contributed by the suspended solids in the effluent is :

$$\text{COD} = 1{,}42\ Xef \qquad (15)$$

where Xef = VSS in the effluent.

After filtration or centrifuging, the effluent COD is represented by Eqs. (13) and (14) :

i.e. $$\text{Eff.COD} = S + \text{Sub}. \qquad (16)$$

(f) CONSTANTS

The constants, Y, b and K used in the above equations are :

(i) Yield Constant, Y, and Endogenous Mass Loss Rate Constant, b.

The yield constant is defined as :

$$dX_1 = Y.dS \qquad (17)$$

where X_1 is the massof biological sludge synthesized. The nett yield of sludge per day is influenced by the synthesis of new active mass, endogenous mass loss, endogenous residue and inert materials in the influent. This nett yield is not a constant, but is dependent on the sludge age.

The endogenous mass loss rate constant,b, indicates the fraction of the organisms' mass in the reactor that disappears everyday by endogenous respiration. Twenty per cent of the live organism mass that disappears per se remains as inert endogenous residue. Marais (1974) reports values of Y and b as 0,43 mg VSS. mg^{-1} COD removed and 0,24 day^{-1} respectively for a settled domestic sewage.

(ii) Substrate Conversion Rate, K.

Marais (1975) reports a K value of 0,070 $mg.l^{-1}.day^{-1}$ for a settled domestic sewage.

The value of K decreases as the industrial waste content of the total waste flow increases (Marais,1973).

CHAPTER 3.

THE ACTIVATED SLUDGE SYSTEM AS A FORM OF SECONDARY BIOLOGICAL TREATMENT - EXPERIMENTAL INVESTIGATION

OBJECTIVES

The specific objectives of the experimental investigation were :

(i) To determine the suitability of the activated sludge system as a form of secondary biological treatment.

(ii) To evaluate the kinetic constants for the activated sludge system.

EXPERIMENTAL EQUIPMENT

Four units were operated as completely mixed activated sludge units. As it was anticipated that problems with sludge bulking may arise due to filamentous growths, a modified CMAS unit was also put into operation : an anaerobic reactor was positioned ahead of the aeration tank and received the feed and recycled under flow from the settling tank. Filamentous organisms are obligate aerobes (McKinney, 1962); it was conjectured that during the residence in the anaerobic reactor the feed should be preferentially absorbed into the faculative organisms, thus restricting the growth of the filamentous organisms.

(a) Conventional CMAS units

The units are shown in Figs. 11 and 12. Each unit consists of :

(i) an aeration tank, constructed out of perspex, having a volume of 2 840 ml.

(ii) a settling tank for solid-liquor separation of the mixed liquor from the aeration tank. It was constructed from an inverted glass cone of 1 000 ml capacity. The sides of the cone were swept clean of adherring sludge by wipers rotating at 1/3 rpm.

The feed rate was controlled by intermittent pumping using a Gorman-Rupp diaphragm pump, the pump cycle being controlled by an electronic timer. Recycle of the sludge from the settling tank was also controlled by the same pump cycle as the feed pumps, the recycle ratio being approximately one.

Compressed air was distributed evenly throughout the mixed liquor by a perspex sparger, the position of which was varied until optimum mixing in the aeration tank was obtained.

The daily feed to each unit was pumped from plastic buckets in an open refrigerator, controlled at 40°C (see Fig. 13).

(b) CMAS with anaerobic pretreatment

The set up is shown in Figs. 14 and 15. The anaerobic reactor consisted of a perspex cylinder, 200 mm in diameter and 600 mm high with air-tight joints. The volume of mixed liquor in the reactor could be set by raising or lowering the outlet of the reactor. The aeration tank, also constructed out of perspex, had a volume of 12 400 ml. (See Fig. 15). Solid liquid separation was achieved in an inclined perspex cylinder of similar dimensions as the anaerobic reactor.

The feed and settled sludge recycle rates were controlled by intermittent pumping, as in the CMAS units.

Aeration was by compressed air evenly distributed throughout the mixed liquor by a perspex sparger. Air sparging resulted in inadequate mixing and was augmented by installing a mechanical mixer.

EXPERIMENTAL PROCEDURE

Effluent Collection

Effluent from the Paarl sewage works was collected in a 200 gallon (0,9 m^3) tanker, seven batches being collected between the 1st February and the 10th April, 1974.

The batches were collected from the same point after settlement of the humus tanks at the intake to the recirculation sump (see Fig. 16.)

FIGURE 11 : SHOWING GENERAL ARRANGEMENT

OF CONVENTIONAL CMAS UNITS

FIGURE 12 : SHOWING GENERAL ARRANGEMENT OF CONVENTIONAL CMAS UNITS

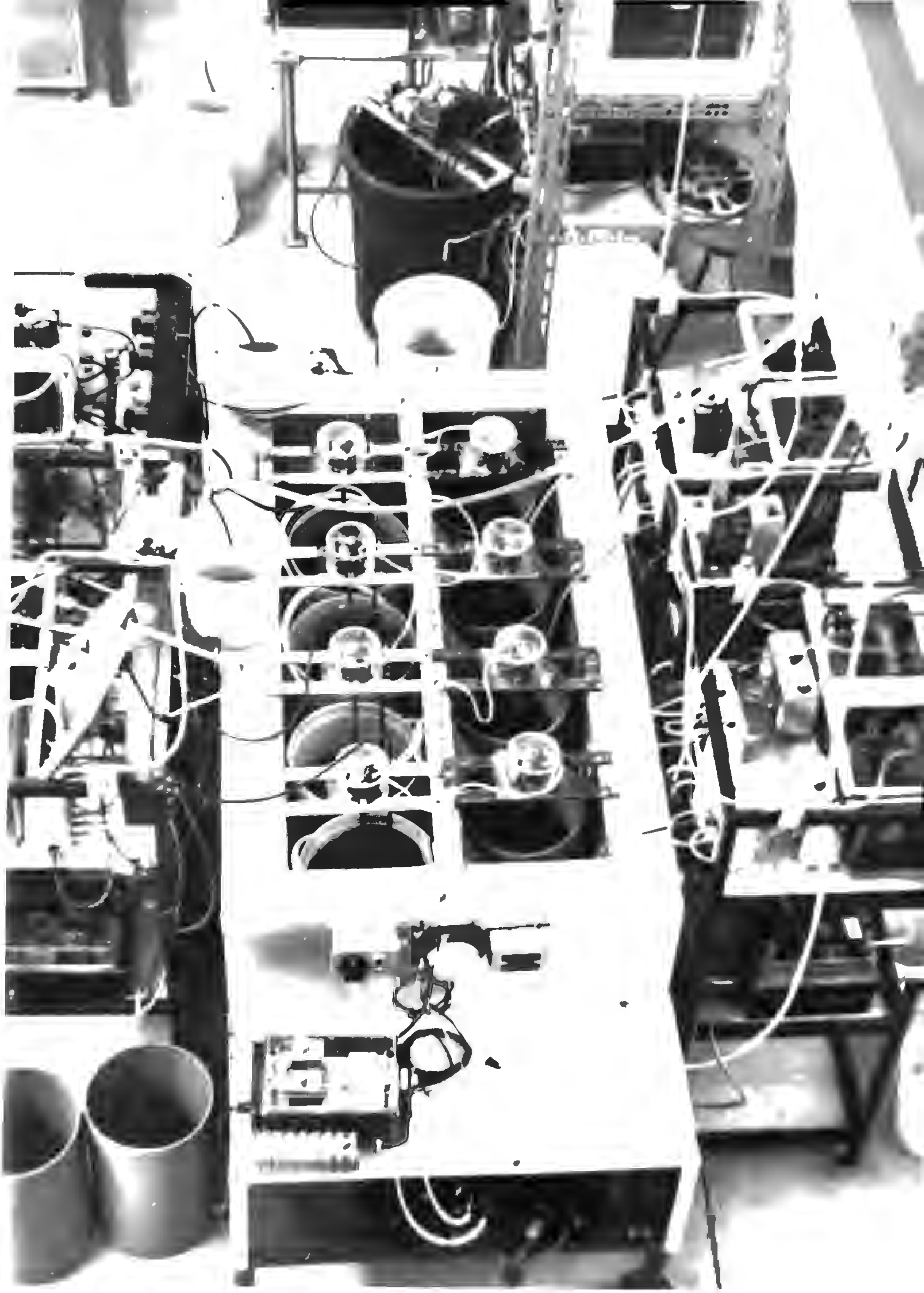


FIGURE 13 : ARRANGEMENT OF FEED FOR CONVENTIONAL CMAS UNITS

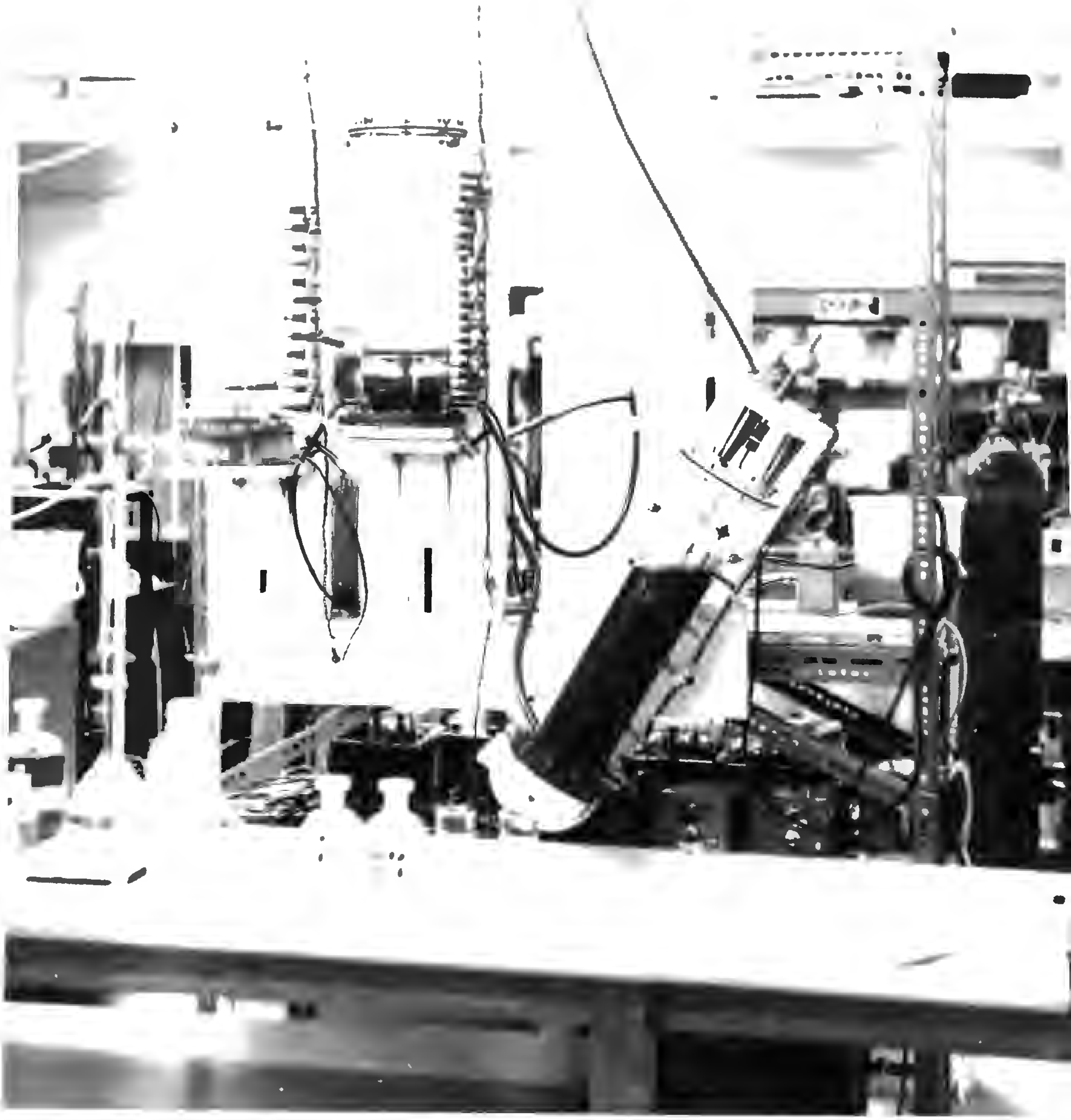


FIGURE 14 : ANAEROBIC REACTOR AND SETTLING TANK OF CMAS UNIT WITH ANAEROBIC PRETREATMENT

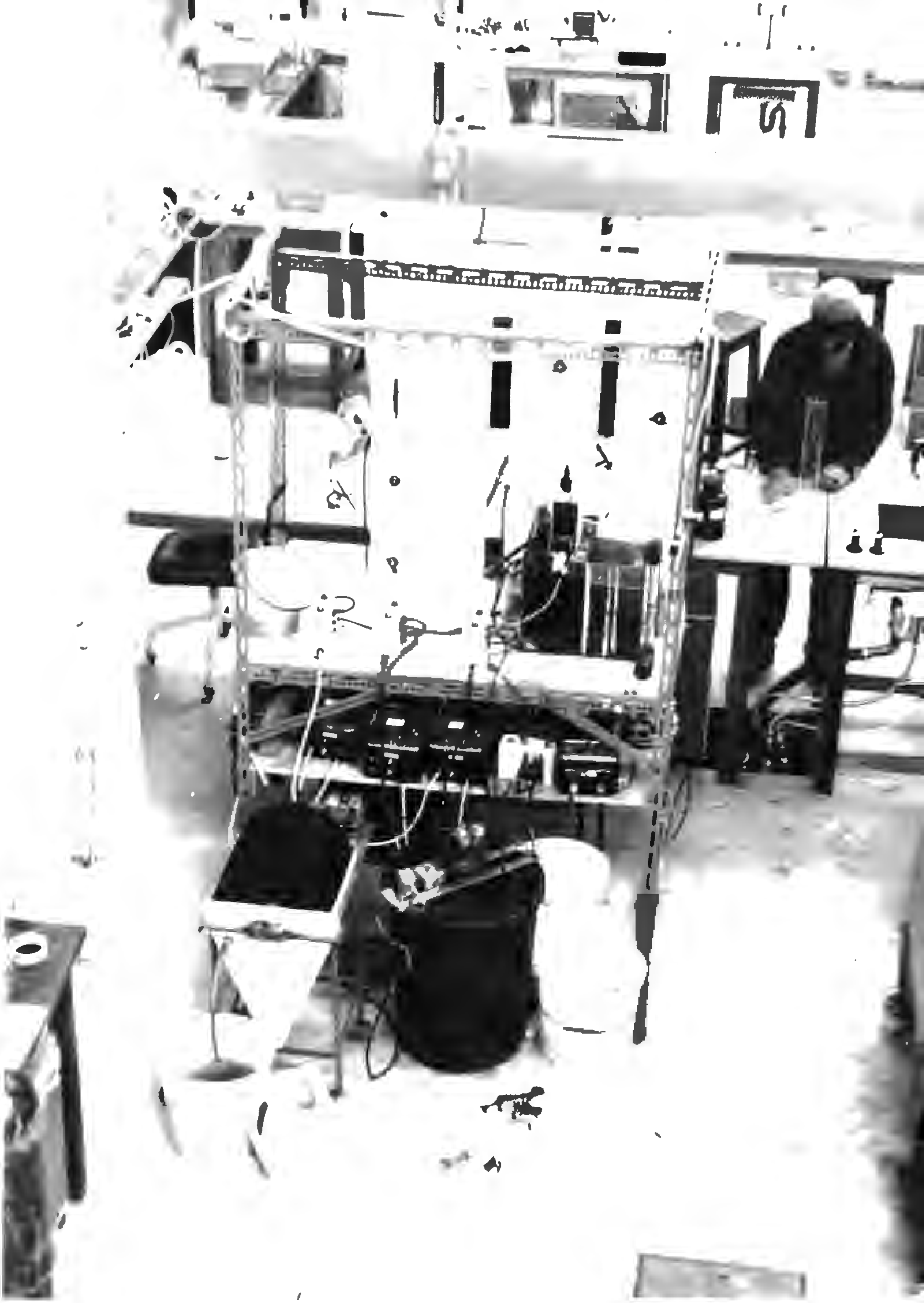


FIGURE 15 : AERATION TANK AND FEED PUMPS OF CMAS UNIT WITH ANAEROBIC PRETREATMENT.

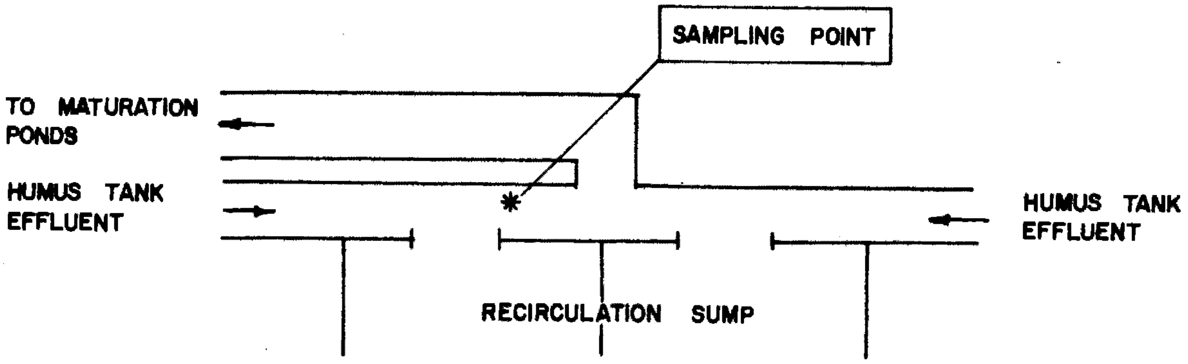


FIGURE 16 : SHOWING POSITION OF SAMPLING POINT

At the laboratory, the contents were stored in two stainless steel tanks in a cold room at 4°C.

The analyses of the first six batches are listed in Table 4.

TABLE 4 : BATCH ANALYSIS

Date of Feed	Batch No.	Tank No.	COD	TKN	NH_3-N	PO_4-P	pH
1/2/1974 to 15/2/1974	1	1	361	3,5	-	4,8	-
		2	393	12,0	-	5,6	5,8
16/2/74 to 20/2/1974	2	1	1040	24,5	4,5	7,8	5,6
21/2/1974 to 7/3/1974	3	1	1446	20,4	6,5	9,4	6,0
		2	1206	23,2	3,4	-	-
8/3/1974 to 25/3/1974	4	1	1400	51,7	27,4	8,9	5,6
		2	1360	52,3	-	8,0	
26/3/1974 to 28/3/1974	5	2	266	-	-	-	6,0
29/3/1974 to 9/4/1974	6	1	1202	29,7	7,0	5,8	6,6
		2	1160	28,0	-	5,6	-

With the exception of Batches 1 and 5, the COD of the effluent was between 1 200 and 1 400 mg.l^{-1}.

The concentration in Batch 1 was low due to dilution water being inadvertently introduced into the tanker. Batch 5 was collected on a Monday when the canneries had not operated over the weekend.

The storage tanks were thoroughly mixed prior to withdrawing the daily feed quantity. The daily feed quantity, before being fed to the units, was diluted to a COD of 1 000 mg. l^{-1}.

Operating Procedures for the CMAS units

The hydraulic retention times (R) and sludge ages (Rs) in the reactors were fixed initially as follows :

Unit	Hydraulic Ret. Time (R) hr.	Sludge Age (Rs) days
A	8	5
B	8	5
C	*8	10
D	24	20
E (Anaerobic pre-treatment	8	5

* The value of R in Unit C was changed to 16 hr on March 11th (Day 39).

In the anaerobic reactor of Unit E (R = 8 hr, Rs = 5 d) the 'nominal' retention time was varied between 0,5 and 1,0 hr as base flow, an 'actual' retention time of 0,25 to 0,5 hr based on the actual flow.

Sludge ages were set by removing and wasting the specific volume of reactor mixed liquor per day. For example, if a sludge age of 10 days is required in a reactor of 2 840 ml capacity, 284 ml of the mixed liquor must be removed and wasted each day. At the longer sludge ages (10 to 20 days) this was achieved by removing the required volume once per day. At the shorter sludge ages, this procedure caused fluctuations in process behaviour and pumping of mixed liquor from the reactor at preset intervals of about an hour was used.

No attempt was made to control the sludge concentration in the reactor directly. The effluent feed rate and sludge age for each unit was set and the sludge concentration allowed to attain its own steady state value.

In order to obtain consistent data, the laboratory scale units have to be operated under 'steady-state' conditions. Steady state was assumed to be established after a period of two sludge ages had passed under each feed rate. For long sludge ages (20 days), steady state was assumed to be established after one sludge age had passed.

Air flow to the reactors was set to maintain a dissolved oxygen concentration of 2 to 4 $mg.l^{-1}$. In some units, this air flow rate was insufficient to keep the reactor contents fully mixed; the air flows to these units were increased with a consequent rise in the dissolved oxygen concentration to about 6 mg.l^{-1}.

The ambient air temperature in the laboratory was kept constant at 20°C. Temperatures in the CMAS reactors varied according to the feed rates of cold sewage and to the air-flow through the reactor but ranged between 17°C and 20°C.

Nutrient balance and addition

Table 5 shows the COD : TKN : PO_4-P ratio for the first six batches of feed.

It was shown earlier that at low sludge ages a ratio of 100 COD : 5,2N : 0,86P should be maintained. Comparing this ratio with the data in Table 5, indicates that all the batches had insufficient nitrogen and only one batch (No.1) showed sufficient phosphorus.

TABLE 5 : COD : TKN : PO_4-P RATIOS FOR INFLUENT WASTE

Batch No.	Tank No.	RATIO		
		COD	TKN	PO_4 -P
1	1	100	2,6	1,30
	2	100	3,1	-
2	1	100	2,4	0,75
3	1	100	1,4	0,66
	2	100	1,9	-
4	1	100	3,7	0,64
	2	100	3,8	0,59
5	1	-	-	-
6	1	100	2,5	0,48
	2			

To compare the influence of an increased nitrogen concentration on the process, a COD : TKN ratio of 100 : 4 was maintained throughout the investigation in Unit B (R = hr, Rs = 5 d). Sufficient urea ($CO(NH_2)_2$), an organic nitrogen compound containing approximately 50 per cent w/w nitrogen, was added to the feed of this unit to maintain the desired ratio.

The phosphorus content of the batches was considered sufficient, no supplementary phosphorus being required.

ANALYTICAL PROCEDURE

Feed Batches

The feed batches were analysed as soon as possible after arrival for :

Total chemical oxygen demand	(COD)	mg.l^{-1}
Total Kjeldahl nitrogen	(TKN)	mg.l^{-1}
Free and saline ammonia	(NH_3-N)	mg.l^{-1}
pH		

At least 10 replicate determinations of COD and TKN were made on each batch sample. The distribution of each set of data was tested graphically for normality. If the data were normally distributed the means were accepted as the best measure of the sample strength. If the data were not normally distributed, the set was discarded and another set tested and analysed.

Total Phosphorus (PO_4 -P) determinations were performed on filtered samples from each batch.

CMAS Units

The following tests were performed twice a week on average :

(a) Aeration Tank Contents

Temperature	°C
pH	
Mixed liquor suspended solids (MLSS)	mg.l^{-1}
Mixed liquor volatile suspended solids (MLVSS)	mg.l^{-1}
Settling tests	
Sludge volume index (SVI)	ml.g^{-1}
TKN in mixed liquor volatile suspended solids	mg.l^{-1}
Dissolved oxygen (DO)	mg.l^{-1}
Oxygen consumption rate	mg.l^{-1}.day^{-1}

(b) Effluents

Analyses were performed on filtered samples using a Buchner funnel :

Chemical oxygen demand (COD)	$mg.l^{-1}$
Total Kjeldahl nitrogen (TKN)	$mg.l^{-1}$
Free and saline ammonia (NH_3 -N)	$mg.l^{-1}$

Periodically the following tests were performed on the filtered effluent :

Permanganate Value (PV)	$mg.l^{-1}$
Total phosphorus (PO_4 -P)	$mg.l^{-1}$
Nitrite and Nitrate nitrogen (NO_2-N,NO_3-N)	$mg.l^{-1}$

The references describing the methods of analysis adopted are listed in Appendix 1.

The Oxygen consumption rate was measured as follows : a one litre narrow necked bottle was filled with mixed liquor from the aeration tank and stirred magnetically. The contents of the bottle were aerated with pure oxygen up to a dissolved oxygen concentration of approximately 10 $mg.l^{-1}$.

A Yellow Springs oxygen probe was inserted into the bottle and the average concentration recorded on a Beckman recorder. When the next feed cycle took place to the reactor, a volume of feed proportional to the volume of the bottle was added to give the same rate of feed as for the reactor. The decrease in dissolved oxygen concentration over the cycle time constitutes an experimental estimate of the rate of oxygen utilization. From the dissolved oxygen time graph drawn by the recorder the oxygen consumption rate was calculated, expressed as $mg.l^{-1}.day^{-1}$. (See Fig. 17 for a typical dissolved oxygen - time plot).

The sludge from each unit was frequently examined under a microscope. These microscopic examinations enabled a close check to be kept on the character of the sludge.

EXPERIMENTAL RESULTS

The routine measurements recorded during the period of investigation are represented graphically in Figs. 18 and 19. For convenience, the plots are so drawn that each variable is easily compared. Trends may be followed more easily in a graphical display than if the results are tabulated. Day 1 corresponds to the 1st February, 1974.

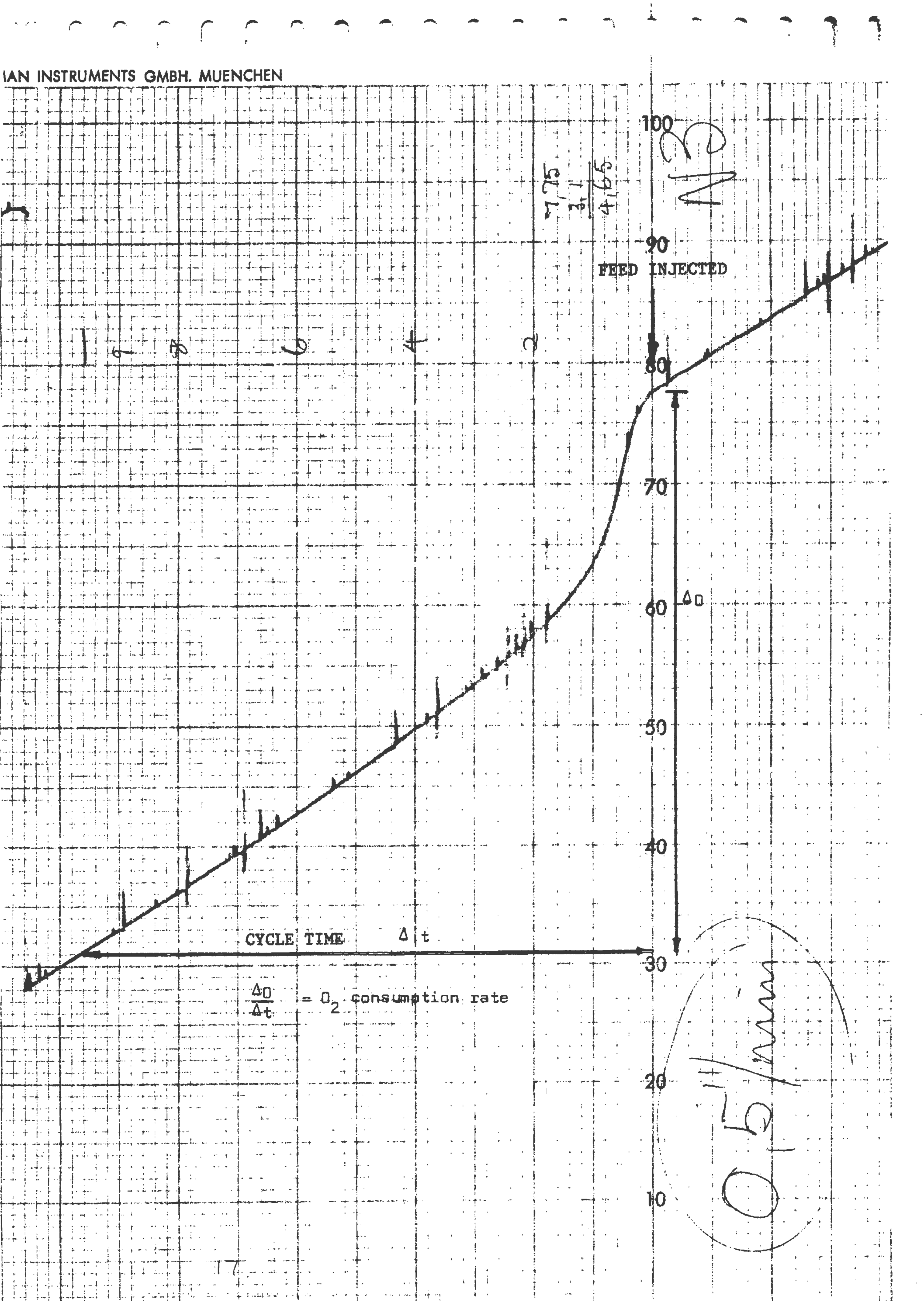


FIGURE 17 : TYPICAL OXYGEN CONSUMPTION PLOT

Filtered Effluent Quality

The effluent qualities from Units A (R = 8hr, Rs = 5d), B (R = 8hr, Rs = 5d), C (R = 16hr, Rs = 10d) and D (R = 24hr, Rs = 20d) appear to be similar (see Fig. 18). In Unit E (R = 8hr, Rs = 5d, An) breakdown of the sludge recycle pump resulted in periodic sludge accumulation in the settling tank. The sludge turned anaerobic and was the cause of the high effluent CODs recorded during the first 37 days. When this problem was rectified, the effluent quality followed much the same trend as from the other units.

Initially Unit C was operated with a hydraulic retention time of 8 hours and a sludge age of 10 days. This resulted in such high sludge concentrations in the reactor that the settling tank was inadequate to cope with the solids-liquid separation. To reduce this problem, the value of R was increased to 16 hours, by reducing the feed rate, but the sludge age was maintained at 10 days.

The effluent COD data from Unit C was divided into two groups - those collected before and those collected after the value of R was changed. Statistical analysis of each group,by plotting on cumulative percentage probability paper, indicated that the data was normally distributed with mean COD values of 190 and 125 $mg.l^{-1}$ respectively. (See Fig.20). A statisitical test showed that the difference in the mean values was not significant at the 4 per cent level. One can conclude that the effluent quality was independent of the hydraulic retention time. This confirms the predictions of Eq. (14). It is now valid to consolidate all the data from Unit C and a statistical analysis is shown in Fig. 20. The data is normally distributed with a mean value of 148 $mg.l^{-1}$.

Figs. 21 and 22 show the statistical distribution plots of the effluent COD for Units A, B, D and E.

A summary of the mean effluent qualities from all the units is as follows :

Unit	A	B	C	D	E
Rs (d)	5	5	10	20	5
COD($mg.l^{-1}$)	151(±30)*	140(±26)	148(±39)	128(±26)	145(±41)
PV ($mg.l^{-1}$)	14	11	13	10	14

(*96 per cent confidence interval).

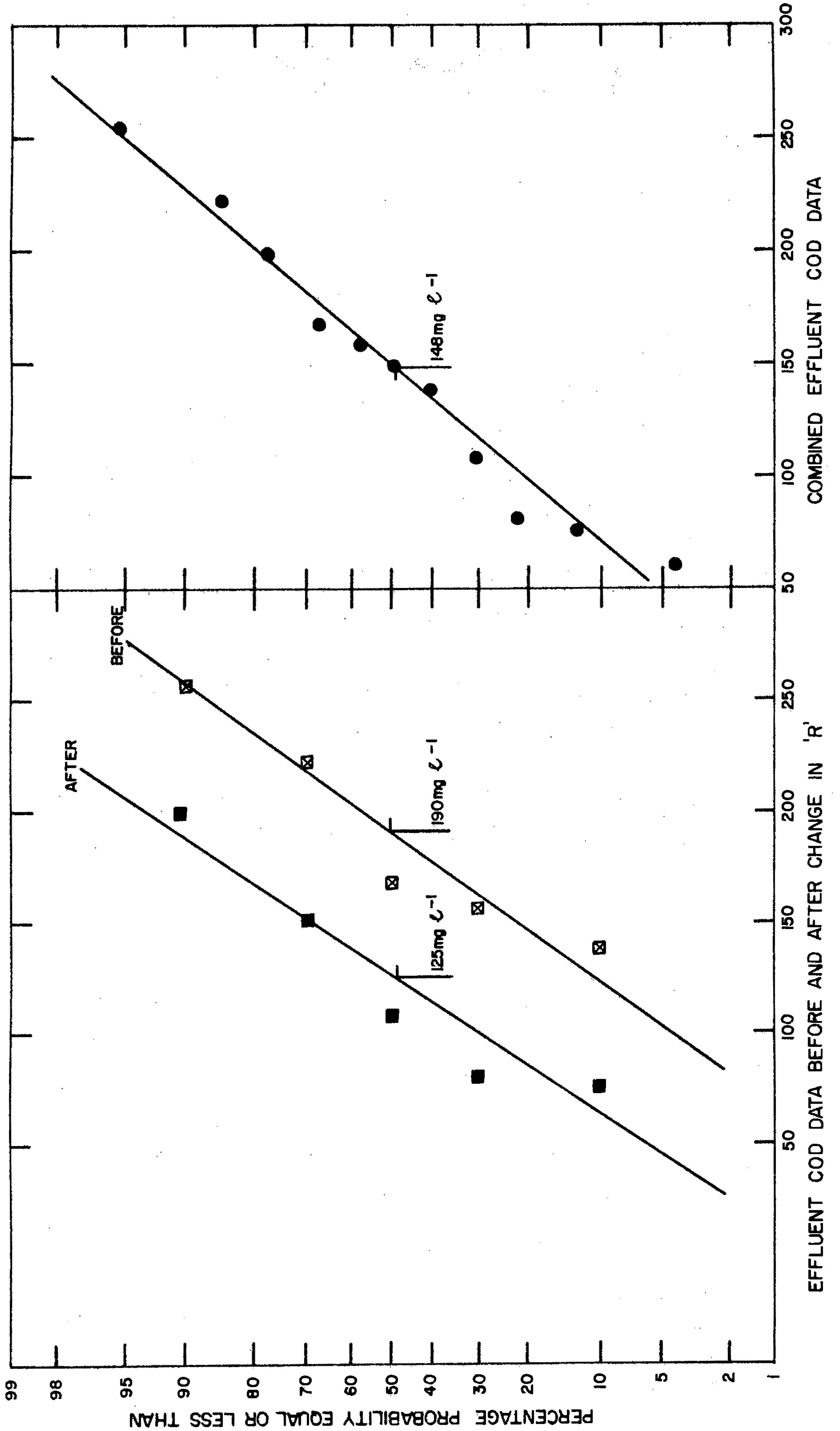
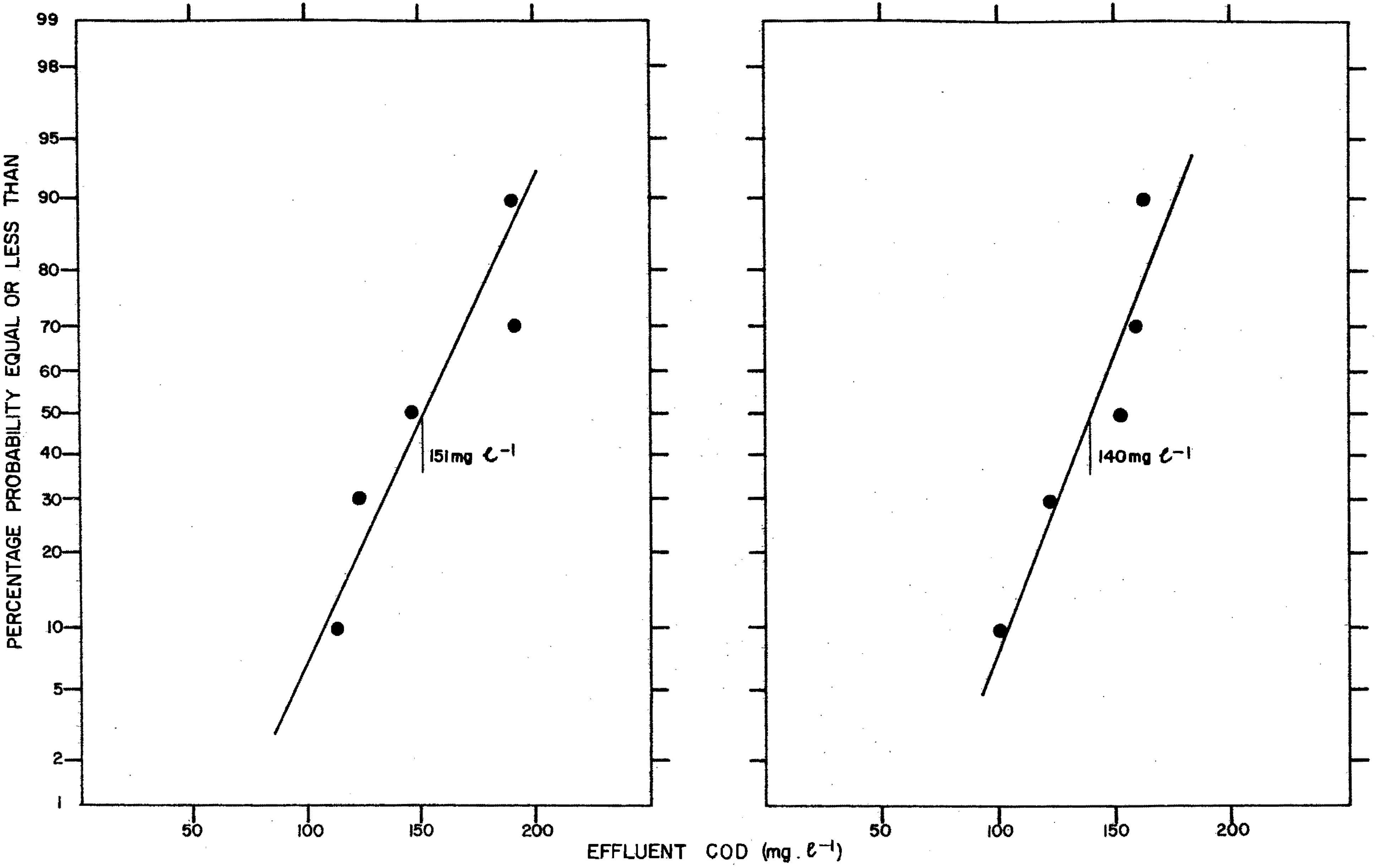


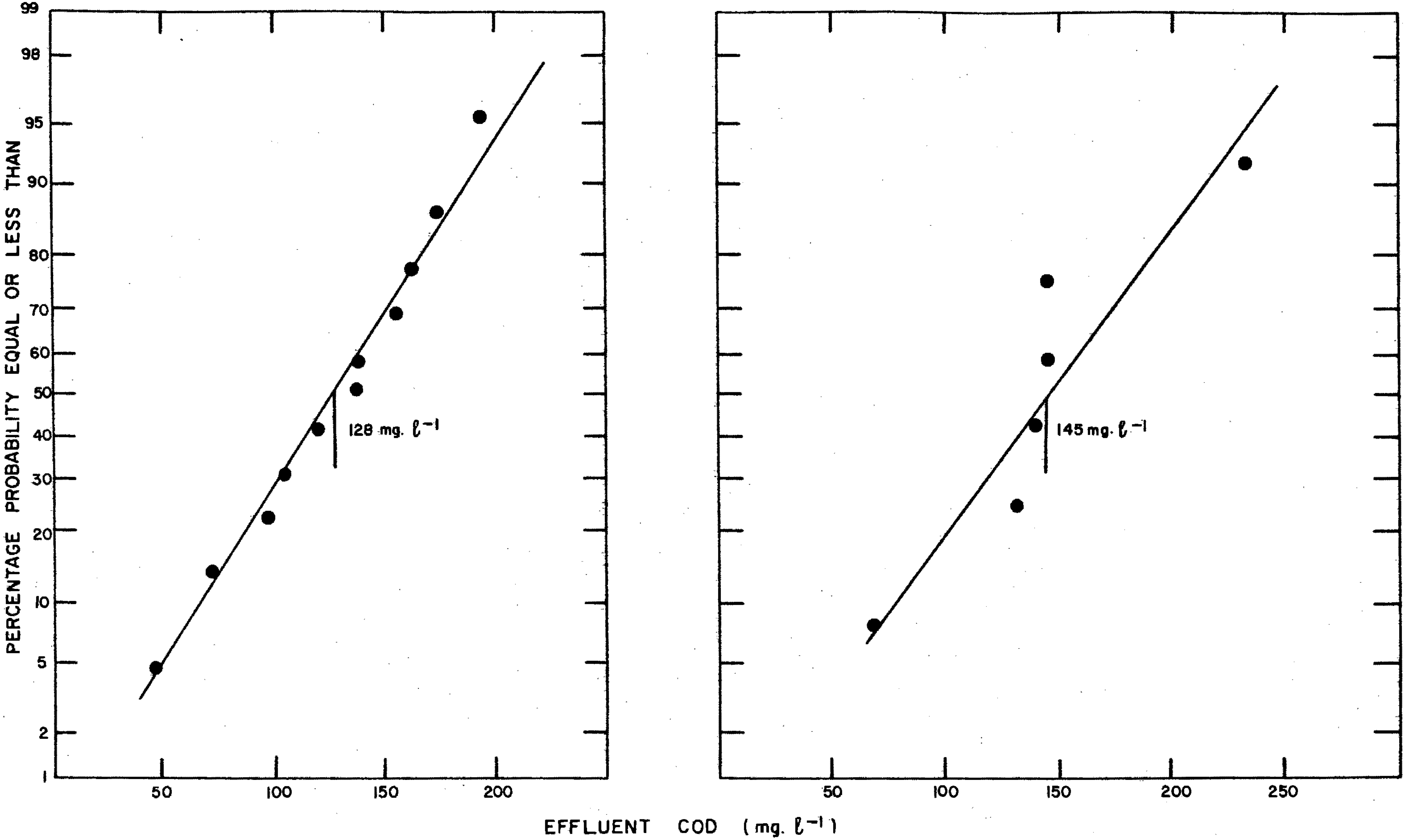
FIG. 20: NORMAL PROBABILITY DISTRIBUTIONS OF EFFLUENT COD DATA FROM UNIT C



UNIT A (R = 8, Rs = 5)

UNIT B (R = 8, Rs = 5)

FIG. 21: NORMAL PROBABILITY DISTRIBUTIONS OF EFFLUENT COD DATA FROM UNITS A AND B



UNIT D (R= 24, Rs = 20)

UNIT E (R = 8, Rs = 5, AN)

FIGURE 22: NORMAL PROBABILITY DISTRIBUTIONS OF EFFLUENT COD DATA FROM UNITS D AND E

Solids Concentration in the reactors (MLSS and MLVSS)

The variation of the MLSS in the reactors in shown in Fig. 18.

Bulking of the sludge in units A (R = 8hr, Rs = 5d) and B (R = 8hr, Rs = 5d) occurred on day 35. This resulted in excessive solids carry over in the final effluent. In Unit E (R = 8hr, Rs = 5d, An) the dispersed nature of the sludge also resulted in solids carry over in the final effluent.

In both instances when excessive solids carry over occurred the final effluents were poured into containers and settled for a day. The supernatants were then decanted and the sludge poured back into the reactors. However, the settling of the sludge sometimes was so poor that sufficient separation was not obtained, resulting in a decline in the MLSS concentration in the respective reactor.

Statistical average values of the MLVSS and MLSS for the different units is shown in Figs. 23A, B, C, D and E.

A summary of the solids concentration data is as follows :

Unit	A	B	C	D	E
Rs (d)	5	5	10	20	5
MLSS(Xv)(mg.l^{-1})	2900(±340)	3520(±234)	2540(±367)	2840(±259)	2700(±205)
MLVSS(Xt)(mg.l^{-1})	2540(±309)	3140(±159)	2200(±333)	2386(±240)	2380(±116)
Xv.Xt^{-1}	0,88	0,89	0,87	0,84	0,88

Settling Characteristics

The variation of the sludge volume index (SVI) for the five units is shown in Fig. 19. The SVI for Unit D (R = 24hr, Rs = 20d) was usually below 100 ml.g^{-1}. The SVI values for Units A (R = 8hr, Rs = 5d), B (R = 8hr, Rs = 5d) and C (R = 16hr, Rs = 10d) were generally in the range 300 to 400 ml.g^{-1}. Units A and B peaked at an SVI value of 750 ml.g^{-1} on day 46. The SVI values for Unit E (R = 8hr, Rs = 5d,An) varied erratically,varying from 100 to 600 ml.g^{-1}.

The high SVI values indicated that the mixed liquors had very poor settling properties. This was substantiated by the performance of the settling

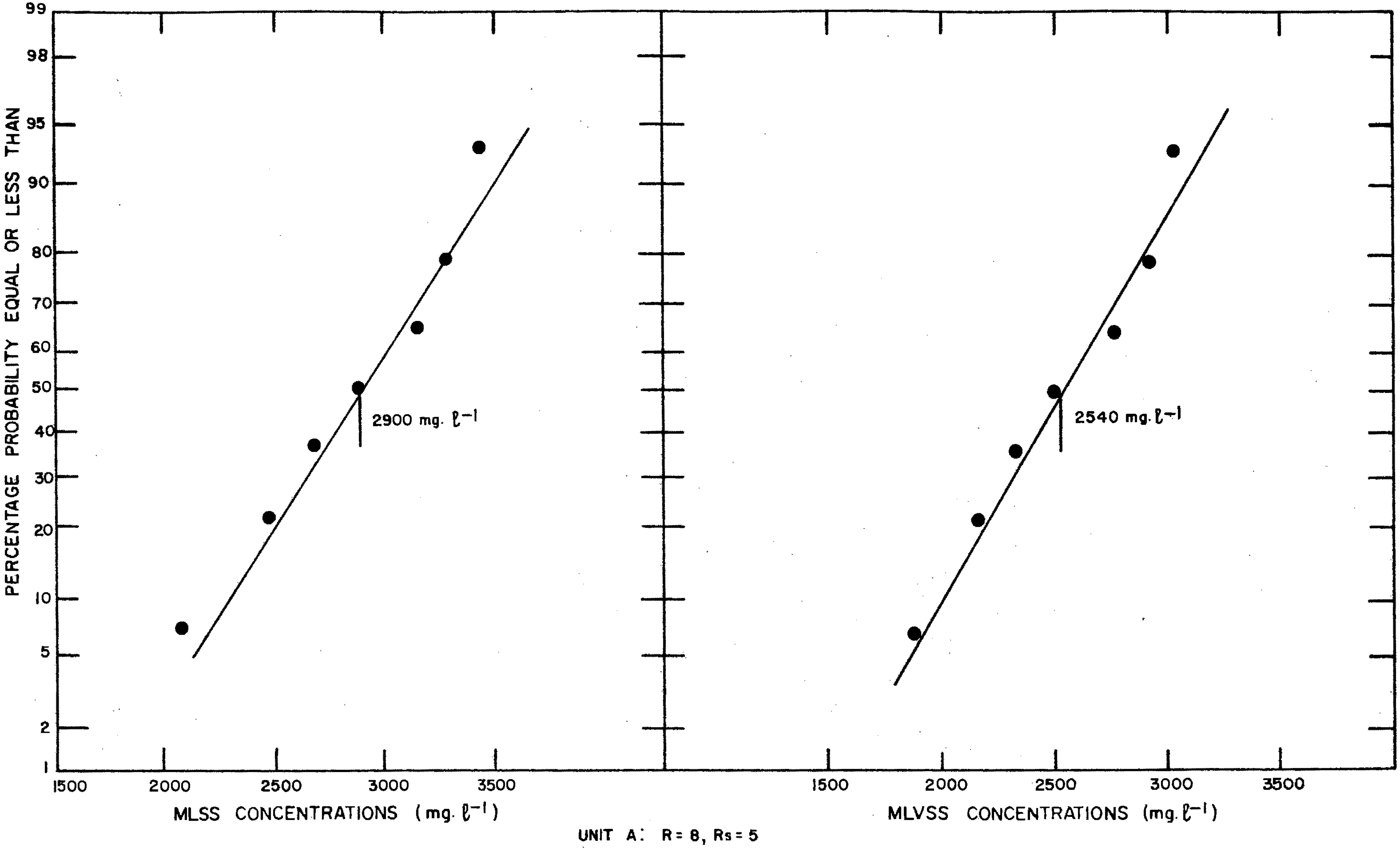
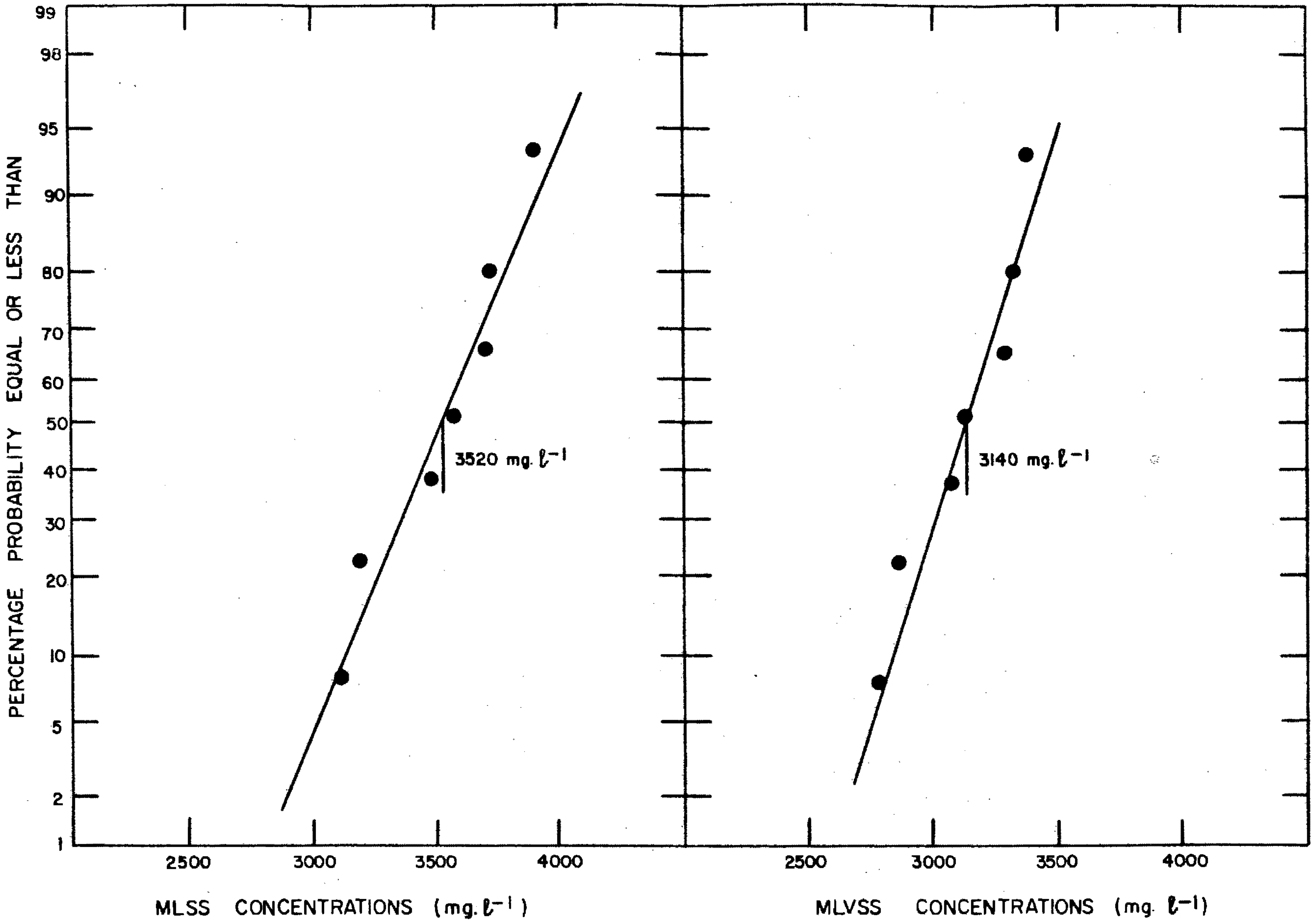
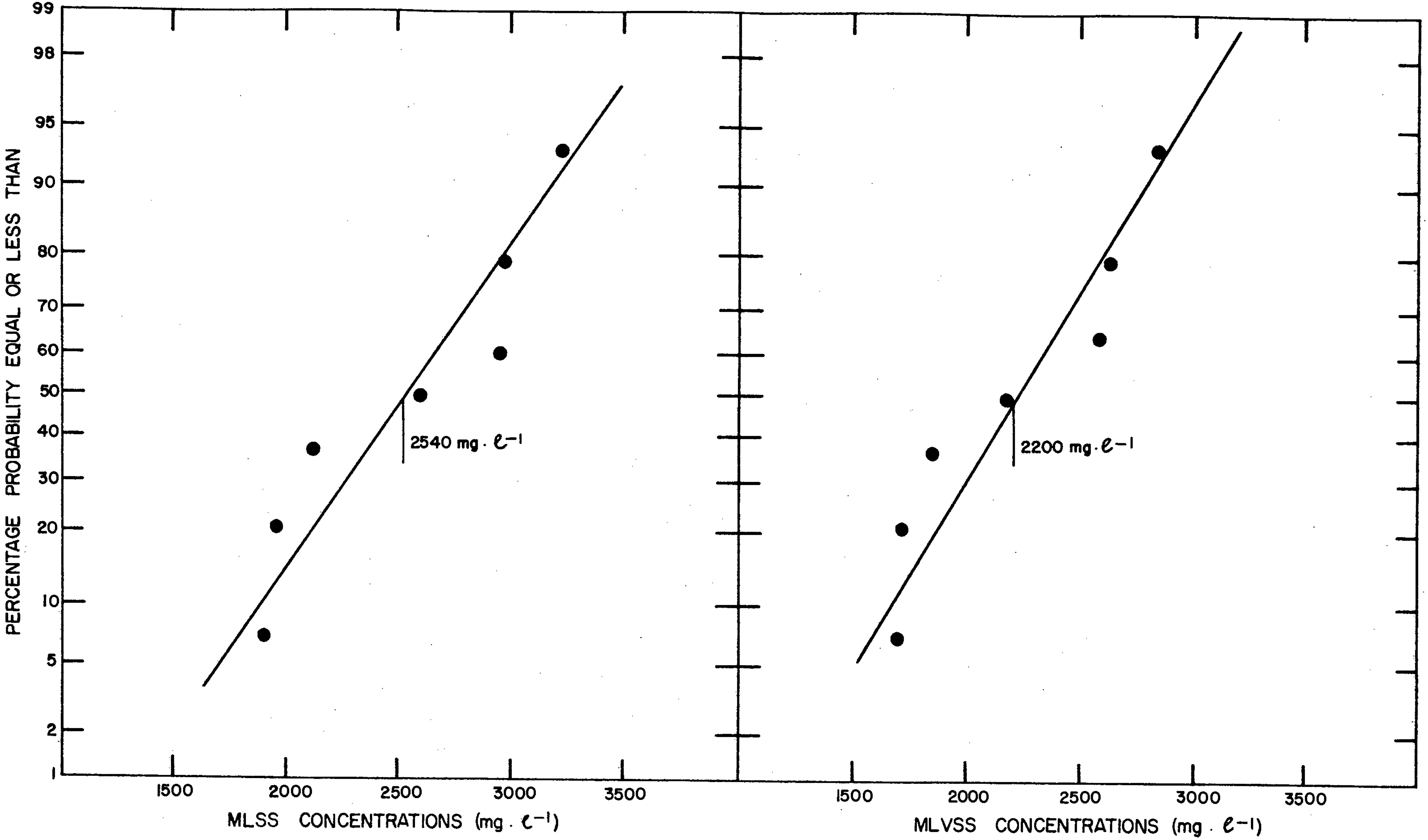


FIGURE 23 A : NORMAL PROBABILITY DISTRIBUTIONS OF SOLIDS CONCENTRATIONS IN UNIT A



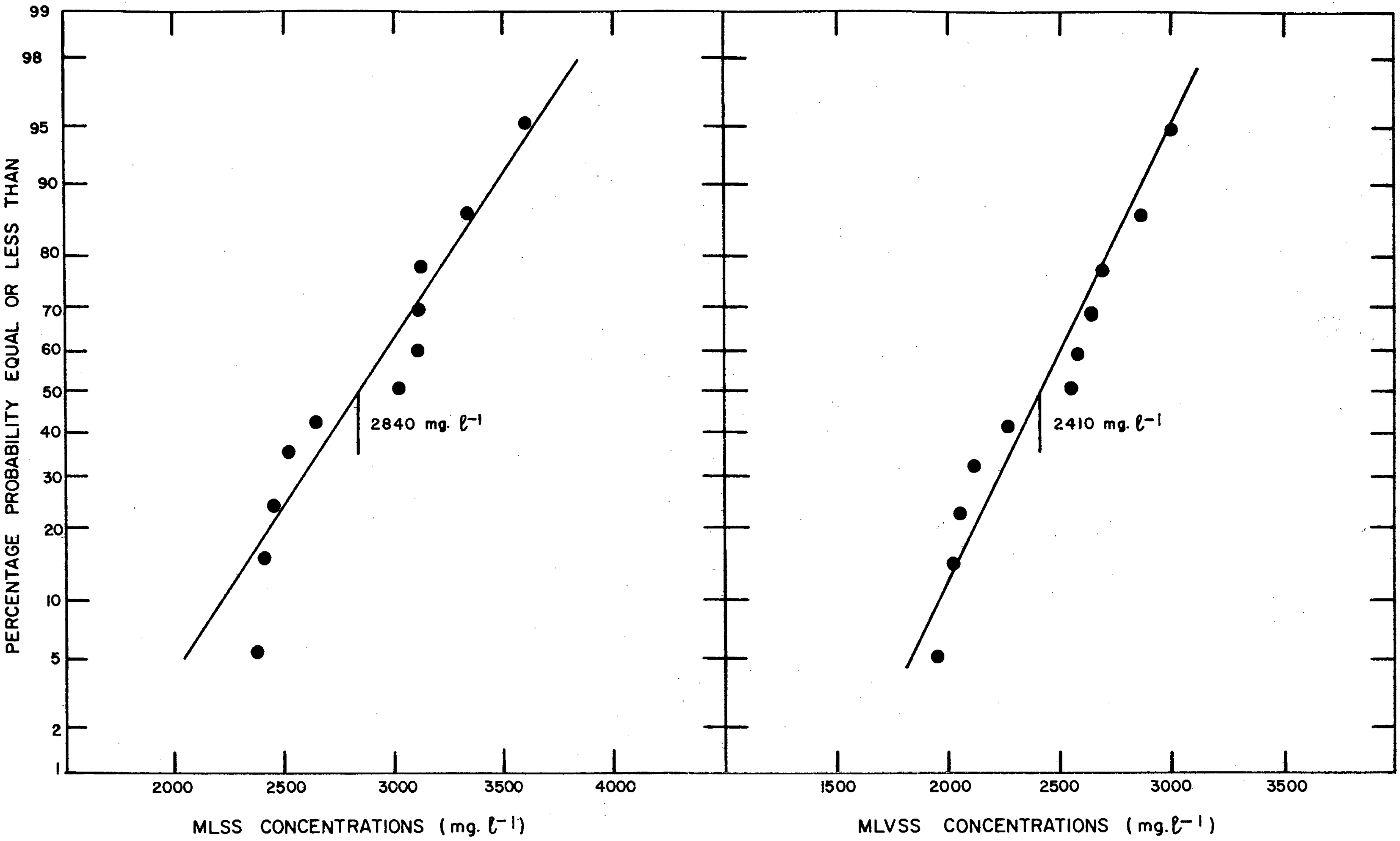
UNIT B : R = 8, Re = 5

FIGURE 23 B : NORMAL PROBABILITY DISTRIBUTIONS OF SOLIDS CONCENTRATIONS IN UNIT B



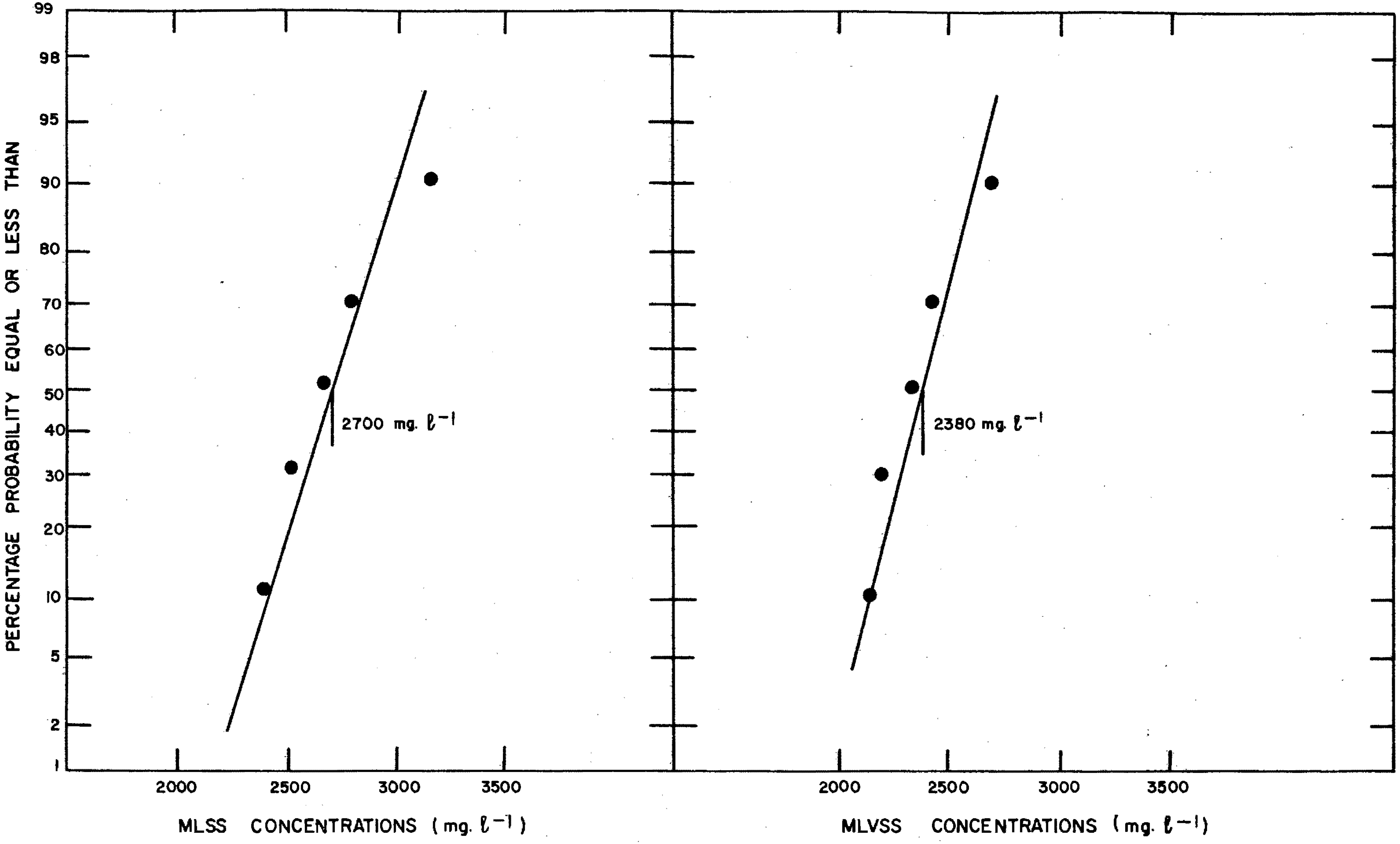
UNIT C (R = 16 , Rs = 10)

FIG. 23 C: NORMAL PROBABILITY DISTRIBUTIONS OF SOLIDS CONCENTRATIONS IN UNIT C



UNIT D (R = 24, Rs = 20)

FIGURE 23 D: NORMAL PROBABILITY DISTRIBUTIONS OF SOLIDS CONCENTRATIONS IN UNIT D



UNIT E : (R = 8, Rs = 5, AN)

FIGURE 23 E : NORMAL PROBABILITY DISTRIBUTIONS OF SOLIDS CONCENTRATIONS IN UNIT E tanks. Whenever the SVI exceeded about 300 $ml.g^{-1}$ the tank was inadequate in size to cope with the solid-liquid separation.

Frequent microscopic examinations were made of the sludges in the various reactors over the period of the investigation. These showed certain characteristic features :

(i) When high SVI values were obtained in Units A, B and C the cause invariably was the presence of filamentous organisms. A microscopic photograph of a bulking sludge is shown in Fig 24, indicating the predominance of filamentous organisms.

(ii) The sludge from Unit D (R = 24 hr, Rs = 20d) was devoid of filamentous organisms. (See Figs. 25 and 26), and throughout the period of investigation gave low SVI values and good settling characteristics.

(iii) In Unit E (R = 8hr, Rs = 5d, An) the high initial SVI values were not due to the filamentous organisms observed in Units A, B and C. The sludge particles appeared to be dispersed having a 'spikey' appearance (See Fig.27). The organisms also did not show any tendency towards flocculating into masses. It was thought that the dispersed nature was due to excessively long residence times in the anaerobic reactor. In an attempt to improve the situation the residence time was reduced from 0,50 to 0,25 hours based on actual flow. This step did result in a temporary improvement of the SVI (100 $ml.g^{-1}$), but a week later a prolific growth of filamentous organisms made its appearance. This growth resulted in the high SVI of 600 $ml.g^{-1}$ being recorded on day 67.

It would appear that the installation of an anaerobic reactor preceeding the main reactor did control the growth of the filamentous organisms observed in the conventional CMAS units. However the organisms which developed were also of a nature which inhibited liquid-solid separation though the effect was not as marked as

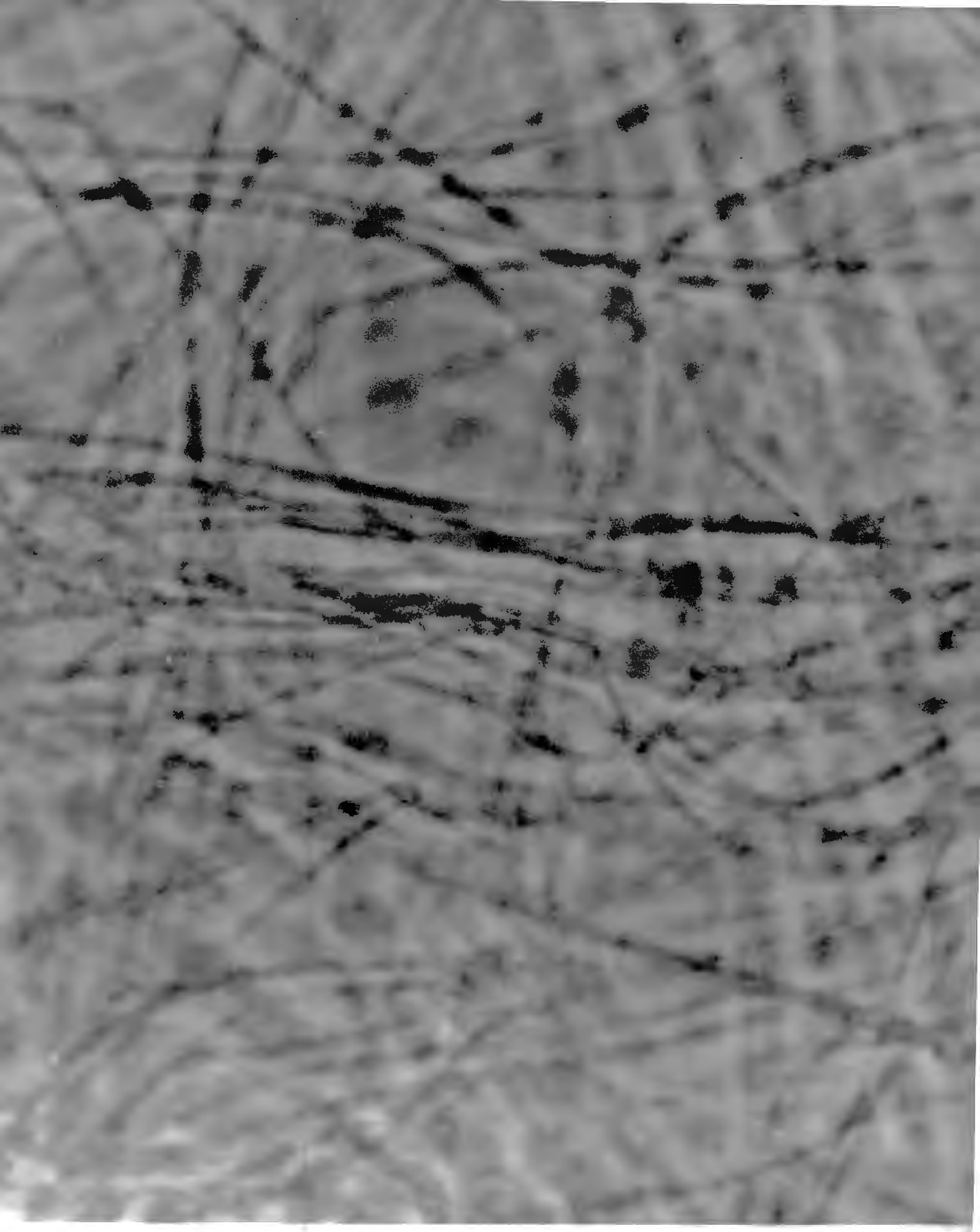


FIGURE 24 : SHOWING THE PREDOMINANCE OF THE FILAMENTOUS ORGANISMS IN A BULKING SLUDGE. (400 x).

THE SLUDGE FROM UNIT D

(R = 24hr, Rs = 20d) (400 x)

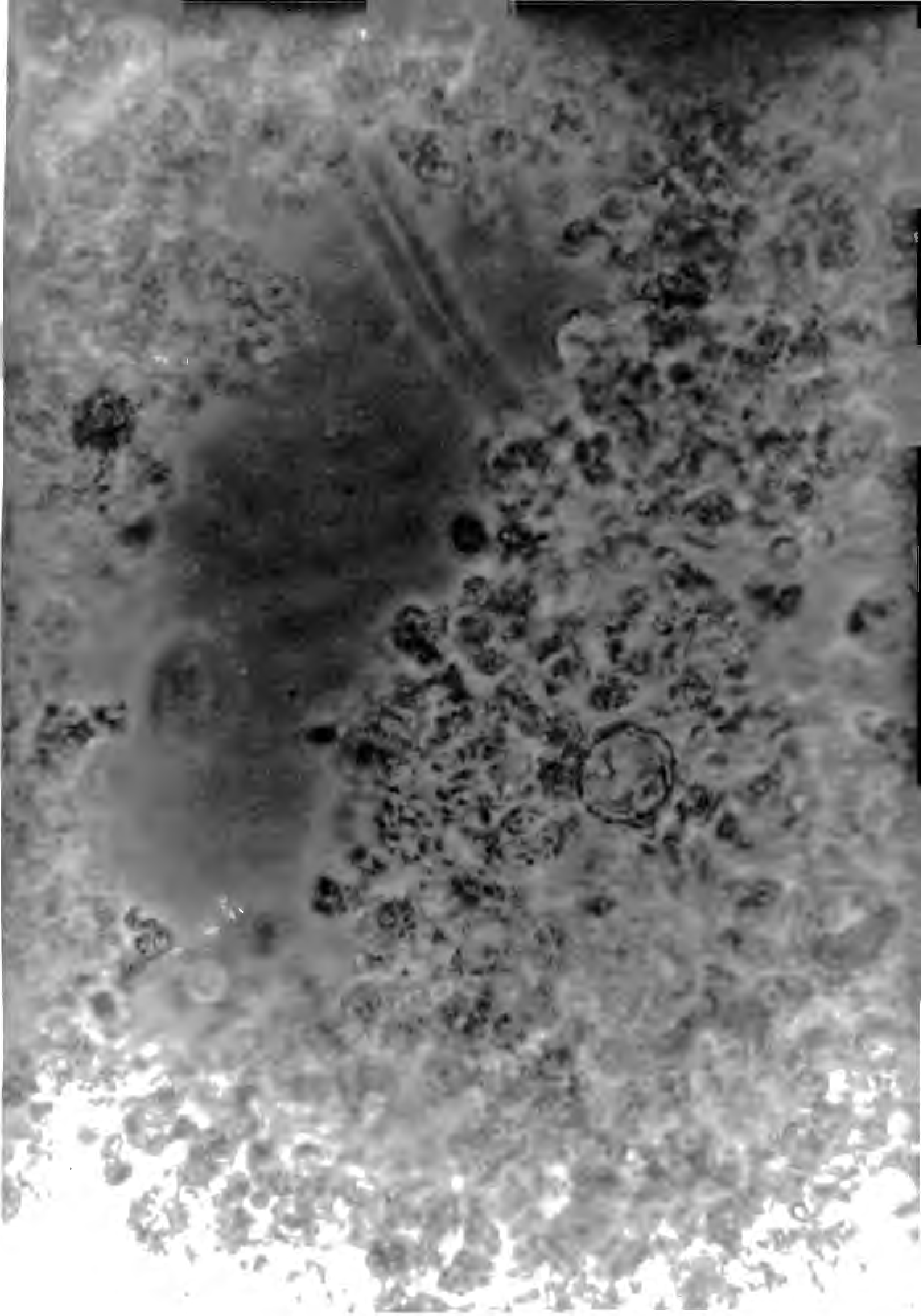


FIGURE 26 : SHOWING THE CHARACTER OF THE SLUDGE FROM UNIT D (R = 24hr, Rs = 20d) (400 x)

FIGURE 27 : SHOWING THE DISPERSED NATURE
OF THE SLUDGE FROM UNIT E
(R = 8hr, Rs = 5d, An) (400 x)

when filamentous organisms were present.

pH

The variation of the pH in each of the five reactors is shown in Fig.19. There was no apparent decrease in pH as the sludge age increased from 5 to 20 days. The fact that there was no drop in pH, and zero nitrite or nitrate nitrogen was measured in the effluent, confirms that nitrification did not occur.

Nitrogen and Phosphorus concentrations

The variations in TKN, NH_3-N (both in the effluent) and TKN in the sludge are shown in Fig. 19. The average values of the TKN and NH_3-N concentrations, together with the average TKN content of the sludges, are shown in Table 6.

TABLE 6 : NITROGEN BALANCE

Unit	A	B	C	D	E
Rs (days)	5	5	10	20	5
R (hr.)	8	8	16	24	8
Xv (mg.l^{-1})	2540	3140	2200	2386	2380
(1) Eff TKN (mg.l^{-1})	5,2	6,4	4,8	5,8	9,7
Eff NH_3-N(mg.l^{-1})	0,4	4,7	3,2	1,7	3,7
TKN in sludge (%)	10,8	11,8	9,7	9,7	10,5
(2)(%N).Xv.R.Rs^{-1}	18,3	24,7	14,2	11,6	16,7
TOTAL:(1+2)	23,5	31,1	19,0	17,4	26,4
FEED TKN (mg.l^{-1})	22,2	40,0	22,2	22,2	22,2
Unaccounted	-1,3	8,9	3,2	4,8	-4,2

The average TKN concentration in the feed to all the units, with the exception of Unit B was 22,2 mg.l^{-1}. (The NH_3-N fraction of this figure was 7,8 mg.l^{-1}). The TKN in the feed to Unit B to which urea was added, was constant at 40 mg.l^{-1}.

The sum of the TKN concentration in the effluents and the TKN concentration accounted for in the volume of sludge wasted from each unit every day ((%N).Xv.R/Rs) are shown in Table 6. It can be seen that, considering the possibility of NH_3-N stripping occurring, the balance is generally good.

It is of interest to note that no nitrification was observed - even at the sludge age of 20 days. This is a result of the very low NH_3-N concentrations in contact with the organisms. (For Rs = 20 days the NH_3-N concentration was 1,7 $mg.l^{-1}$).

Total Phosphorus (PO_4-P) concentrations in the effluents from the units were periodically measured. The concentrations varied from 1,0 to 3,5 $mg.l^{-1}$ as the sludge age increased from 5 to 20 days.

A phosphorus balance is shown in Table 7. As PO_4-P concentrations in the sludge were not determined, the literature value of 2 per cent (page 13) was used for the purpose of completing the phosphorus balance. It can be seen that, with the literature value of 2 per cent P, the balance is acceptable.

TABLE 7 : PHOSPHORUS BALANCE

Unit	A	B	C	D	E
Rs days	5	5	10	20	5
R (hr)	8	8	16	24	8
Xv ($mg.l^{-1}$)	2540	3140	2200	2386	2380
(1)Eff.PO_4-P($mg.l^{-1}$)	1,2	1,3	2,1	3,3	1,2
(2)0,02Xv.R.Rs^{-1}	3,4	4,2	2,9	2,4	3,2
TOTAL (1 + 2)	4,6	5,5	5,0	5,7	4,4
FEED PO_4-P	5,9	5,9	5,9	5,9	5,9

Table 8 compares the COD:N:P ratios observed from the performance of the units. It is of interest to note that both the nitrogen and phosphorus requirements decreased as the sludge age increased from 5 to 20 days - confirming the predictions on page

TABLE 8 : COD:N:P RATIOS

Unit	Rs (d)	COD Removed : N : P
A	5	100:2,0:0,6
B	5	100:3,9:0,5*
E	5	100:1,5:0,55
C	10	100:2,0:0,45
D	20	100:1,9:0,30

* Urea added to feed.

Oxygen Requirements

The oxygen consumption rate tests were initiated on day 28. The values obtained are shown in Fig. 28.

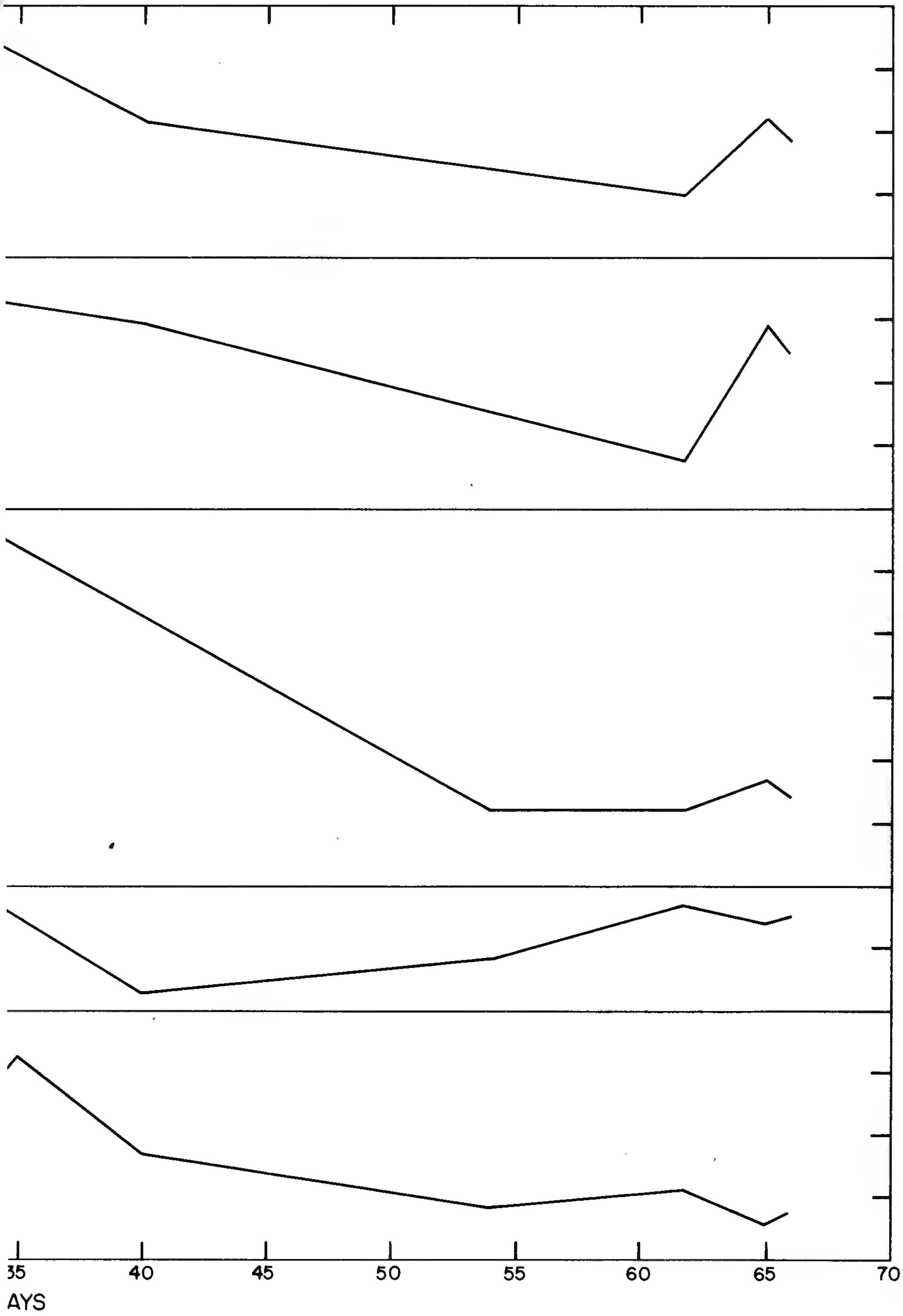
The 'steady state' in Units A (R = 8hr, Rs = 5d) and B (R = 8hr, Rs = 5d) was upset on day 42. This results in three values only being averaged to represent an approximate value for the oxygen consumption rate of the two units.

The oxygen consumption rates in Units C (R = 16hr, Rs = 10d), D (R = 24hr, Rs = 20d) and E (R = 8hr, Rs = 5d, An) were approximated by four, six and three values respectively.

Although more results would have been preferable, the approximate results for the five units will enable an acceptable comparison to be made with the theoretical predictions.

A summary of the average oxygen consumption rates from all the units is as follows :

Unit	A	B	C	D	E
Rs (d)	5	5	10	20	5
R (hr)	8	8	16	24	8
O_2 (mg.l^{-1}.d^{-1})	1580	1691	871	693	1240



S FOR ALL UNITS

Summary of experimental results

	A	B	C	D	E
Rs (d)	5	5	10	20	5
R (hr)	8	8	16	24	8
Inf.COD(mg.l^{-1})	1000	1000	1000	1000	1000
Eff.COD(mg.l^{-1})	151	140	148	128	145
MLSS (mg.l^{-1})	2900	3520	2540	2840	2700
MLVSS (mg.l^{-1})	2540	3140	2200	2386	2380
MLVSS/MLSS	0,88	0,89	0,87	0,84	0,88
$\Delta S.Xv^{-1}.R^{-1}$ (i)	1,00	0,82	0,58	0,37	1,08
$Si.Xt^{-1}.R^{-1}$ (ii)	1,04	0,86	0,59	0,35	1,12
$Si.R^{-1}$ (iii)	3,0	3,0	1,5	1,0	3,0
O_2(mg.l^{-1}.day^{-1})	1580	1691	871	693	1240

NOTE: (i) The parameter $\Delta S.Xv^{-1}.R^{-1}$ is the sludge utilization rate; (SUR), measured as kg COD removed.kgMLVSS^{-1}.day^{-1}.

(ii) The parameter $Si.Xt^{-1}.R^{-1}$ is the 'sludge loading rate' (SLR), measured as kg COD applied. kg MLSS^{-1}.day^{-1}. This parameter is most commonly used.

(iii) The parameter $Si.R^{-1}$ is the 'Volumetric COD Loading' measured as kg COD applied. m^{-3} reactor volume. day^{-1}. Assuming a COD : BOD ratio of 2,50 :1 the values of 3,0 and 1,0 kg COD.m^{-3}.day^{-1} correspond to 75 and 25 lb BOD.1000 ft^{-3}. These values fall in the range investigated by Norgaard et al, (1967) - see Fig.7.

Determination of the Yield Constant, Y.

The Sludge Utilization Rate (SUR), tabulated above, is in terms of the MLVSS. To express the SUR in terms of the 'active volatile solids' (Xav) the following relationship is used (Marais, 1973):

$$Xv = Xav \quad (1 + 0{,}2.b.Rs) \tag{18}$$

It follows that :

$$SURav = \frac{S}{R.Xav} = \frac{1+b.Rs}{Y.Rs.}$$

i.e. $\frac{1}{Rs} = Y.SURav - b$

or $\frac{1}{Rs} = Y.SURv\ (1+0{,}2b.Rs)-b$ (19)

In order to solve for Y, the assumption that b = 0,24 day^{-1} at 20°C is made. This value has been experimentally verified by Marais, (1974).

Fig. 29 shows the plot of 1/Rs versus SUR (1+0,2b.Rs). The slope of the resulting straight line through the data points approximates the value of Y, and was calculated as 0,39 mg $VSS.mg^{-1}$ COD removed.

Determination of the Reaction Rate Constant, K.

A fundamental steady state equation for the CMAS system is :

$$\frac{S}{Xav.R} = KS \tag{20}$$

i.e. SURav = KS

or SURV (1+0,2b.Rs) = KS (21)

SURv (1+0,2b.Rs) versus S is shown plotted in Fig. 30. The slope of the line, defining the value of K, was calculated as 0,045 $mg.l^{-1}.day^{-1}$. The intersection on the abscissae represents the unbiodegradable COD present in the effluents.

This value of 120 $mg.l^{-1}$, in a feed of 1 000 $mg.l^{-1}$, indicates that approximately 12 per cent of the waste from Paarl is unbiodegradable.

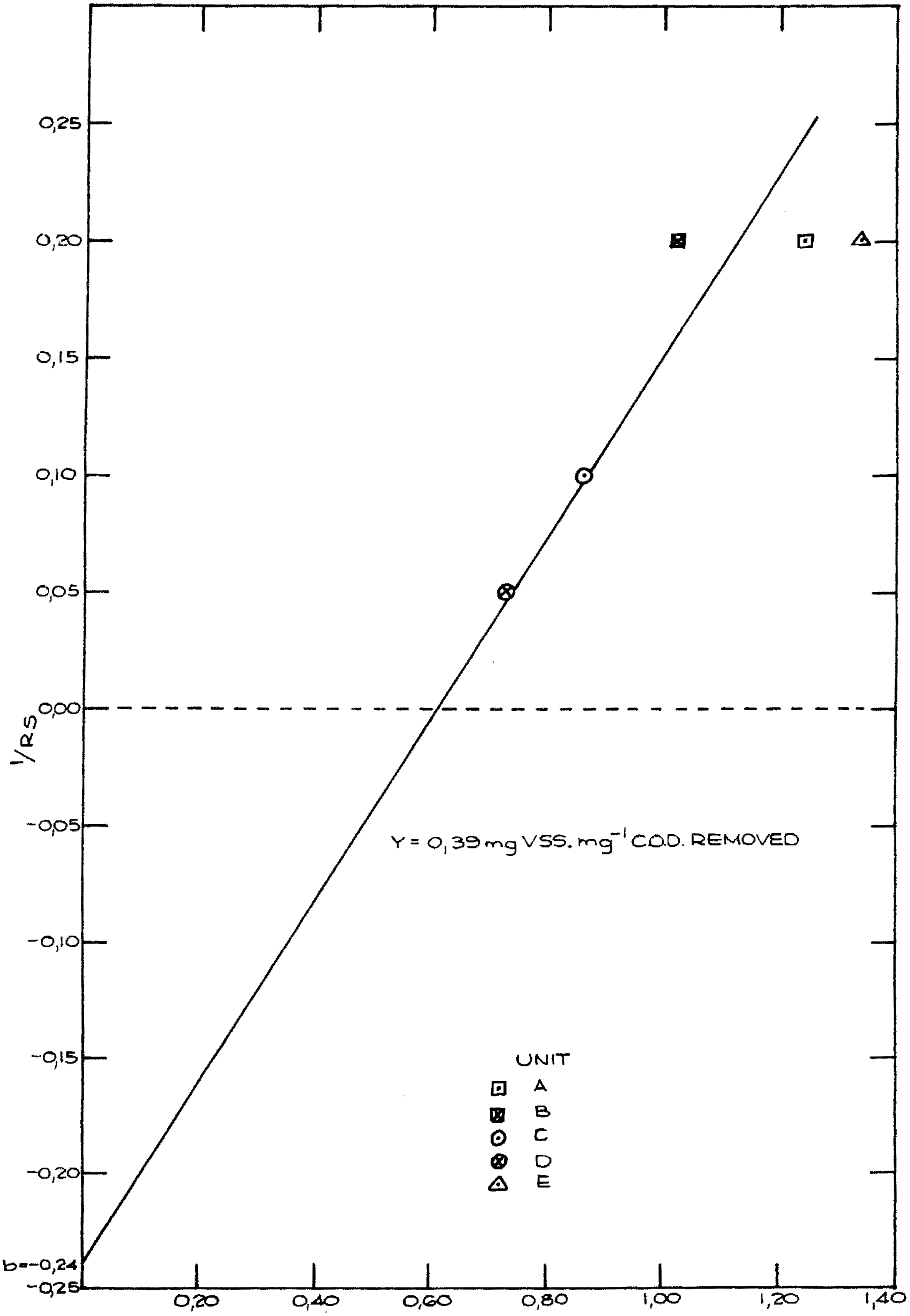


FIGURE 29: DETERMINATION OF YIELD, Y

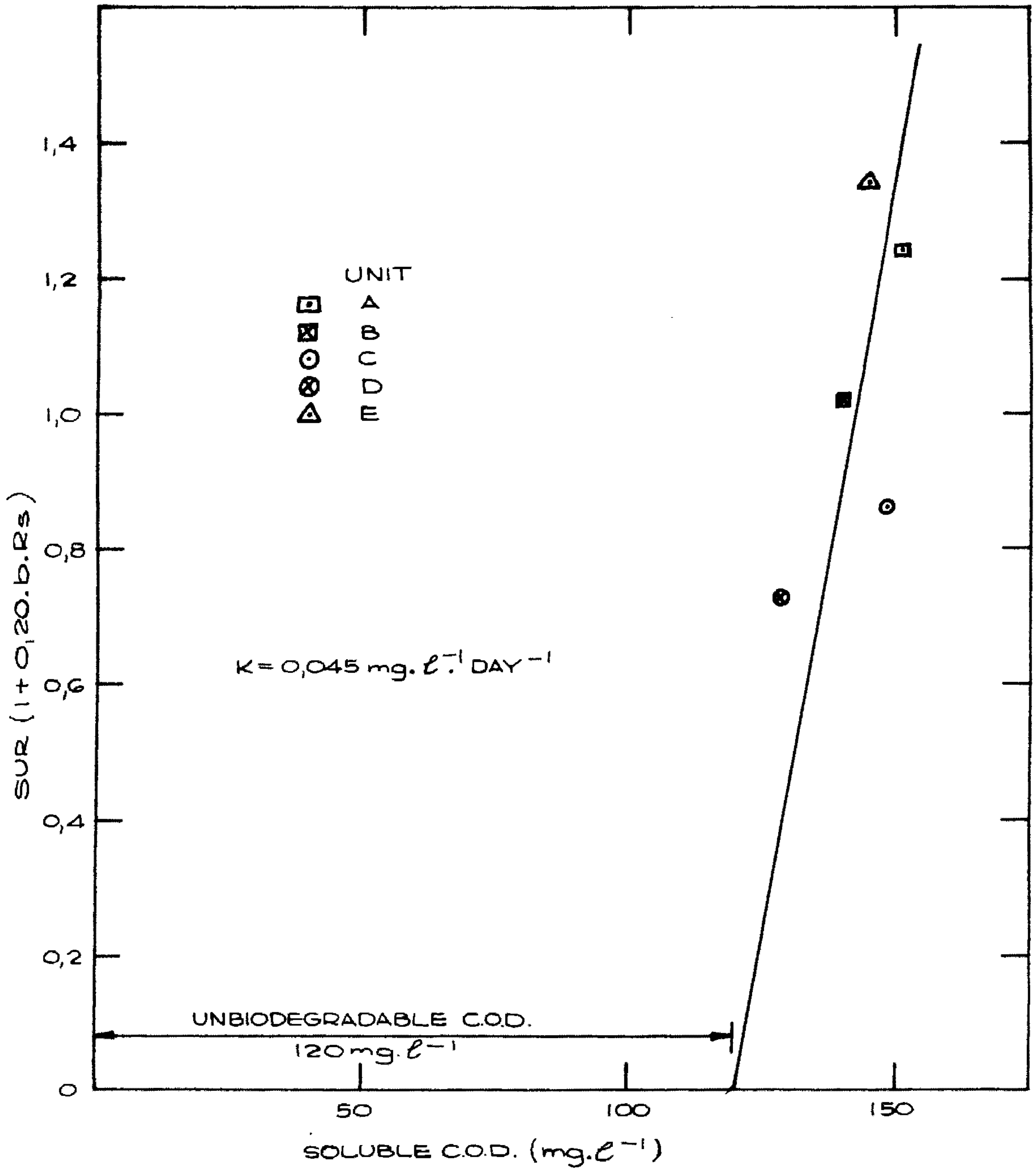


FIGURE 30: DETERMINATION OF REACTION RATE CONSTANT, K

CORRELATION BETWEEN EXPERIMENTAL RESULTS AND THEORETICAL PREDICTIONS.

The theoretical MLVSS concentrations, oxygen consumption rates and effluent qualities were calculated from Eqs. (8, 10 and 16). (The values of Y, b and K used were 0,39 mg VSS. mg COD^{-1}, 0,24 day^{-1} and 0,45 mg.l^{-1}.day^{-1} respectively).

$$\text{Eq. (8)} : X_v = \frac{Y(S_i-S)}{1+b.R_s} . \frac{R_s}{R} (1+0,2b.R_s)$$

$$\text{Eq.(10)} : O_2 = \frac{S_i-S}{R} - 1,42 \frac{X_v}{R_s}$$

$$\text{Eq.(16)} : \text{Eff.COD} = \text{Sub} + \frac{1}{YK} \left(\frac{1}{R_s} + b\right)$$

Figs. 31, 32 and 33 show the correlations between the theoretical predictions and the experimental results. With the exception of the results from Unit E (R = 8hr, Rs = 5d, An) good correlation is obtained. It is possible that the residence time in the anaerobic reactor of Unit E results in the solids concentration and oxygen requirements being lower than predicted by theory.

CONCLUSIONS FROM ACTIVATED SLUDGE TREATMENT.

From the investigations into the treatment of the effluent from the sewage works at Paarl during the 1974 canning season by the activated sludge process, the following conclusions can be formed :

(i) The effluent is biodegradable. This is evident by noting that the reduction in COD was approximately 88 per cent from an influent of 1 200 to 1 400 mg.l^{-1} to an effluent of 140 to 170 mg.l^{-1}. The significant improvement in the quality of the effluent by secondary biological treatment is illustrated in Fig. 34 which is a photograph of an influent and effluent sample.

(ii) The kinetic behaviour of the activated sludge process appears to conform to that normally accepted. The 'Yield Constant, Y (0,39 mgVSS.mg^{-1}COD removed) is slightly lower than that found for settled municipal sewage (0,43 mgVSS.mg^{-1}removed, Marais 1974)

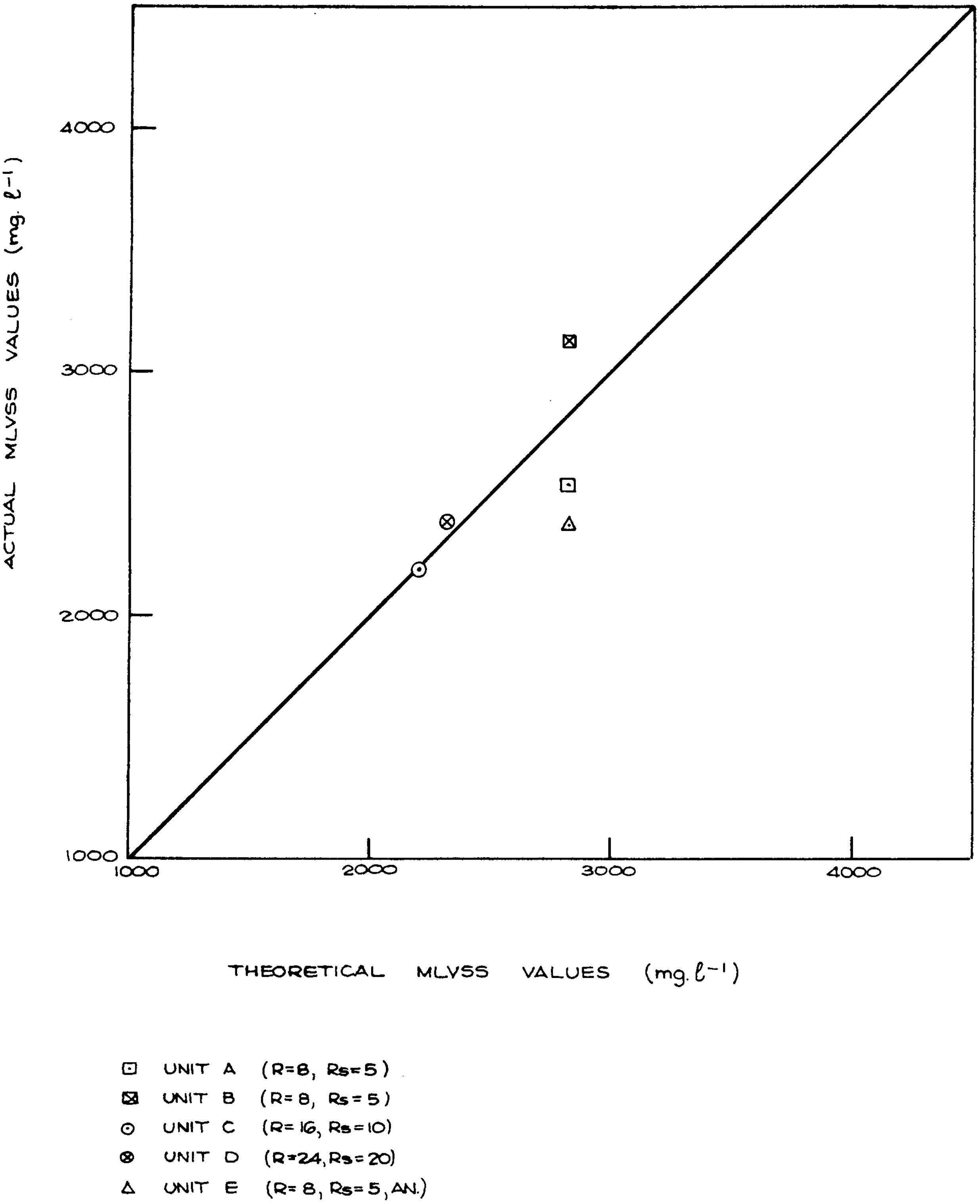


FIGURE 31: CORRELATION BETWEEN THEORETICAL AND EXPERIMENTAL MLVSS VALUES

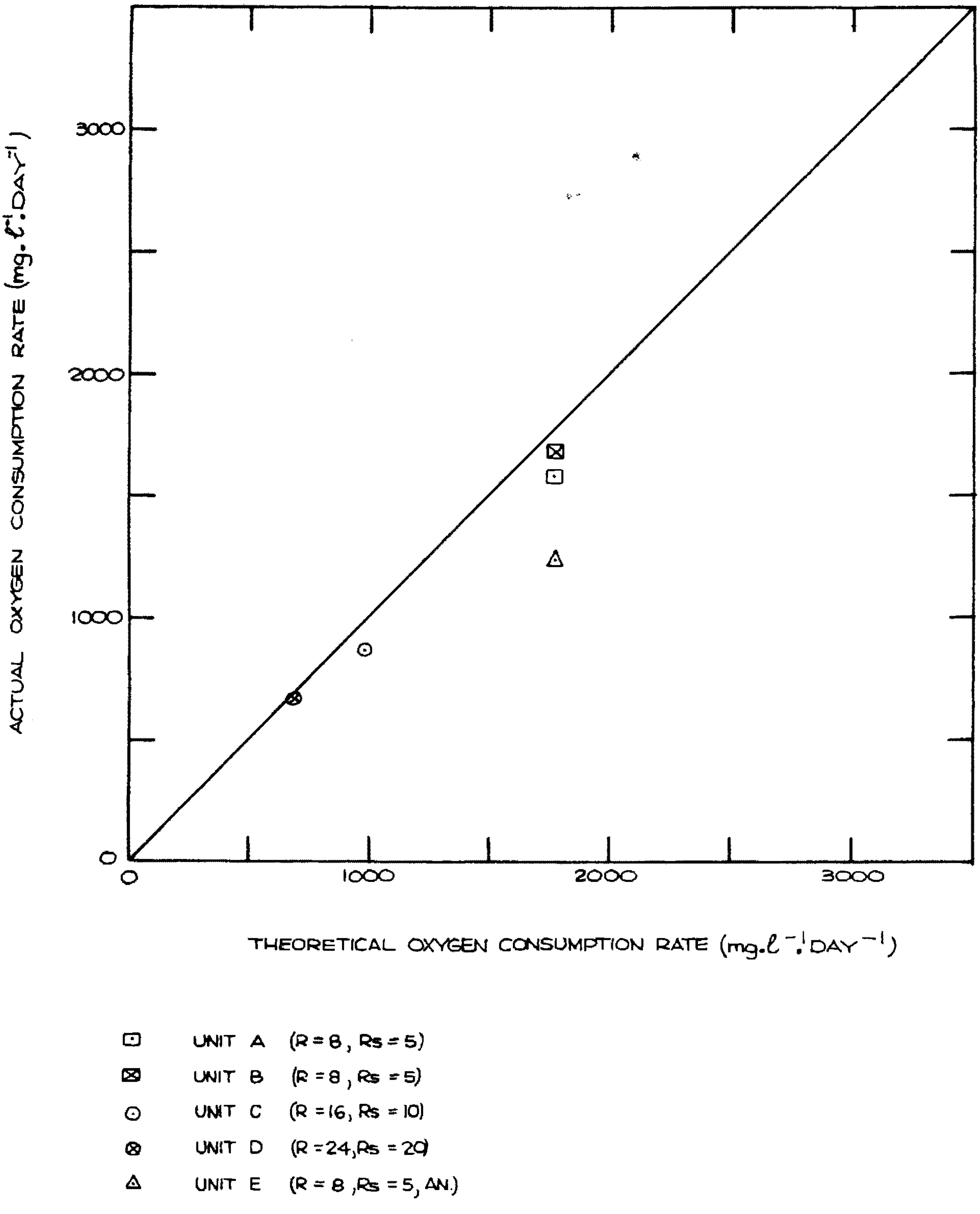


FIGURE 32: CORRELATION BETWEEN THEORETICAL AND EXPERIMENTAL OXYGEN CONSUMPTION RATES

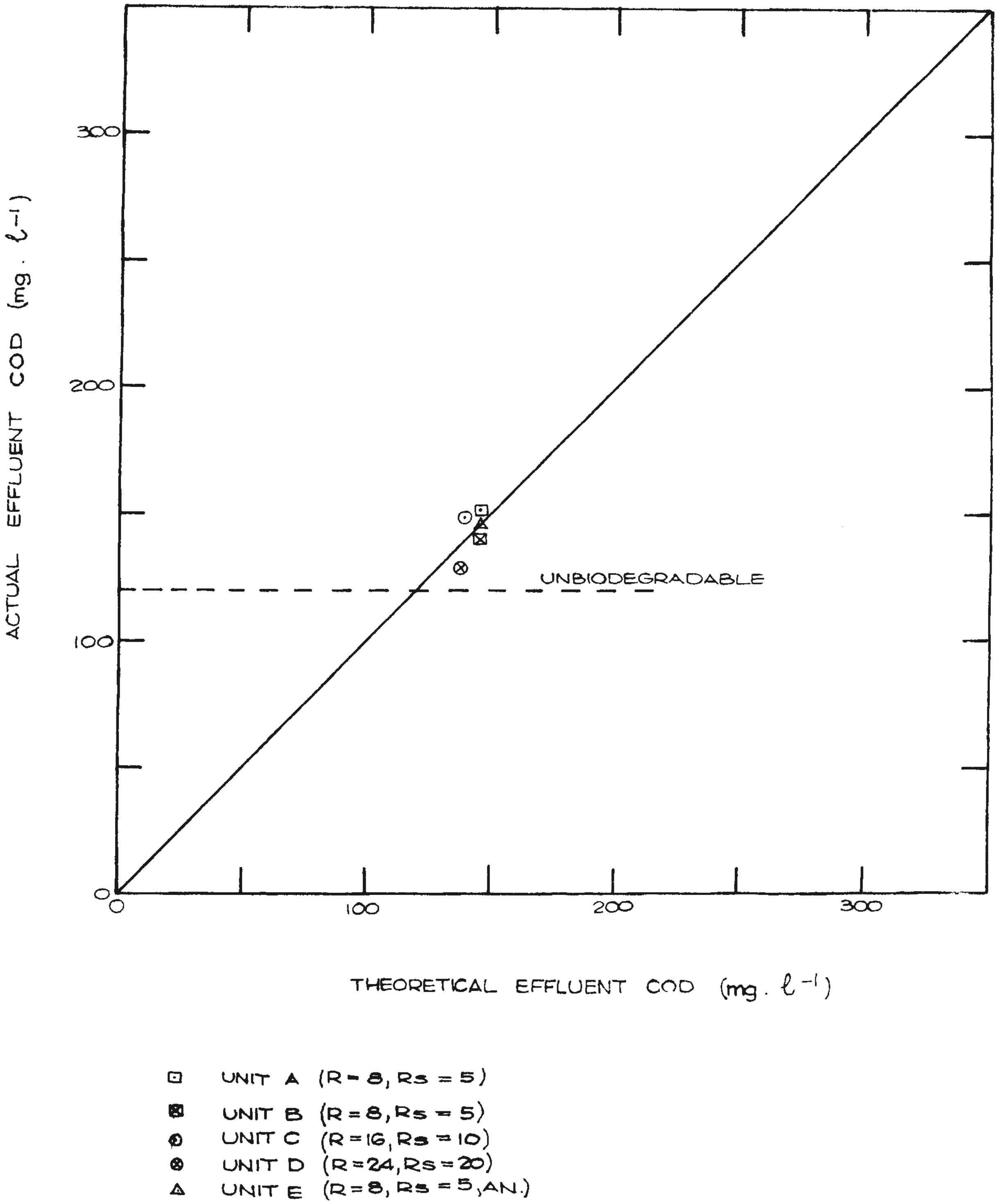


FIGURE 33: CORRELATION BETWEEN THEORETICAL AND EXPERIMENTAL FILTERED EFFLUENT COD. VALUES

FIGURE 34 : EFFECT OF SECONDARY BIOLOGICAL TREATMENT

and the Reaction Rate' Constant $K = 0{,}045\ mg.l^{-1}.day^{-1}$ as against $0{,}07\ mg.l^{-1}.day^{-1}$ for settled municipal sewage (Marais, 1973). These values indicate lower ease of biodegradability. The oxygen demand conforms reasonably well to the theoretical predictions.

(iii) There appears to be no real deficiency in the nutrients, nitrogen and phosphorus. This is indicated by the experimental results which all showed that at least 1 $mg.l^{-1}$ of NH_3-N was present in the effluents. The sludges had nitrogen concentrations between 10 and 12 per cent and phosphorus concentrations of 2 per cent - which are normal. Urea addition to one unit did not result in any perceptible improvement in effluent COD or settling properties.

(iv) Although the waste is biodegradable it is not treatable by the activated sludge process except at inordinately long sludge ages. At sludge ages of 5 and 10 days there was excessive bulking of the sludges so that it became very difficult to run the laboratory scale units. It would certainly be impossible to run a full scale plant at sludge ages below 10 days. At 20 days sludge age no bulking occurred - indeed the settling properties of the sludge were excellent. However, the provision of a full scale plant operating at this long sludge age would require a hydraulic retention time of 24 hours if the sludge concentration is to be kept at 2 800$mg.l^{-1}$ MLVSS. Such long sludge ages are usually necessary where nitrification is required during winter conditions. In this plant the loading is seasonal, during the summer, and there is no excess nitrogen to nitrify. The effluent quality will not improve over that from a system operating at a shorter sludge age. The nett oxygen demand will increase. The size of the reactors will be about 60 per cent greater than that required for carbonaceous energy removal only. The increased size of the plant is solely required to improve the settling qualities of the mixed liquor. There thus seems little justification for the installation of an activated sludge plant as the form of secondary treatment.

CHAPTER 4

ROTATING DISC TREATMENT.

INTRODUCTION

The investigation into the feasibility of employing the rotating disc system as the form of secondary treatment was initiated towards the end of the 1974 canning season.

A laboratory scale series disc unit was available and a programme of testing was inaugurated.

Subsequent to the investigation into secondary treatment application, wastewater from a fruit and vegetable cannery was obtained and the feasibility of employing the disc system as a form of 'roughing' treatment was investigated. A 'banked' disc unit was used in this investigation.

PRINCIPLE OF THE ROTATING DISC SYSTEM

The system operates on a principle very similar to that of biological filtration in that the biomass adheres to and grows on discs - the fixed media. As the discs rotate the organisms are alternatively in contact with the air and the waste water (See Fig.35).

The dissolved oxygen concentration in the liquor is controlled by the speed of rotation of the discs.

The biomass periodically 'sloughs off' the discs and accumulates in either a compartment under the discs or in a settling tank positioned after the disc units, from where it is periodically pumped to anaerobic digestors.

The attractive feature of the RDU is that, unlike the systems based on the activated sludge process, successful operation is not dependent on the efficient performance of a settling tank. The problems of sludge bulking are obviated and less skilled control is demanded.

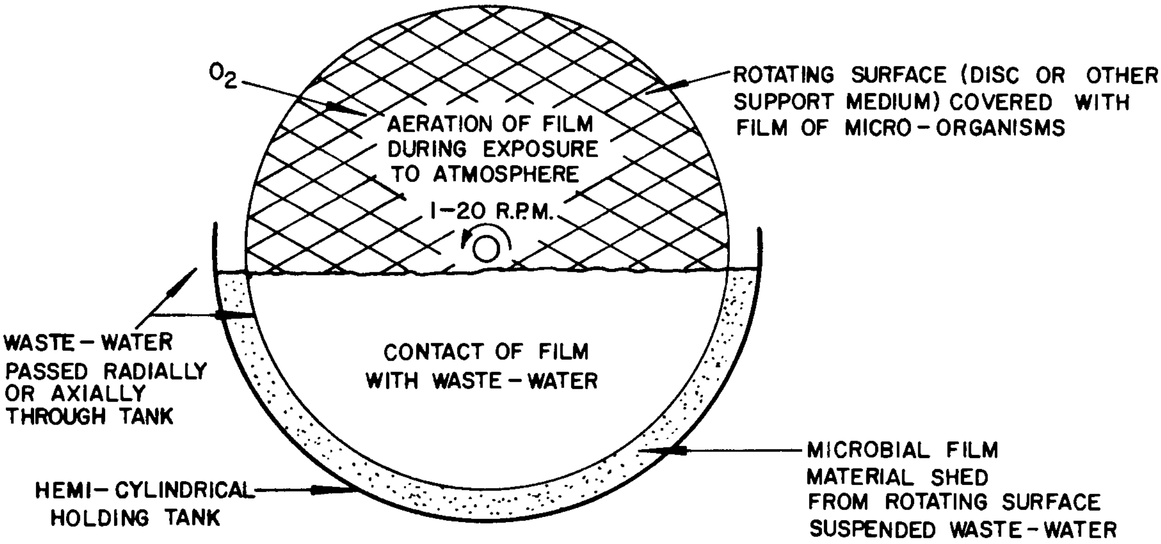


FIG. 35 : PRINCIPLE OF THE OPERATION OF A R.D.U.

LITERATURE REVIEW

The Rotating Disc system, or the rotating biological disc contractor as it is commonly known as, was first investigated in America in 1901 but very little interest was displayed in the findings (Pretorius, 1971).

In 1958 extensive investigations were carried out in Germany (Grieves, 1972) and the more important findings were :

(i) Optimum rotational velocity was 5 - 7 rpm for a 1 metre diameter disc. The peripheral velocity should not exceed 22 $m.min^{-1}$, since above this speed excessive shearing of the organisms from the disc occurs.

(ii) The discs should rotate in the direction of the waste water flow.

(iii) The system is especially suitable to small plants on account of the low maintenance costs and insensitivity to fluctuations in biological load.

(iv) The operating costs were "considerably less" than those for equivalent activated sludge or trickling filter plants.

Further investigations in 1963 indicated that the nett power requirements could be as low as 0,011 to 0,0135 $Kwh.lb^{-1}$ BOD removed (0,024 to 0,030 $Kwh.kg^{-1}$ BOD removed, Grieves, 1972).

Welch (1968) successfully applied the system to the treatment of highly concentrated milk wastes. His conclusions were :

(i) the process was very stable to hydraulic surges or organic overloads.

(ii) optimum results were obtained with disc units in series.

(iii) the dissolved oxygen concentration in the reactor, and the process efficiency, could be controlled by the disc rotational velocity.

Discs are constructed out of either PVC, asbestos cement, pegboard, steel mesh or expanded polystyrene.

The disc system has been applied for 'roughing' treatment of a wide variety of industrial wastes (Antonie, 1971). Loadings were reported in the range of 300 to 1 300 lb BOD. 1 000 $ft^{-3}.day^{-1}$ (approximately 60 to 250 g $BOD.m^{-2}.day^{-1}$). For 'complete' treatment loadings of 100 to 400 lb BOD. 1 000 $ft^{-3}.day^{-1}$ have been employed (approximately 20 to 80 g $BOD.m^{-2}.day^{-1}$).

Antonie states that the sludges produced settled well with settling rates of between 4,5 and 7,5 $m.hr^{-1}$. Typical sludge yields of 0,4 to 0,6 g dry $solids.g^{-1}$ BOD removed were reported.

Steele (1974) found the rotating disc systems particularly suited for treating widely fluctuating flows. He reports on an experimental disc system subjected to a fluctuating load of 400 per cent of the design for a period of 2,5 hours. The shock loadings caused insignificant changes in the effluent quality.

Steele also concluded that the disc system is effective in biologically treating effluents which are termed 'unbiodegradable', e.g. coking wastes with high phenol contents. He also states that the disc system appears to offer ideal living conditions for organisms which treat hydrocarbons. He reported 99 per cent reduction of oil and petrol wastes at disc loadings of 10 - 20 $g.m^{-2}.day^{-1}$. Loadings of 1 $g.m^{-2}.day^{-1}$ resulted in 82 to 95 per cent removal of machine oil and lubricants from a waste stream.

Chittenden et al (1971) reported on the treatment of the effluent from an anaerobic lagoon by means of the disc system. A meat packing factory discharged an effluent with a BOD of 1 400 $mg.l^{-1}$ into the lagoons. The lagoons effected a 75 to 85 per cent BOD reduction. Results obtained from the 38 $kl.day^{-1}$ three stage pilot disc plant indicated that the first stage effected an 80 per cent BOD reduction with a disc loading of 50 g $BOD.m^{-2}.day^{-1}$. The overall (three stage) BOD reduction was 83 per cent. Dissolved oxygen limitations prevented higher loadings being applied to the first stage discs.

Birks and Hynek (1971) reported on the installation and performance of a bio-disc system to upgrade the effluent from a cheese factory. Septic tanks were positioned ahead of the disc unit and effected a 50 per cent COD reduction on the wastes. The spetic tank effluent fed to the disc system had a COD of 1 500 $mg.l^{-1}$. The four stage disc unit effected an overall COD removal of 85 per cent. The COD removal rate over the first stage was reported as 55 g $COD.m^{-2}.day^{-1}$ for a disc loading of 90 g $COD.m^{-2}.day^{-1}$.

Antonie et al (1974) drew the following conclusions from a 1,9 $Ml.day^{-1}$ pilot plant treating domestic sewage :-

(i) The percentage BOD (or COD) removal was dependent on the hydraulic loading rate ($l.day^{-1}.m^{-2}$). A BOD removal of 85 per cent was obtained at a loading of 110 $l.day^{-1}.m^{-2}$, whereas at a loading of 20 $l.day^{-1}.m^{-2}$ the BOD removal was 95 per cent.

(ii) The optimum hydraulic retention time required for the disc units ranges from 1 to 1,5 hours.

(iii) The 'start-up time', i.e. the time elapsed before the unit produces an acceptable effluent,was always 1 to 1,5 weeks.

(iv) The mixed liquor solids settled very rapidly, producing a sludge of 4 - 5 per cent solids.

Cochrane et al (1973) conducted pilot plant scale investigations into the treatment of cannery wastes with a disc unit. Their results indicated that 90 per cent of the organic matter was removed, but the effluent required further treatment before discharge.

Welch (1971) reportedly used the process for in line treatment of waste waters in sewers.

Pretorius (1971) reported on the application of disc units to treat septic tank effluent emanating from small communities. He reported a COD removal rate of 22 g $COD.m^{-2}.day$ - effecting an overall COD reduction of 75 per cent. Complete nitrification was obtained with nitrate formation rates of between 1,5 to 2, 5 g NO_3^--$N.m^{-2}.day^{-1}$.

From the literature survey the following conclusions can be made :

(i) The rotating disc system has been employed in both 'roughing' and 'complete treatment' systems.

(ii) The loading rate for secondary biological treatment applications appears to be 100 g $COD.m^{-2}$,day, whereas that for 'roughing' ranges up to 300 g $COD.m^{-2}.day^{-1}$.

(iii) The ability of the systems to treat 'unbiodegradable' wastes is probably due to the low applied loading, expressed as kg $COD.kg^{-1}MLVSS.day^{-1}$ (i.e. a long sludge age).

(iv) Referring to page 13 the long apparent sludge age would clearly reduce the required COD:N:P ratio in the influent.

(v) The first stage of most multi-stage applications is the most efficient, producing at least 80 to 90 per cent of the overall COD removal. The economic feasibility of installing further stages to reduce the COD by a further 10 to 15 per cent should be carefully appraised.

No literature on the application of the disc system as a form of secondary biological treatment of fruit cannery wastes could be found. It is probable that, in secondary treatment, the COD reduction over one stage of discs may not be suffient. However, the installation of further stages to produce the required COD reduction may not be an economic proposition.

The literature survey indicates the excellent reductions achieved in the first stage of the disc system treating raw waste. The application as a 'roughing' unit therefore merits investigation.

CHAPTER 5.

ROTATING DISC SYSTEM AS A FORM OF SECONDARY BIOLOGICAL TREATMENT- EXPERIMENTAL INVESTIGATION

OBJECTIVE

The specific objective of this investigation was to ascertain the feasibility of employing the rotating disc system as the form of secondary treatment at the Paarl sewage works, treating the effluent from the overloaded bio-filters.

EXPERIMENTAL EQUIPMENT

An existing laboratory scale series rotating disc unit was employed, shown in Fig. 36.

Nine peg-board discs, each 330 mm in diameter rotated about a common shaft in a mild steel container. The surface area of each disc was 1 710 cm^2 (see Fig. 37). The discs were separated by 'V-notch' baffles - resulting in each compartment being completely mixed and the overall flow pattern essentially 'plug-flow'. The volume of each compartment was 3,2 litres.

The speed of rotation of the discs was controlled by a rheostat on the drive motor.

The feed was pumped intermittently to the unit by a Gorman-Rupp pump and flowed axially through the unit.

The sludge which sloughed off the discs accumulated in the bottom of the container and was periodically drained off and wasted.

EXPERIMENTAL PROCEDURE

The waste fed to the unit was the effluent from the high rate filters at Paarl, in point of fact the remains of Batch 6 (see page 13). A further Batch 7 was collected toward the end of the canning season. Table 9 shows the analyses of the feed.

FIGURE 36 : ARRANGEMENT OF THE SERIES R.D.U.

FIGURE 37 : SHOWING THE DISCS OF THE SERIES R.D.U.

TABLE 9 : ANALYSES OF FEED BATCHES.

Batch No.	COD	TKN	PO_4-P	COD : TKN : PO_4-P
6	1 160	28,0	5,6	100 : 2,4 : 0,48
7	850	48,0	7,0	100 : 5,6 : 0,80

The feed rate was initially set at 15 $l.day^{-1}$, increased to 30 $l.day^{-1}$ after one month and after a further week increased to 60 $l.day^{-1}$.

The flows of 15, 30 and 60 litres per day resulted in hydraulic retention times in each compartment of 5; 2,5 and 1,25 hours respectively.

The speed of rotation of the discs, set at 15 rpm (Tip speed 16 $m.min^{-1}$) remained unaltered throughout the investigation and the depth of immersion of the discs remained fixed at 140 mm.

ANALYTICAL PROCEDURE

Filtered samples from each compartment in the unit, together with a filtered final effluent sample, were analysed for COD at least twice weekly.

EXPERIMENTAL RESULTS

The average of the COD values at the different flow rates are shown in Fig. 38.

The pH in each compartment was periodically measured. In general, the pH increased from the first to the last compartment - typical values being 7,9 to 8,5.

DISCUSSION ON RESULTS

A comparison of the COD mass loading (g $COD.m^{-2}.day^{-1}$) on each disc, together with the total COD reduction, is shown in Table 10.

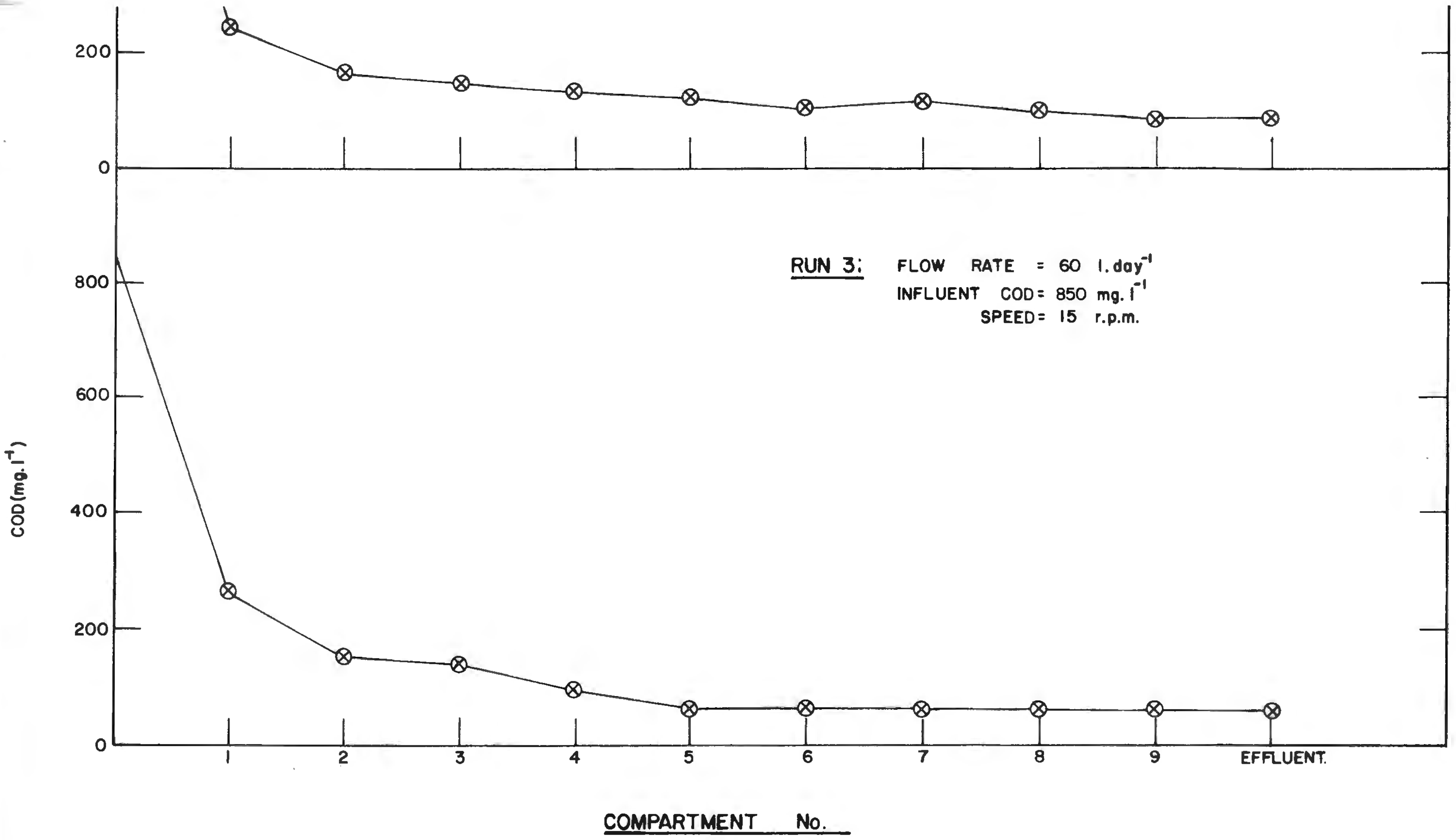


FIGURE 38: COD PROFILES OBTAINED FROM THE RDU

TABLE 10 : COMPARISON OF LOADING RATES AND COD REDUCTIONS

Feed Flow	15. l day^{-1}			30 $l.day^{-1}$			60 $l.day^{-1}$		
Feed COD	900 $mg.l^{-1}$			850 $mg.l^{-1}$			850 $mg.l^{-1}$		
Disc No.	Liq. COD	$\frac{g\ COD}{m^2.day}$	Total COD Red'n(%)	Liq. COD	$\frac{g\ COD}{m^2.day}$	Total COD Red'n(%)	Liq. COD	$\frac{g\ COD}{m^2.day}$	Total COD Red'n(%)
1	260	78,9	71,1	244	149,1	71,3	267	298,2	68,6
2	191	22,8	78,8	165	42,8	80,6	154	93,7	81,9
3	167	16,8	81,4	146	28,9	82,8	138	54,0	83,8
4	135	14,6	85,0	131	25,6	84,6	97	48,4	88,6
5	110	18,8	87,8	122	22,9	85,6	57	34,0	93,3
6	105	9,6	88,3	108	21,4	87,3	57	20,0	93,3
7	110	9,2	87,8	116	18,9	86,7	57	20,0	93,3
8	107	9,6	88,1	99	20,4	88,4	57	20,0	93,3
9	94	9,4	89,6	85	17,4	90,0	53	20,0	93,8

These results probably overestimate the mass loading (g $COD.m^{-2}.day^{-1}$) as the organisms adhering to the fixed sides of the container have been ignored.

It can be ssen from Table 10 that at the highest flow rate (60 $l.day^{-1}$) the first three discs effected an 84 per cent reduction on the waste - the first disc reducing the COD by 69 per cent at a disc loading of up to 298 g $COD.m^{-2}.day^{-1}$. The 84 per cent COD reduction was achieved with a total hydraulic retention time of 3,75 hours.

The large biomass growth on the first three discs, corresponding to the large COD reduction, is shown in Fig. 39. The sludge which sloughed off the discs, accumulated at a greater rate in the first three compartments than in the others, approximately 1,5 litres sludge per week.

Table 11 compares the COD mass loading and removal rates (g $COD.m^{-2}.day^{-1}$) and per cent COD removal for each disc during the three runs.

The COD loading and percentage COD removal for the first three discs are shown in Fig. 40. The following may be noted.

(i) The percentage COD removed over the first disc decreased from 71 to 69 per cent as the loading rate was increased from 79 to 298 g $COD.m^{-2}.day^{-1}$. This implies that the maximum percentage COD removal that can be expected over the first disc is approximately 70 per cent, at a loading of 300 g $COD.m^{-2}.day^{1}$.

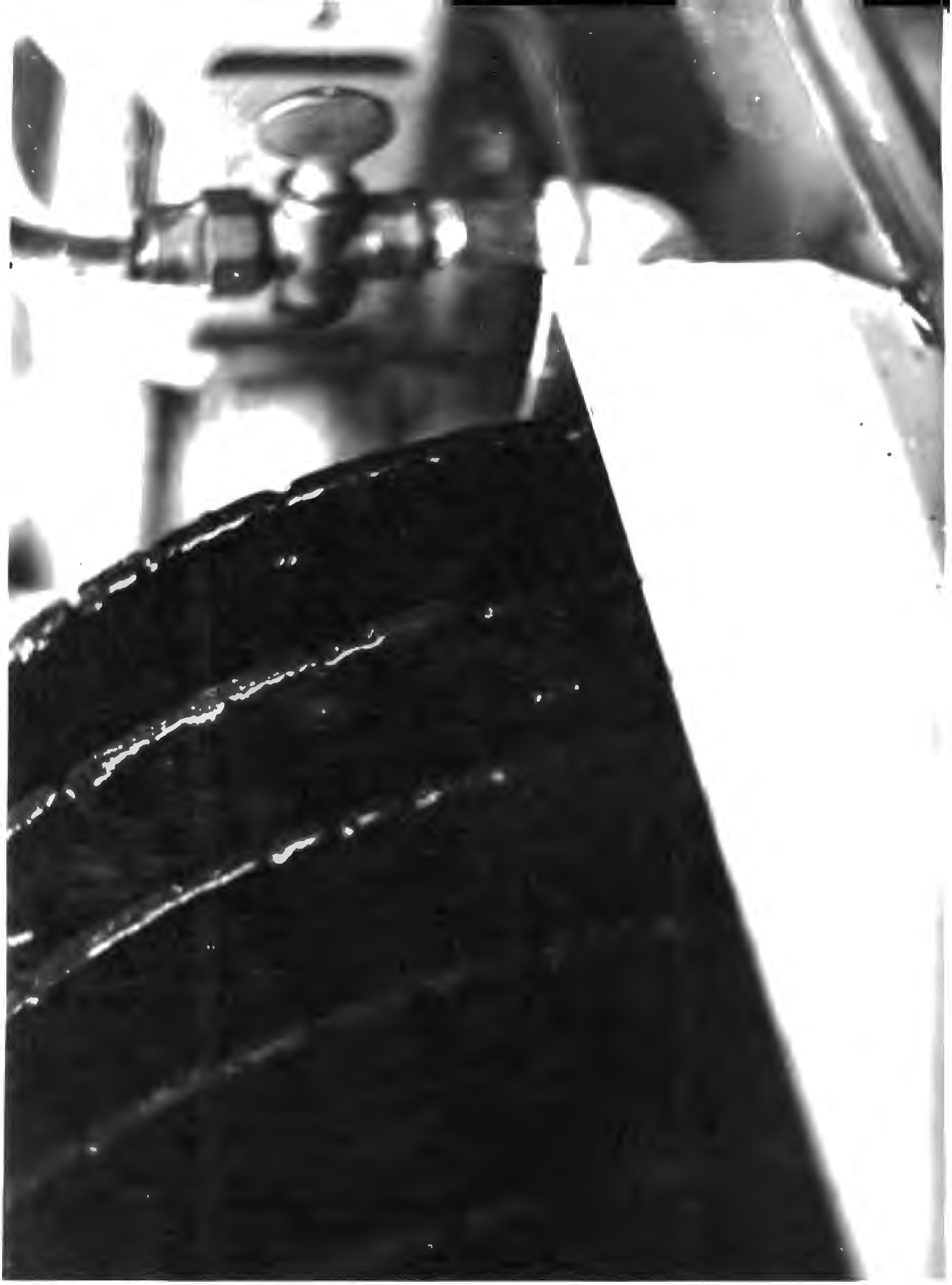


FIGURE 39 : SHOWING GROWTHS ON DISCS.

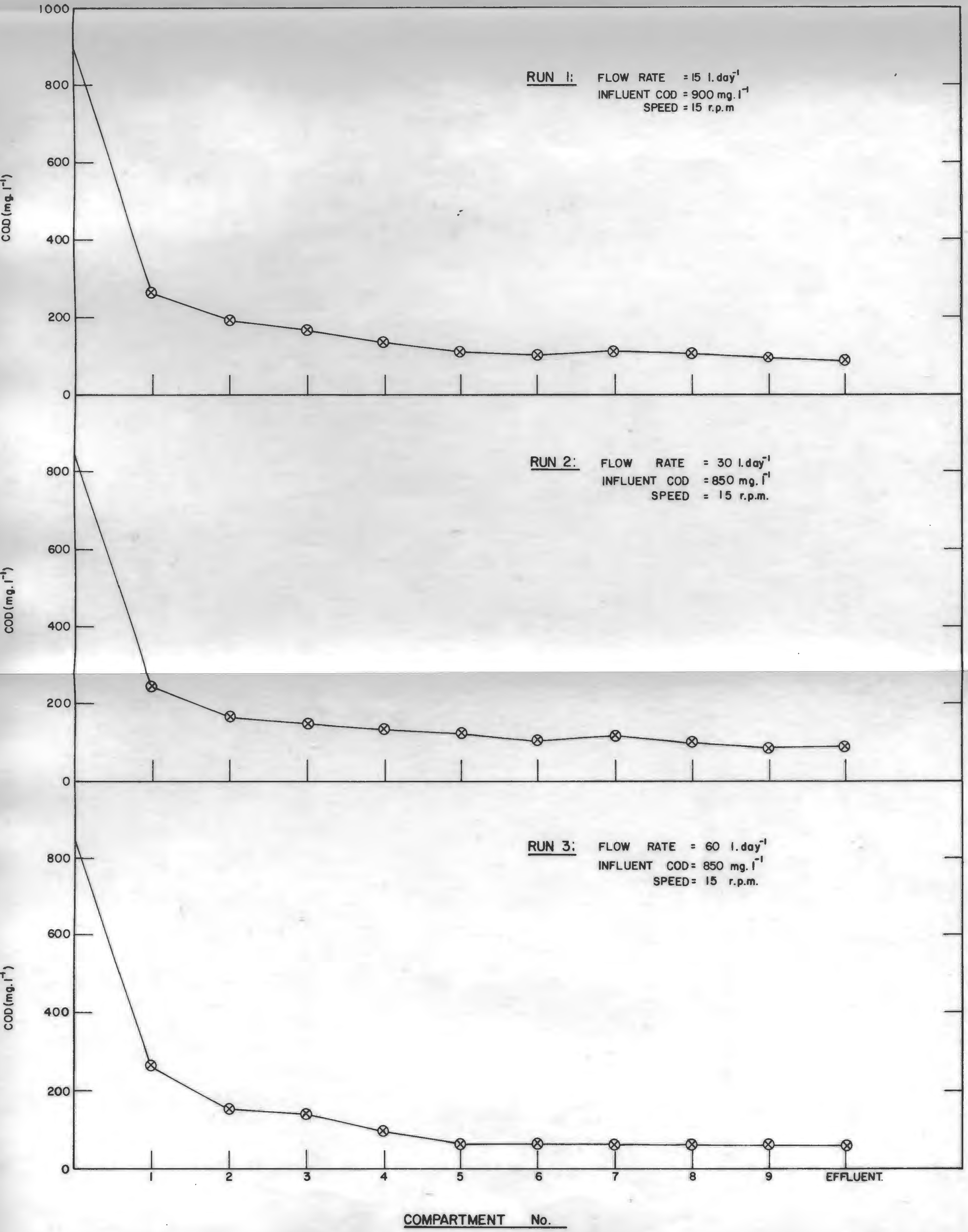


FIGURE 38: COD PROFILES OBTAINED FROM THE RDU

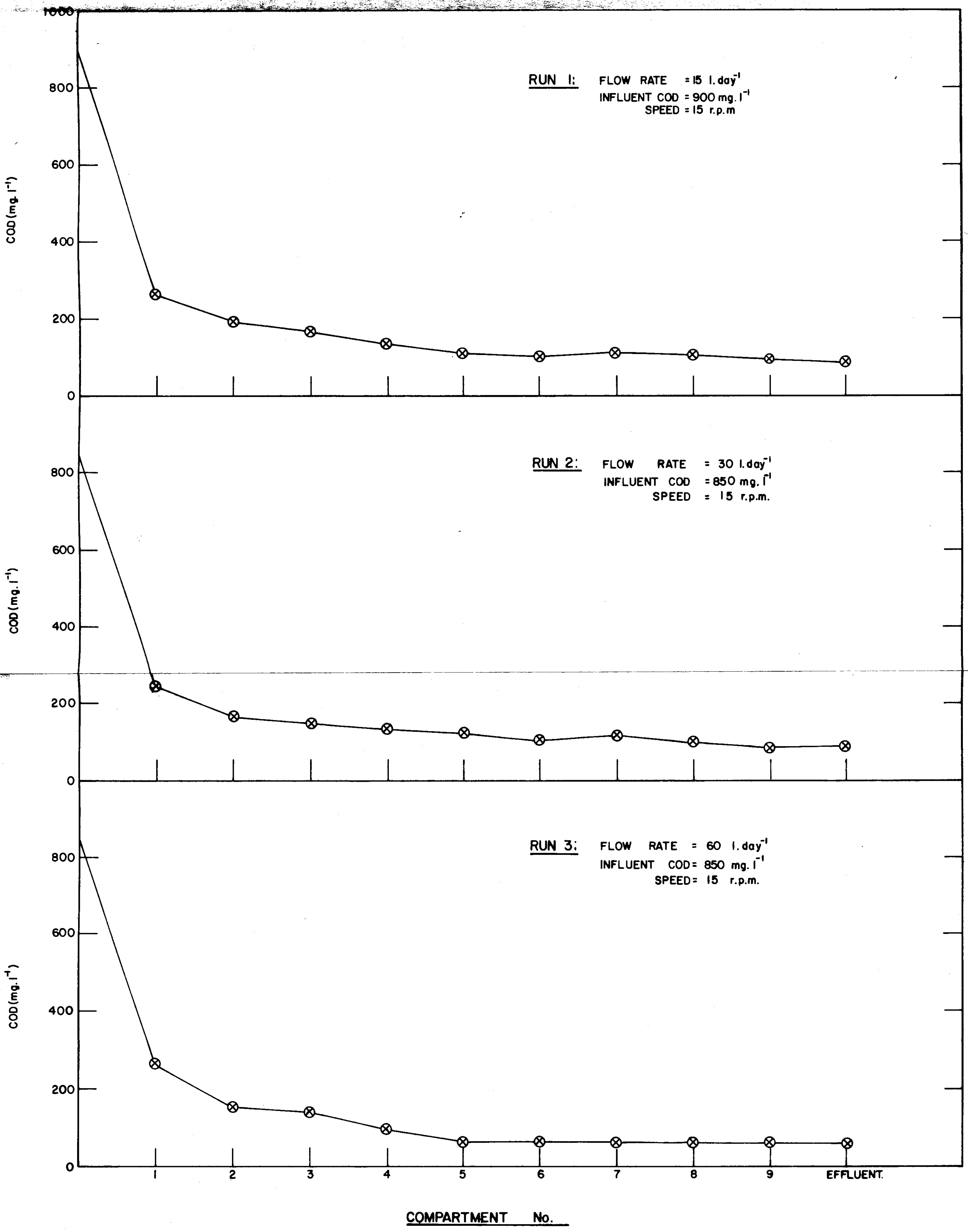


FIGURE 38: COD PROFILES OBTAINED FROM THE RDU

TABLE 11 : COMPARISON OF COD LOADING AND REMOVAL RATES FOR INDIVIDUAL DISCS.

Feed Flow RH	15 l. day^{-1} 5 hrs.			30 l. day^{-1} 2,5 hrs			60 l.day^{-1} 1,25 hrs.		
Disc No.	$\frac{\text{g COD applied}}{\text{m}^2\text{.day}}$	$\frac{\text{g COD removed}}{\text{m}^2\text{.day}}$	% COD removal over disc.	$\frac{\text{g COD applied}}{\text{m}^2\text{.day}}$	$\frac{\text{g COD removed}}{\text{m}^2\text{.day}}$	% COD removal over disc.	$\frac{\text{g COD applied}}{\text{m}^2\text{.day}}$	$\frac{\text{g COD removed}}{\text{m}^2\text{.day}}$	% COD removal over disc.
1	78,9	56,1	71,1	149,1	106,3	71,3	298,2	204,6	68,6
2	22,8	6,1	26,5	42,8	13,9	32,4	93,7	39,6	42,3
3	16,8	2,1	12,6	28,9	3,3	11,5	54,0	5,6	10,4
4	14,6	2,8	19,2	25,6	2,6	10,3	48,4	14,4	29,7
5	11,8	2,2	18,5	22,9	1,6	6,9	34,0	14,0	41,2
6	9,6	0,4	4,5	21,4	2,5	11,5	20,0	COD CONSTANT	
7	9,2	-	*	18,9	-	*	20,0		
8	9,6	0,3	2,7	20,4	3,0	14,7			
9	9,4	1,1	12,1	17,4	2,5	14,2	20,0	1,4	7,0

* Denotes a COD increase.

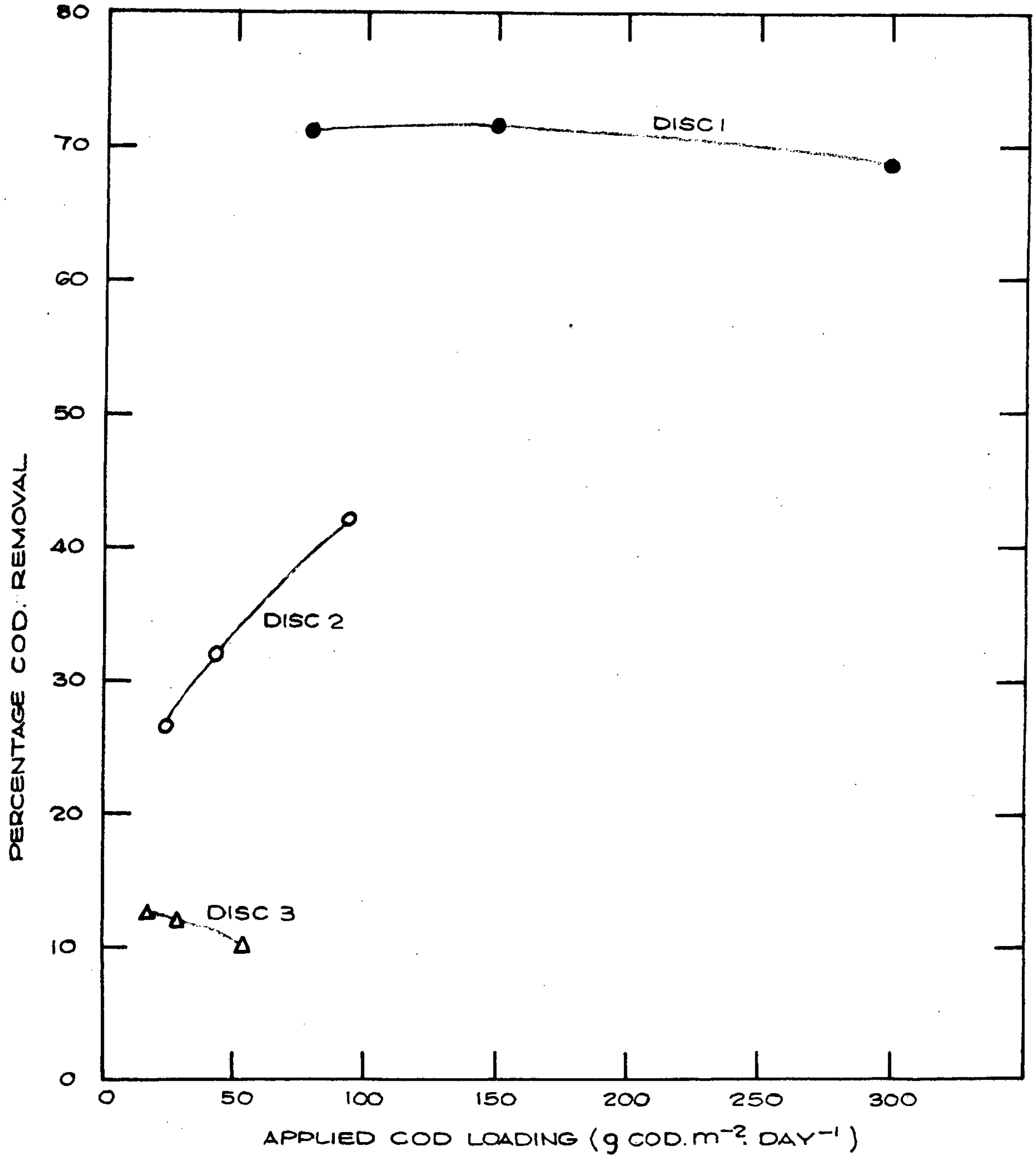


FIGURE 40: PERFORMANCE OF DISC UNIT

(ii) The percentage COD removal over the second disc increased from 27 to 42 per cent as the loading rate was increased from 23 to 94 g $COD.m^{-2}.day^{-1}$.

CONCLUSIONS FROM THE DISC SYSTEM AS A FORM OF SECONDARY TREATMENT

The investigation into the application of the disc system as a form of secondary treatment gave rise to the following conclusions :-

(i) A COD reduction of approximately 70 per cent at a disc loading of 300 g $COD.m^{-2}.day^{-1}$. can be expected over the first stage of discs.

(ii) A further two stages of discs would be required to produce an overall COD reduction of 84 per cent.

(iii) The cost of installing a further two stages of discs for an additional 14 per cent COD reduction does not appear to be an economic proposition.

The excellent performance of the first disc was obtained on an effluent from which the more easily biodegradable fraction had already been removed. This justified an investigation into the use of the disc system as a form of 'roughing' treatment.

CHAPTER 6.

ROTATING DISC SYSTEM AS A FORM OF ROUGHING TREATMENT - EXPERIMENTAL INVESTIGATION

OBJECTIVE

The specific objective of this investigation was to ascertain the feasibility of employing the rotating disc system as a form of 'roughing' treatment to treat the predominantly cannery wastes prior to discharge to the high rate filters at the Paarl sewage works.

This investigation was carried out over the period August to November, 1974. This period covers the canning off-season in Paarl and no waste was available. Waste was obtained from Messrs. Gants (Pty) Limited - a canning concern in Strand, Cape Province, producing a variety of fruit and vegetable products throughout the year.

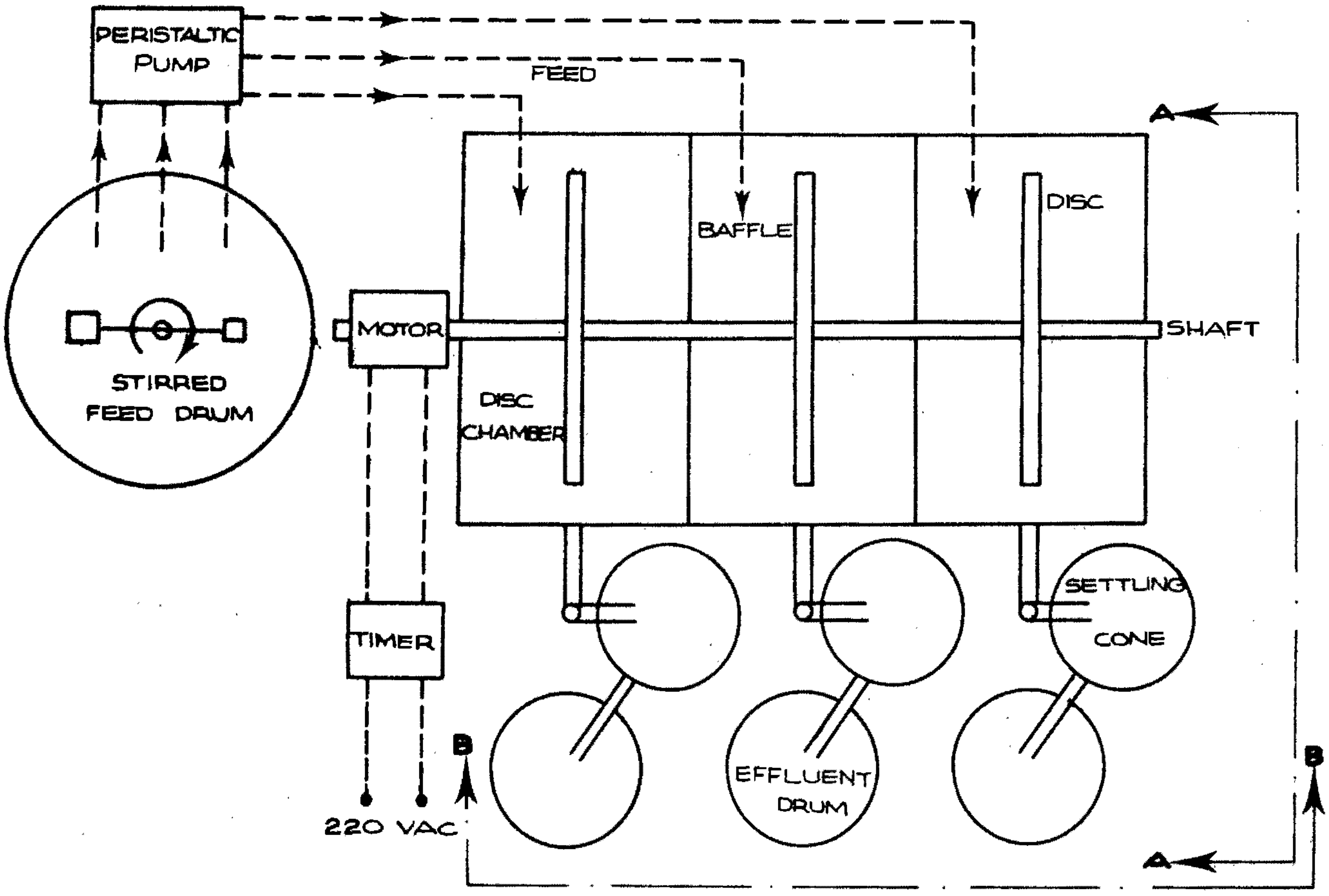
It was felt that the response of the disc unit to the waste would not differ qualitatively from that on Paarl waste and would provide sufficient information to enable a judgement to be formed on the suitability of the disc system as a form of 'roughing' treatment for cannery wastes in general.

EXPERIMENTAL EQUIPMENT

The unit used in this investigation differed from the series unit used previously in that -

(i) The discs were mounted in a hemispherical mild steel container of radius 18,2 cm. The container was divided into three variable-volume disc chambers that could be operated either in parallel or in series (Fig.41).

(ii) Free liquid volume and disc area (i.e. number of discs) in each chamber could be varied independently, so that for a particular waste the hydraulic residence time could be maintained in the range 0,8 - 4,0 hours whole the organic loading rate (g COD.m^{-2} disc area.day^{-1}) could be varied over the range 60 - 300 g COD.m^{-2}.day^{-1}. Details of the free liquid volumes and disc areas are given in Table 12.



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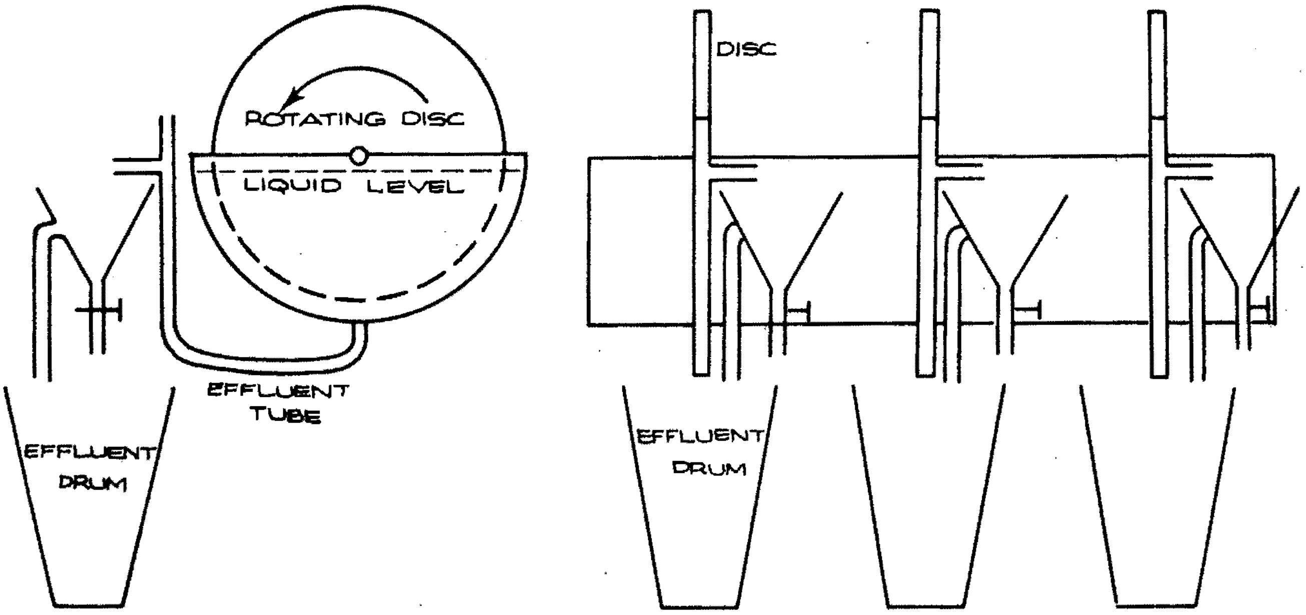

SECTION A A

SECTION B B

FIGURE 41 : LAYOUT OF DISC UNIT

TABLE 12.

Parameter	Disc Chamber 1	Disc Chamber 2	Disc Chamber 3
Number of discs	1	2	3
Disc diameter (m)	0,34	0,34	0,34
Total disc area (m^2)	0,1815	0,3630	0,5445
Free liquid volume (l)*	1,4	2,8	3,0

*the free liquid volume varied depending on the thickness of the sludge layer attached to the discs - the figures cited are observed averages, with a variation of ± 5%

The discs were constructed out of peg-board. Initially, however, the discs were constructed out of a brass mesh covered with a plastic coating. The peg-board discs were substituted shortly after start-up as excessive shear of the organisms by the disc mesh was observed.

Disc speed could be varied over the range 18 - 40 rpm. No significant sloughing of the film was observed even at the highest rotational speed. To keep the disc outer edge speed within the range normally used in practice (± 20 $m.min^{-1}$) the rotational speed was set at 20 rpm in this investigation, giving a tip velocity of 21 $m.min^{-1}$. Using this tip velocity as a scale-up parameter, the equivalent rotational speed for a typical industrial-sized unit (2,5 m diam. disc) would be 2,5 rpm, which is within the practical operating range reported (Antonie, 1971).

Separate sludge cones were installed on each chamber to collect the mass of sludge produced daily. Several methods of sludge withdrawal were investigated. In the first set-up used, with sludge being drawn off by a normal gravity flow, the rate of flow through the outlet tube was so low that the larger sludge particles were not drawn through, causing an accumulation of sludge in the disc chambers. This resulted in low dissolved oxygen levels, souring of the discs and the mixed liquor sludges.

The method of sludge withdrawal found to be successful, and finally adopted, was to drive the disc off a timer at 12 minutes ON and 30 seconds OFF. During the 12 minutes drive period the liquid volume in the disc chamber increased slightly over that given by the level of the overflow tube due to rotation of the disc through the liquid. During the 30 second 'off' period, the excess liquid hold-up was discharged rapidly, effectively discharging the solids. This method of operation ensured representative withdrawl of solids from the disc chamber and prevented settling of sludge in the effluent tubes.

EXPERIMENTAL PROCEDURE

(i) Waste Influent

Table 13 shows the analyses of the batches of waste collected from Gants (Pty) Limited during the investigation :

TABLE 13 : ANALYSES OF WASTE FROM GANTS

Batch No	Source	COD($mg.l^{-1}$)		Suspended Solids ($mg.l^{-1}$)	TKN ($mg.l^{-1}$)	PO_4-P ($mg.l^{-1}$)	pH
		Total	Soluble				
1	Guava	3 395	3 360	< 20	26,6	3,9	6,8
2	Beetroot	2 218	2 201	< 20	13,8	4,7	5,1
3	Beetroot	1 060	1 040	< 20	9,4	4,0	4,9
4	Bean	1 595	1 455	90	19,6	8,9	4,0
5	Bean	1 390	1 168	200	15,1	6,6	4,2
6	Pea	1 207	1 078	100	32,3	4,6	6,8
7	Pea	890	840	110	20,9	7,1	7,0
8	Pea	766	702	100	14,7	4,5	6,1

Table 14 shows the ratio COD:TKN:PO_4-P (based on Total COD) for the batches. As a comparison, the usual COD:TKN:PO_4-P ratio of the Paarl waste is also listed.

TABLE 14 : COD:TKN:PO_4-P RATIO FOR WASTE BATCHES

Batch No.	COD	TKN	PO_4-P
1	100	0,78	0,12
2	100	0,62	0,21
3	100	0,89	0,38
4	100	1,23	0,56
5	100	1,09	0,47
6	100	2,68	0,38
7	100	2,35	0,80
8	100	1,92	0,58
Paarl	100	0,88	0,22

When compared with the theoretically required ratio of 100 COD:3,3 N:0,6P - sludge age 5 days (refer to page 13), Table 14 shows that all the batches were nutrient deficient.

Apart from settled domestic sewage which was added in the ratio of 1:1 to only the first two batches fed to the unit, no other supplementary nitrogen and phosphorus source was added. Table 15 shows the COD:TKN:PO_4-P ratio for the two 'waste + domestic sewage' batches. The ratios still indicate an apparent nutrient deficiency.

TABLE 15 : COD:TKN:PO_4P RATIOS OF 'WASTE + SEWAGE' BATCHES.

Batch No.	COD	TKN	PO_4-P
1	100	1,32	0,53
2	100	1,85	0,60

At the laboratory the waste was stored in 500 1 stainless steel tanks situated in a cold room at 4 °C. The tanks were thoroughly mixed prior to withdrawing the daily feed quantity.

(ii) Operating Procedure.

The hydraulic retention time was varied from 1 to 4 hours by changing the position of the inter-compartmental baffles.

The applied COD mass loading was varied in the range 50 to 300 g $COD.m^{-2}.day^{-1}$ for each hydraulic retention time.

The average duration of each run was 10 to 12 days.

The speed of rotation of the discs was maintained at 20 rpm throughout the investigation, resulting in a tip velocity of 21 $m.min^{-1}$.

In order to compare the excess sludge yield with that from other treatment processes, the sludge yield per gram of soluble COD removed was determined. The parameter soluble-

COD-removed was chosen so as to eliminate settleable solids in the feed as a variable. Sludge production per g of soluble COD removed was calculated by (i) determining the mass of settled sludge accumulated in the settling cones over 24 hour periods of steady state operation and (ii) correcting this figure for the mass of settleable solids in the feed which were presumed merely to have passed unchanged through the reactor. The production of biological solids (as MLSS) with respect to soluble COD removal was determined from :-

$$Y = \frac{W - QX_i}{Q(S_i - S_o)}$$

Where W = total mass of settled solids collected per day (g MLSS)

Q = feed flow rate (l)

X_i = settleable solids in feed (g MLSS.l^{-1})

S_i = soluble COD in feed (g. l^{-1})

S_o = soluble COD in effluent (g.l^{-1})

and Y = net yield g MLSS.g^{-1} soluble COD removed.

ANALYTICAL PROCEDURE

Each batch of waste was analysed for total COD, soluble COD, Total Kjeldahl Nitrogen (TKN), Total phosphorus (PO_4-P) and suspended solids.

The contents of each compartment and the final effluent were regularly analysed for COD - both total and soluble, while TKN and PO_4-P analyses were frequently performed.

Dissolved oxygen concentration and pH values were occasionally monitored.

Total suspended solids concentrations were measured during the sludge yield measurements.

Periodic microscopic examinations of the sludge from the discs were performed. These examinations enabled a close check to be kept on the character of the sludge.

EXPERIMENTAL RESULTS

The experimental data relating COD mass loading rate (g COD.m^{-2}.day^{-1}) to COD mass removal rate and percentage COD reduction are tabulated in Appendix II.

DISCUSSION ON RESULTS

1. Effect of Hydraulic Retention Time, Rh

Antonie (1972) related percentage BOD and TKN removal to hydraulic retention time Rh, but in his investigation, the organic loading varied inversely with Rh, and the effect of the hydraulic retention time could not be assessed independently.

In this investigation, Rh could be set independently of the organic loading rate. Fig. 42 shows the COD mass loading-removal rate relationship, for the bean and pea wastes (batches 5 and 6 respectively) plotted separately for Rh = 1;2 and 4 hours. It is evident from the distribution of the data that in the COD mass loading rate range of 80 to 300 g COD.m^{-2}.day^{-1}, and hydraulic retention time range of 1 to 4 hours, Rh does not affect performance.

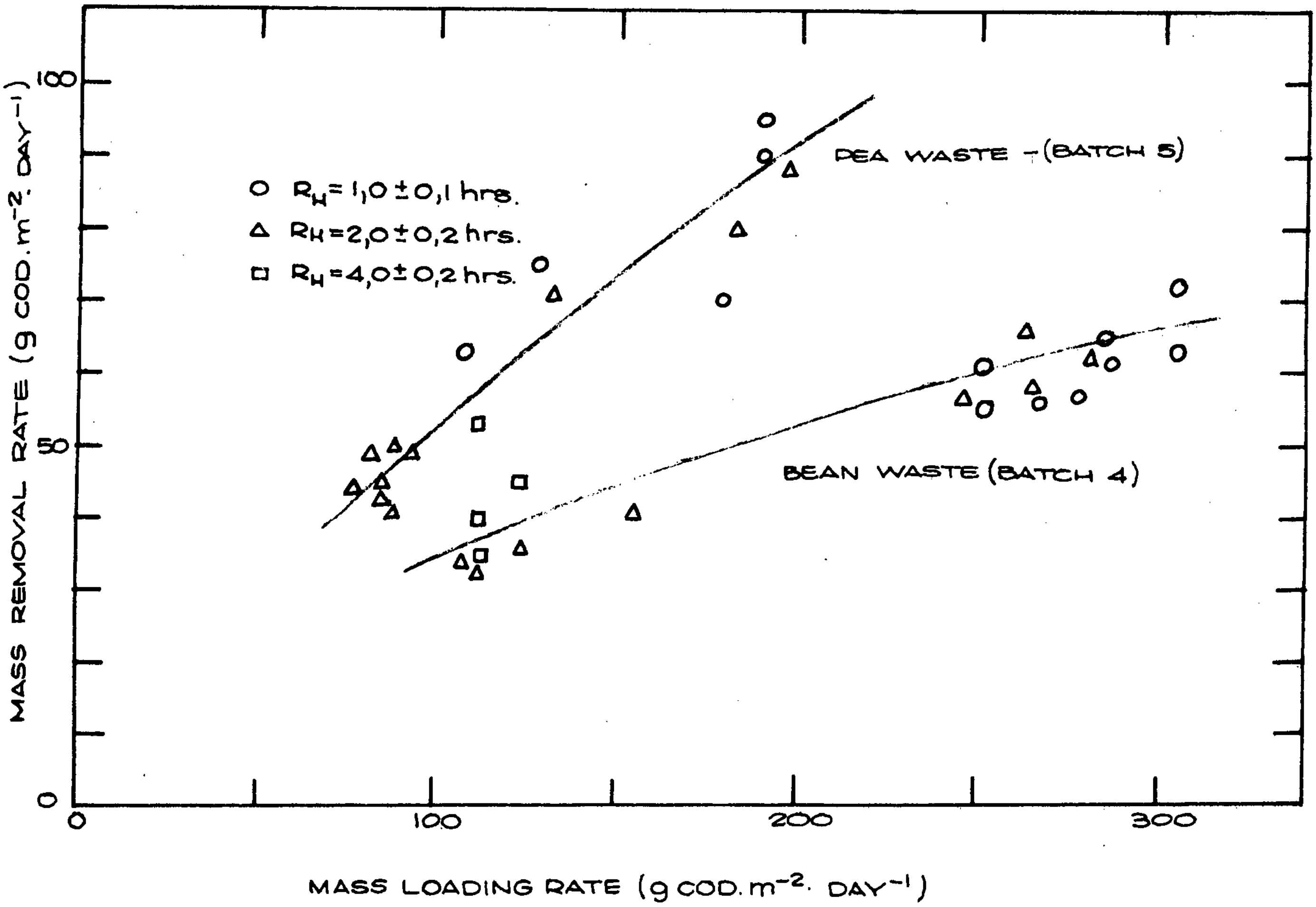

FIGURE 42: EFFECT OF HYDRAULIC RETENTION TIME, RH

2. COD Mass Loading and Removal Rates over One Stage.

Fig. 43 shows the COD loading-removal rate relationship for the two 'waste + sewage' batches. The following may be noted.

(i) For loadings in the range 100 - 300 g COD applied $.m^{-2}.day^{-1}$ the corresponding removal rates all lay in the range 50 - 90 g $COD.m^{-2}day^{-1}$.

(ii) The COD mass removal rate (g $COD.m^{-2}.day^{-1}$) increased as the mass loading rate (g COD $applied.m^{-2}.day^{-1}$) increased but the efficiency (mass COD $removed.mass^{-1}$ COD applied) decreased (see also Sections (3) and (4)).

The analyses of the effluents showed that residual TKN (2,2 - 4,1 $mg.l^{-1}$ and PO_4-P (2,1 - 3,4 $mg.l^{-1}$ remained, even at maximum COD removal (g $COD.m^{-2}.day^{-1}$) conditions. This would indicate that COD removal was not nutrient-limited, despite the apparently deficient COD:N:P: ratios of the feeds (Table 15). Nutrient requirements observed per unit COD removal are discussed in more detail in Section (5).

Figure 44 shows the results obtained from unsupplemented beetroot, bean and pea wastes (batches 3, 4, 5, 6 and 7). The following may be noted :

(i) The mass loading-removal rate relationship is dependent upon the nature of the waste.

(ii) The COD mass removal rate increased as the mass loading rate was increased for each waste.

Fig. 45 compares the results obtained for 50 per cent beet/sewage and and pure beet feeds with results reported by Steele (1974) on domestic sewage. From the figure, it appears that the rate of COD removal in a 50 per cent beet/sewage mixture is dominated by the removal rate on the domestic sewage fraction. This is indicated as follows. Assume the removal rate for the pure beet waste is given by line AB. Removal of the 50/50 mixture for a loading of 160g $COD.m^{-2}.day^{-1}$ can theoretically be approximated as the sum of separate loadings of 80 g $COD.m^{-2}.day^{-1}$

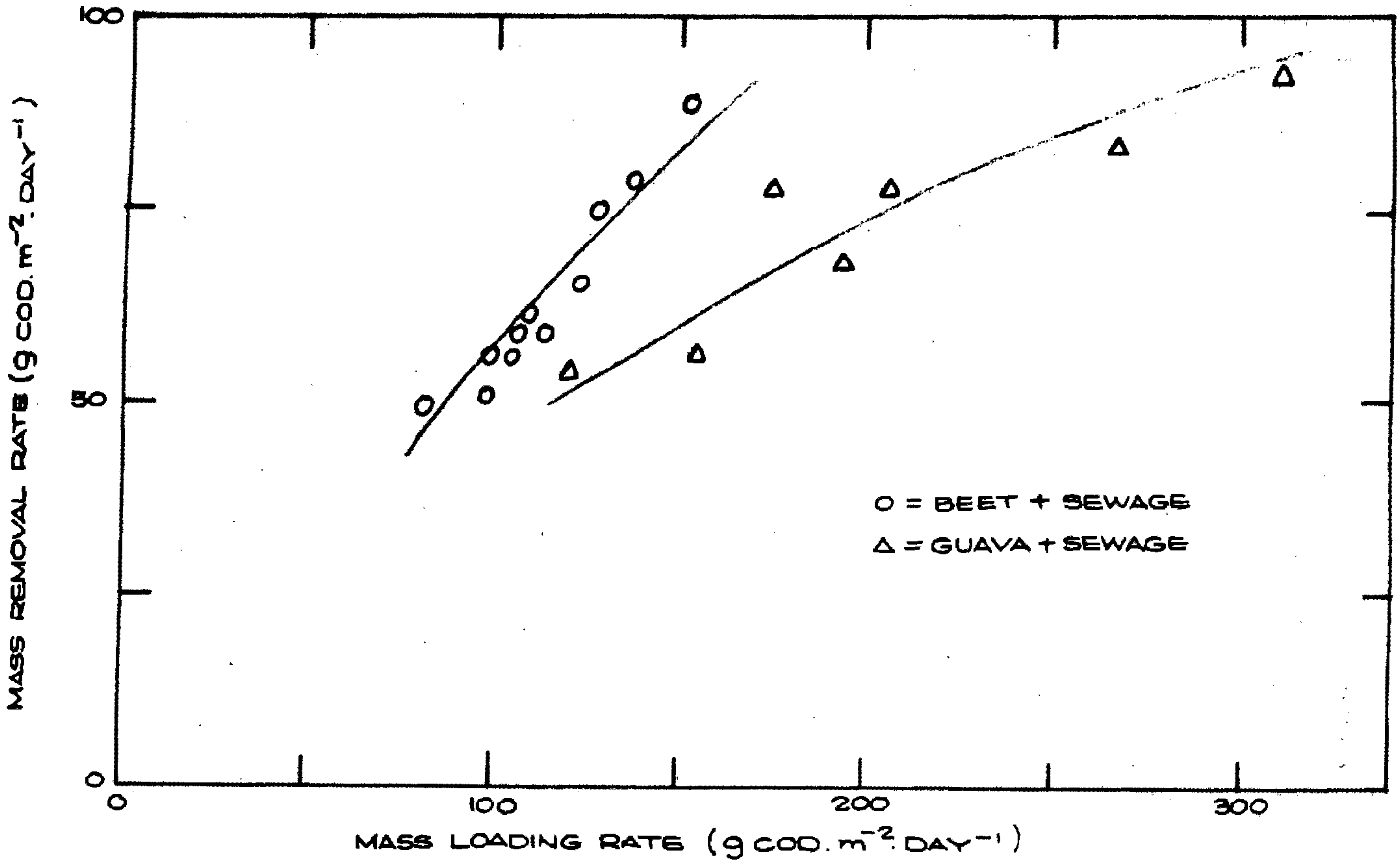

FIGURE 43: MASS LOADING-REMOVAL RATE RELATIONSHIP FOR WASTE & SEWAGE BATCHES

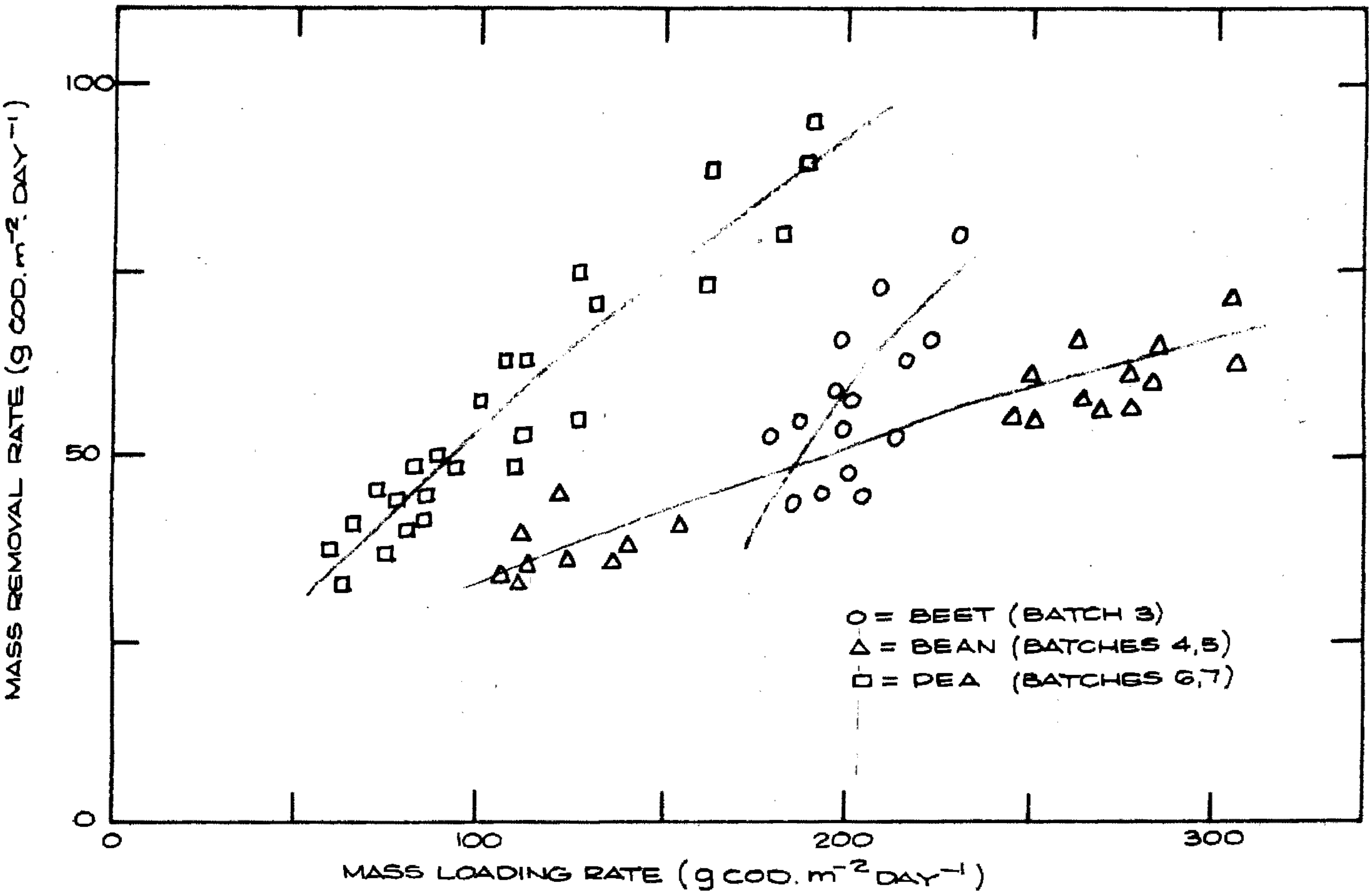

FIGURE 44: MASS LOADING-REMOVAL RATE RELATIONSHIP FOR NEAT CANNERY WASTES

for each fraction. At this loading, this gives removals of 67g $COD.m^{-2}.day^{-1}$ for the domestic sewage and 20g $COD.m^{-2}.day^{-1}$ for the beet waste, totalling 87g $COD.^{-2}.day^{-1}$. This result is plotted as a point C in the figure. Repeating for a total loading of 100 g $COD.m^{-2}.day^{-1}$ with the 50/50 mixture, point D is similarly given, thus defining line AE. This line approximately fits the experimental data obtained for the 50/50 mixture. Hence it would appear that the increased removal rate for the mixture is principally due to the removal of the sewage fraction.

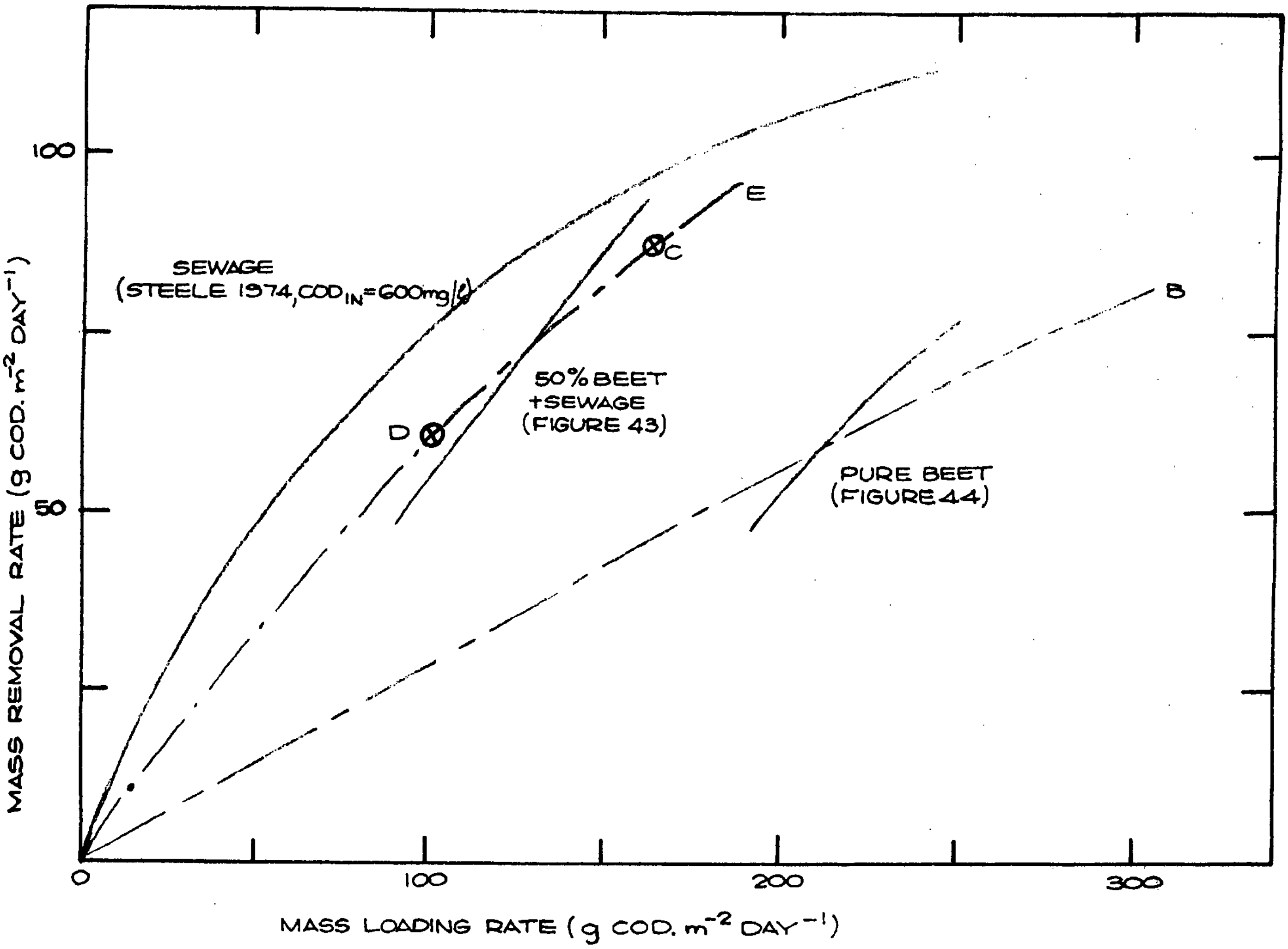

FIGURE 45: SHOWING EFFECT OF DOMESTIC SEWAGE PORTION OF FEED

3. COD Surface Loading vs. Surface Removal over two stages

In its normal application, the Biodisc process involves 2 - 5 'banks' of discs operating as series stages. It was therefore decided to simulate a two-stage system in order to determine whether the performance characteristics of the second stage differed in any way from the first-stage results reported in the previous section.

The system consisted of two equi-volume disc chambers (free liquid volume = 3l ± 5%) separated by a baffle with two flow-through points 3 and 10 cms. from the bottom. To keep the loading rate (g $COD.m^{-2}day^{-1}$) in the two chambers within the same range, the first chamber contained two discs (total area = $0,3630m^2$) while the second contained only one disc (area = $0,1815m^2$). Sludge removal was by the same flow-through principle (i.e. with interrupted disc drive) as for batches 3 to 8, except that only the outflow from the second chamber was connected to a settling chamber. MLSS concentrations in the chambers were periodically checked to ensure that no sludge accumulation occurred in the first chamber.

The results obtained in two runs on pea wastes (batches 7 and 8) are tabulated in Appendix II (Table A.2) and are plotted in Fig. 46. The following may be noted from the figure :

(i) Approximately 50 per cent COD removal was obtained in the first stage. At loadings of 100 - 110g $COD.m.^{-2}day^{-1}$ for example, COD removal ranged from 40 - 65g $COD.m.^{-2}day^{-1}$.

(ii) At the same loading rates, COD removal rates in the second stage were consistently lower than in the first stage. For batch 8, second-stage removals were typically in the range 20 - 35 g $COD.m^{-2}.day^{-1}$, even at loading rates greater than 100g $COD.m^{-2}.day^{-1}$. For batch 7, however, at loadings of 50 - 90g $COD.m^{-2}.day^{-1}$ removals in the first and second stages were respectively 40 - 50 and 30 - 40g $COD.m^{-2}.day^{-1}$.

Analyses of the effluents showed that residual nitrogen and phosphate remained in the effluents from both batches. A possible explanation for the poor per cent COD removals obtained in the second stages (particularly for batch 8, where the average second-stage COD removal was about 28 per cent) may be the presence of unbiodegradable fractions in the two wastes (Batch 7 and 8) used.

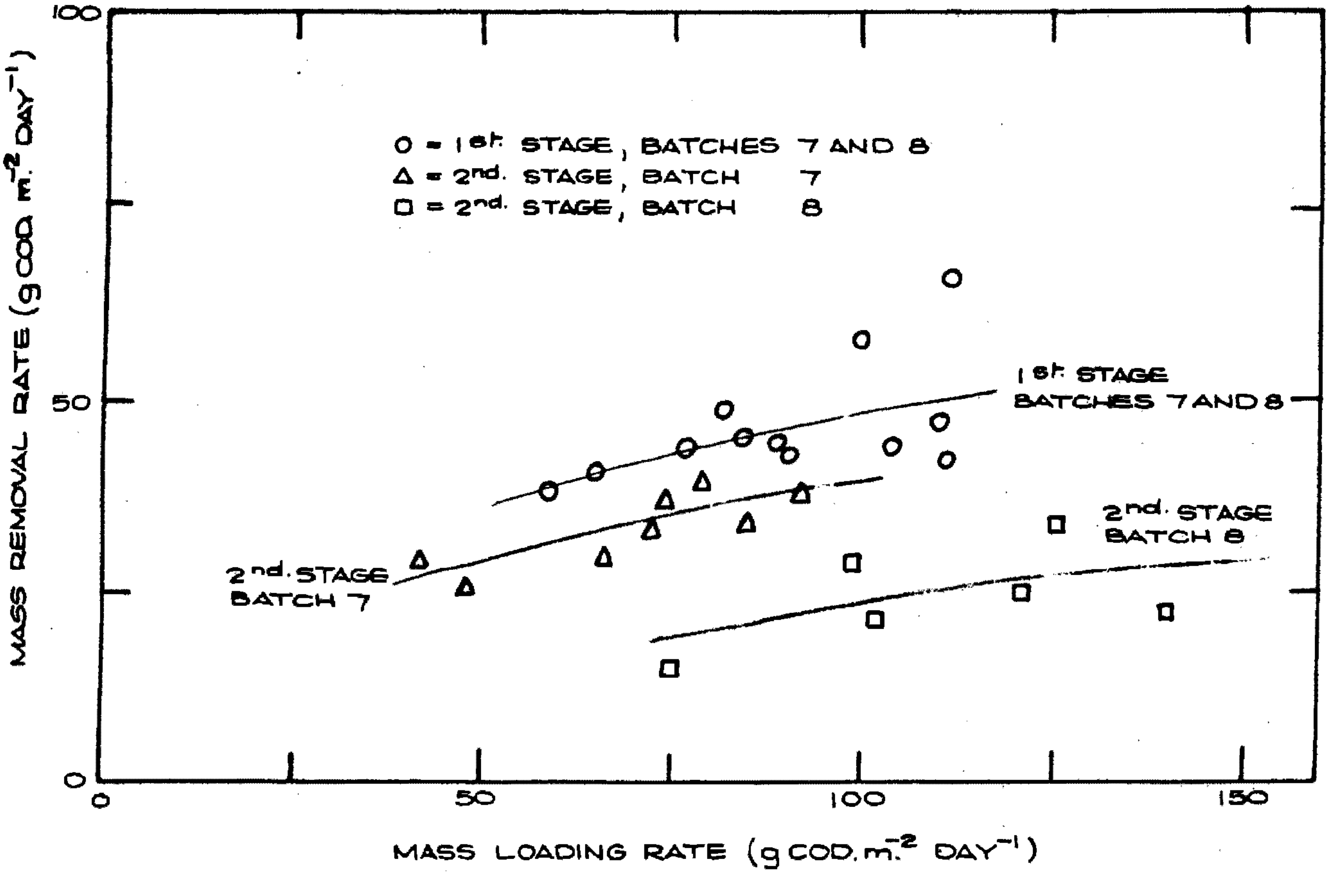

FIGURE 46: COD REMOVAL OVER TWO STAGES

Table A2, Appendix II, shows that the second stages were operating with influent COD concentrations of 300 to 500 mg.l^{-1}. If the biodegradable COD was significantly lower due to an unbiodegradable fraction, then :

(i) the COD mass removal rate (g COD.m^{-2}.day^{-1}) would be lower at the same loading rate, and

(ii) the percentage biodegradable COD reduction would be higher than when based on a total COD basis.

4. COD mass loading rate and Percentage COD removal

Fig. 47 shows the COD mass loading - percentage COD removal relationship for the results tabulated in Appendix II. The overall correlation exhibits considerable scatter. This is to be expected since the results were obtained with five different types of canning waste feeds of widely differing characteristics (Table 13).

In general, however, at a loading rate of 100g COD.m^{-2}.day^{-1} approximately 40 - 60 per cent COD reduction was obtained. As the loading rate increases to 300g COD.m^{-2}.day^{-1}, percentage COD reduction declines to approximately 30 per cent removal. This decrease in percentage COD reduction with increased loading rate is a logical consequence of the observed behaviour of the biodisc, viz. that the rate of COD removal (g COD.m^{-2}.day^{-1}) flattens off at high loading rates (Figs. 43, 45, and 46).

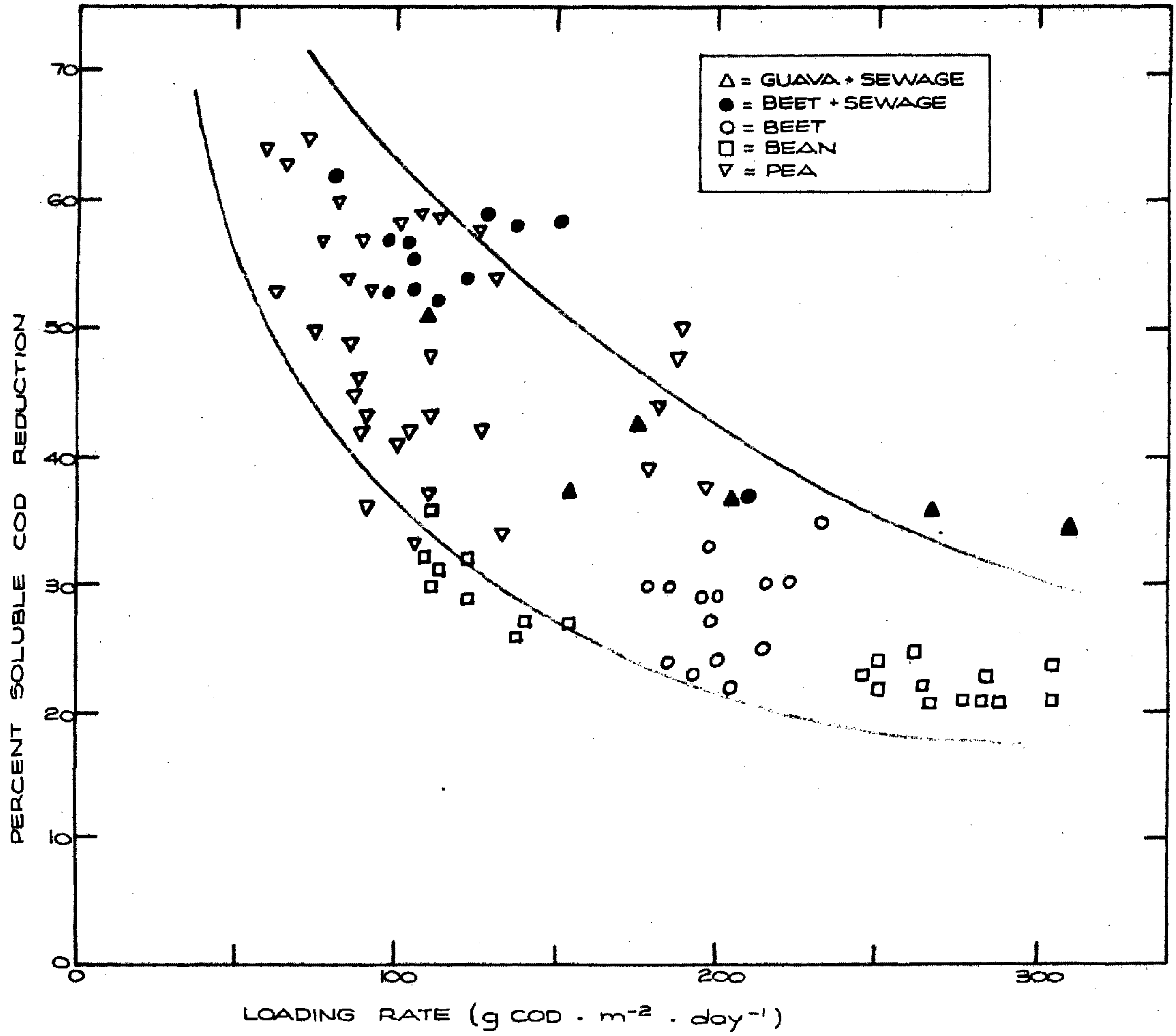

FIGURE 47 : VARIATION OF PERCENTAGE COD REMOVAL

5. Sludge production and characteristics.

The sludge production rate in terms of g settleable MLSS.g^{-1} soluble COD removed.day^{-1} was measured for the five different canning wastes.

Fig. 48 shows that the sludge production rate ranged from 0,14 to 0,32 with a mean of 0,224 g settleable MLSS.g^{-1} soluble COD removed.day^{-1}. This latter figure corresponds to the net sludge production from an activated sludge works operating with a sludge age of 12 days (refer to Appendix III). This would indicate that long mean sludge ages existed on the discs, with consequent high endogenous breakdown. This results in a decreased sludge production.

The suspended solids concentrations in the disc chambers' liquid varied from 150 to 600 mg.l^{-1}, with a mean around 400 mg.l^{-1}, and appeared dependent on the volumetric and organic loading rates to to the unit.

The volatile fraction (VSS/SS) of the suspended solids remained consistently in the range 73 - 78 per cent (cf. 80 per cent - Antonie, 1971).

Microscopic examination of the sludge on the discs generally showed a predominance of filamentous organisms. Fungal filaments predominated and very few protozoa were observed when the pH of the mixed liquor was 4,0 to 5,1 - Batches 3, 4 and 5. With batches 6, 7 and 8 the pH was approximately neutral and bacterial filaments prodominated with protozoa well represented.

Fig. 49 shows a typical settling curve observed in a 30 minute selling test conducted on 1 litre of mixed liquor with an MLSS concentration of 605 mg.l^{-1}. The following may be noted from the figure :

(a) The initial settling rate is good. The settling velocity approximates 2,4 m.hr^{-1} (cf. 4,5 to 7,5 m.hr^{-1} - Antonie, 1971).

(b) Compaction after 30 minutes is poor (180 ml. sludge. l^{-1} mixed liquor)

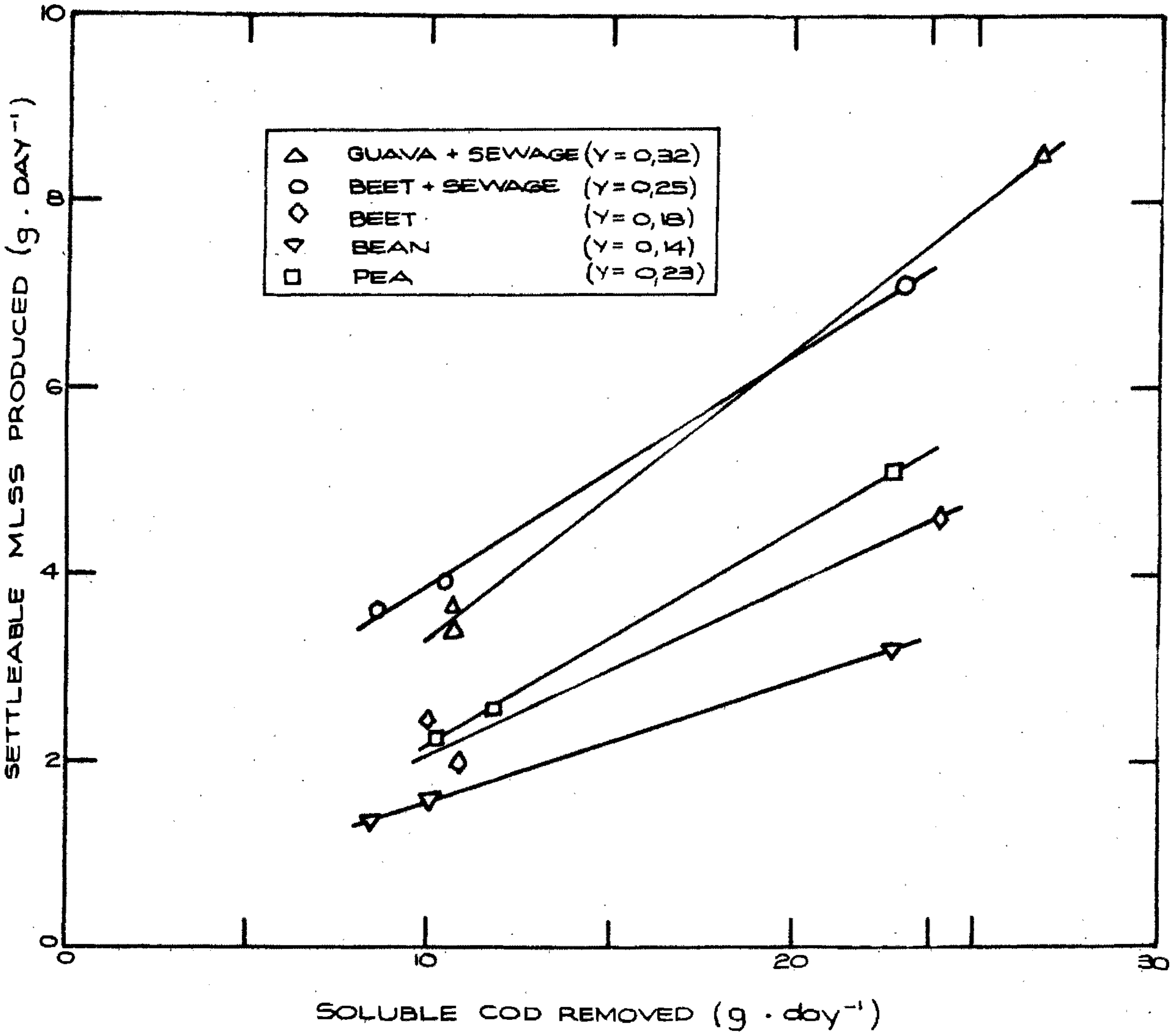

FIGURE 48: SHOWING SLUDGE PRODUCTION RATES

(c) The SVI is 298 $ml.g^{-1}$. (Measured SVI values were usually in the range 200 - 300 $ml.g^{-1}$).

These settling characteristics indicate good solids/liquid separation but poor sludge compaction.

The rapid initial settling observed, despite the highly filamentous nature of the sludge mass, appears to be characteristic of the physical operation of the Biodisc system. The microbial film on the discs is very dense : at much lower removal rates (maximum 12,7g $COD.m^{-2}.day^{-1}$) than in this study, Pretorius (1971) has reported a biomass concentration of 26,1 $g.m^{-2}$ on the discs. When sloughing of the film occurs, therefore, large dense sludge particles are passed into the mixed liquor. These heavy floc particles settle readily even when they are highly filamentous on a microscopic scale. For wastes such as cannery effluents where filamentous sludges are characteristically produced, and bulking is an almost inherent feature of the activated sludge process operating with sludge ages of less than 20 days, the biodisc thus offers distinct advantages with regard to sludge/liquid separation.

6. Apparent Nutrient Requirements.

The effluent from both units contained residual TKN and PO_4-P concentrations throughout the investigation. The concentrations ranged from 2 to 6 $mg.l^{-1}$TKN and 2 to 3 $mg.l^{-1}PO_4$-P.

Fig. 50 shows the relationship between COD removal ($mg.l^{-1}$) and nutrient uptake ($mg.l^{-1}$) for the first five batches of waste. From the figure a mean COD:N:P ratio of 100:2,1:0,6 is indicated.

This ratio corresponds to the theoretical ratio in an activated sludge process operating with a sludge age of 12 days - COD:N:P - 100:2,1:0,35 (refer page 13, Fig. 9 and Appendix III).

It would appear that nitrogen and phosphorus were not limiting in the process.

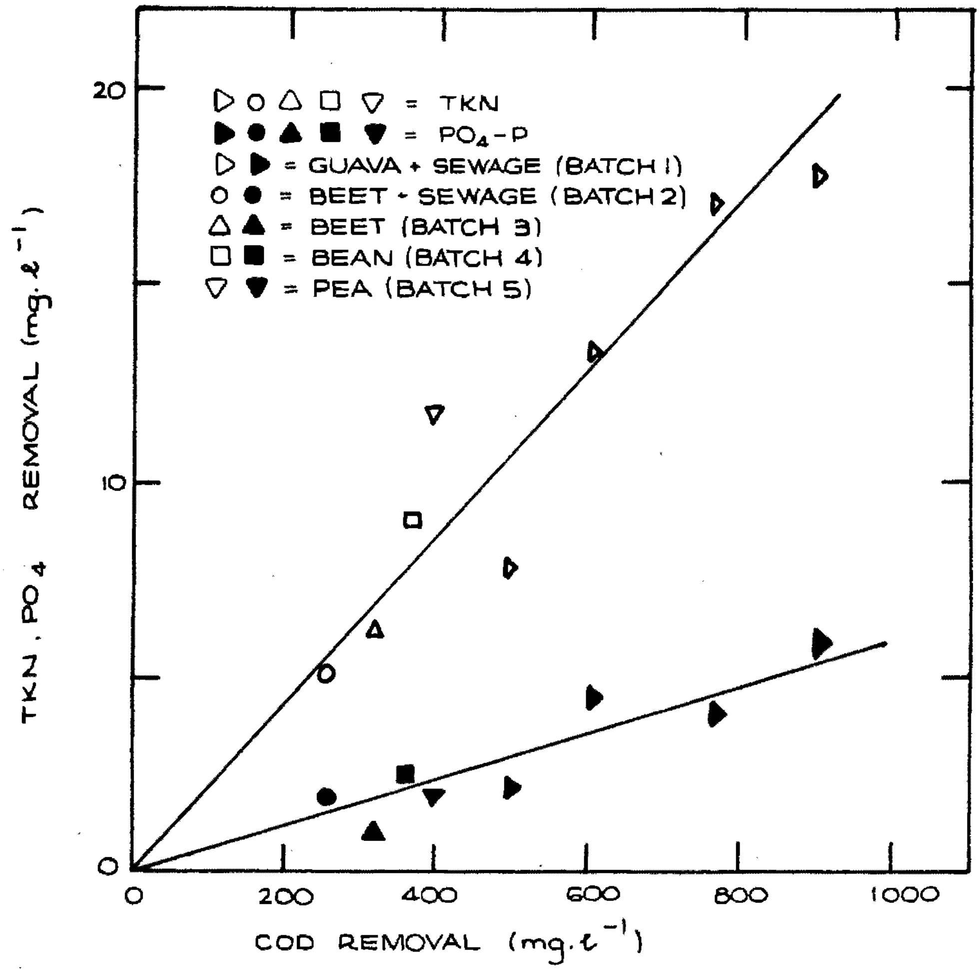

FIGURE 50: NUTRIENT REMOVAL RELATIONSHIP

7. Summary of Results.

(a) The rate of COD removal in the Biodisc unit was a function of the type and compostion of the canning waste feeds. Generally, the mass COD removal per unit surface area of disc increased as the mass surface loading rate increased. Typical figures were :

	100	200	300
Loading rate (g soluble COD.m^{-2}.day^{-1})	100	200	300
Removal rate (g soluble COD.m^{-2}.day^{-1})	35-60	50-100	65-105

(b) The efficiency of COD removal decreased with increasing loading rate. Typical figures were :

Loading rate (g soluble COD.m.$^{-2}$$day^{-1}$)	100	200	300
% COD removal	35-60	25-50	20-35

(c) COD removal rate (g COD.m^{-2}.day^{-1}) was found to be unaffected by the hydraulic retention time of the waste in the disc compartments over the range R_H = 1 - 4 hours.

(d) In two-stage series operation, COD removal in the second stage was generally much lower than in the first stage, ranging from 20-40g COD removed.m^{-2}.day^{-1} at a loading rate of 100g COD.m^{-2}.day^{-1}.

(e) Initial settling of the sludge was rapid but compaction after 30 minutes settling was poor. SVI's in the range 200 - 300 ml.g^{-1} were generally observed.

(f) Microscopic examination of the sludge on the disc indicated highly filamentous growths, with fungi predominating at low pH and bacteria predominating at neutral pH.

(g) A mean sludge yield of 0,224g MLSS.g COD^{-1} removed was observed, with VSS/SS ratios in the range 73 - 78 per cent. Nutrient removal per unit COD removal indicated a mean COD : TKN : PO_4-P ratio of 100 : 2,1 : 0,6. The sludge yield value corresponds to that predicated for an activated sludge process with a sludge age of approximately 12 days. For this sludge age, the predicted nutrient requirements are COD : N : P of 100 :2,10 : 0,35. Comparing the theoretical and experimentally observed yields and nutrient requirements, it is concluded that the wastes were not nutrient deficient.

CONCLUSIONS FROM THE DISC SYSTEM AS A FORM OF ROUGHING TREATMENT

The investigation into the application of the rotating disc system as a form of 'roughing' treatment gave rise to the following conclusions:

(i) A disc loading of 300 g $COD.m^{-2}.day^{-1}$ appears to be the maximum stage loading at which the performance of the of the disc system is still competitive with the conventional Plastic Medica filtration, i.e. 30 to 40 per cent COD removal.

(ii) The installation of further stages to increase the overall COD removal does not appear to be economically justifiable.

(iii) The performance of the disc system does not appear to be nutrient limited.

Although the disc system offers much promise as a form of 'roughing' treatment, the area of discs - loaded at 300 g $COD.m^{-2}.day^{-1}$ - required at Paarl for a flow of 8 000 $m^3.day^{-1}$ (COD = 4 000 $mg.l^{-1}$) would be approximately 11 ha (or 8 000 discs of 3 m diameter).

The cost of this large area and number of discs, together with the cost of shafts, bearings, motors, electrics and civil construction would render this an uneconomical alternative.

CHAPTER 7

SECONDARY BIOLOGICAL FILTRATION AS A FORM OF SECONDARY TREATMENT

INTRODUCTION

The combined settled sewage flow at the Paarl sewage works is divided into two streams, in the portion 1/5 to 4/5 (of the total flow). The 1/5 flow is treated by fine media biological filters with a media nominal size of 44mm. The 4/5 flow is treated by coarse media filters with media nominal size of 75mm. There are four 24 m diameter x 1,8 m deep fine media filters and four 30 m diameter x 3 deep coarse media filters. The flow conditions for 1973 have been shown in Fig. 1.

The COD mass loading-removal rate relationship for the fine and coarse media filters during the 1973 canning season, are shown in Fig. 51. The plot shows that the fine media filter was significantly more efficient than the coarse media filter

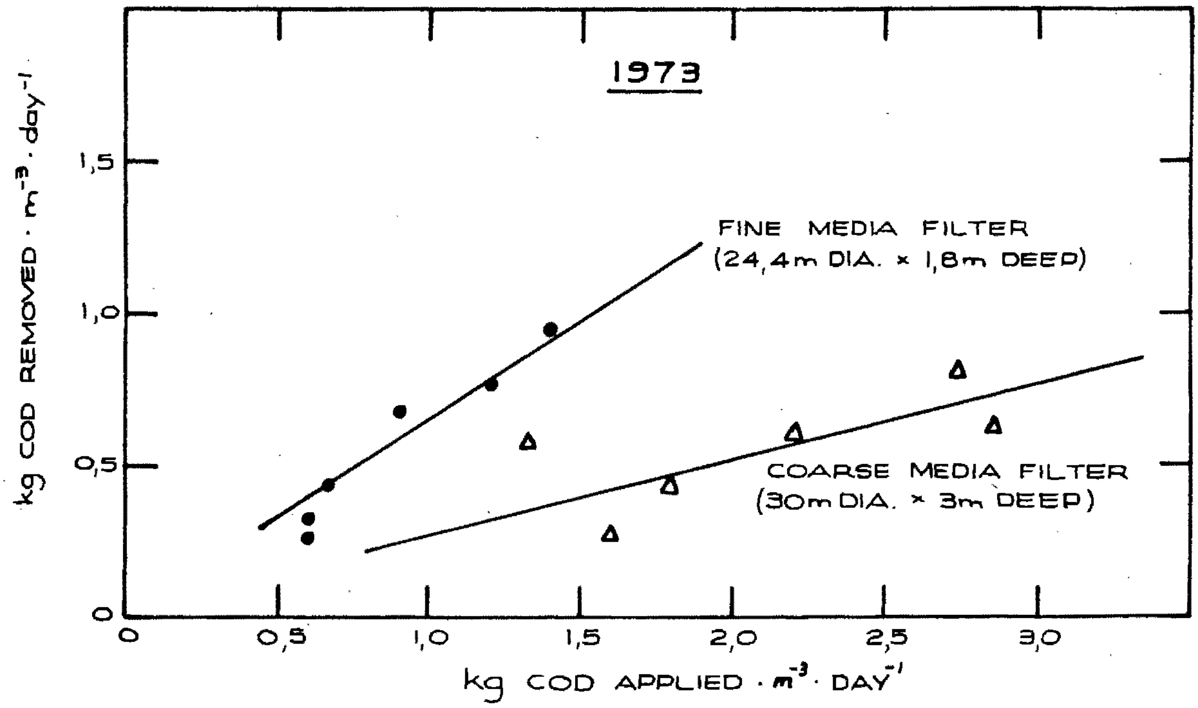

FIGURE 51 : LOADING-REMOVAL RATE RELATIONSHIP FOR 1973

The greater removal efficiency of the fine media filter may be attributed to :

(i) Difference in filter depth - 1,8 m as opposed to 3 m and/or

(ii) Difference in hydraulic load ($m^3.m^{-3}$ media volume.day^{-1}) and/or

(iii) Difference in specific surface area of the filter media - 136 $m^2.m^{-3}$ for the fine media and 80 $m^2.m^{-3}$ for the coarse (assuming 50 per cent voids).

The greater COD removal capabilities of the fine media filters prompted the conversion of one of the 24 m diameter x 1,8 m deep filters into a secondary filter for the 1975 canning season. This was achieved by pumping humus tank settled primary coarse filter effluent to the selected filter. No provision for recirculation of secondary filter effluent was made.

The performance of the filter was closely monitored throughout the 1975 season with the aim of ascertaining the optimum performance characteristics of the filter, and thereby the feasibility of employing biological filtration as the form of secondary treatment.

No literature could be found on the application of two stage biological filtration for the treatment of a mixture of cannery and domestic wastes. It was decided to apply as wide a range of COD loadings on the filter as possible to obtain the optimum figure for design.

EXPERIMENTAL PROCEDURE

The sampling programme involved collecting hourly aliquots of filter influent (taken from the distributior arm) and effluent over 24 hr one day each week of the canning season. Composite samples were prepared by taking equal volumes of each aliquot as the flow to the filter was constant over the day.

The flow rate to the filter was calculated from pressure gauge readings taken from a gauge on the pump discharge. Regular correlations between pressure gauge readings and flow rates were performed. The steady daily flow rate was varied in the range 1 309 to 3 469 $m^3.day^{-1}$, the latter figure representing the hydraulic limit of the filter as flooding of the outlet ports occurred at higher hydraulic loads.

ANALYTICAL PROCEDURE

The filter influent composite samples were analysed for pH, COD, BOD, TKN and PO_4-P, whereas the effluent samples were analysed for only pH, COD and BOD. The analyses on the effluent composite samples were performed after 1,5 hr settlement in an Imhoff Cone.

EXPERIMENTAL RESULTS

Table 16 shows the performance of the secondary filter throughout the 1975 canning season.

Table 17 together with Figs. 52 and 53 show the COD and BOD mass loading-removal rate relationships obtained over the secondary filter for the 1975 season. The mass loading-removal rate relationship obtained over the coarse media primary filters during the same period has been included in the plots of Figs. 52 and 53. For comparison purposes, the mass loading-removal rate relationship obtained over the fine media acting as a primary filter during 1973 has been included in Fig. 52. It is clear that, for the fine media, the mass loading-removal relationship was not very different.

Fig. 54 shows the variation in the percentage COD removal as the COD mass loading rate on the secondary filter was increased from 1 to 4 kg COD.m^3.day^{-1}.

DISCUSSION ON RESULTS

(i) Mass loading-removal rate relationship

Figs. 52 and 53 show that as the mass loading rates on the secondary filter were increased there was no apparent decline in the mass removal rates - as was the case with the primary filters.

The maximum COD loading possible during the season was 4 kg COD.m^{-3}.day^{-1}. Attempts were made in April and May to increase the COD mass loading rate to above 5 kg COD.m^{-3}.day^{-1}, but the strength of the influent and the filter's hydraulic limit of 3 469 m^3.day^{-1} rendered this impossible.

The maximum COD and BOD concentrations recorded in the filter influent were 1 449 and 879 mg.l^{-1} respectively. With the filter's hydraulic limit of 3 469 m^3.day^{-1} the maximum allowable loading rate during a canning season would then be

TABLE 16 : PERFORMANCE OF SECONDARY FILTER

Date	28/1	4/2	11/2	18/2	4/3	11/3	18/3	25/3	2/4	8/4	15/4	22/4	29/4	13/5	20/5	27/5
Flow($m^3.d^{-1}$)	1560	1618	1608	1309	1898	2559	2559	1898	1898	2815	2815	3469	3469	3469	3469	3469
Influent pH	6,9	6,4	6,8	6,1	6,7	6,9	6,9	6,2	6,4	6,5	6,9	6,7	6,7	6,6	7,3	7,4
COD($mg.l^{-1}$)	608	1102	1340	1449	1304	1352	1190	1229	1322	1341	1270	1069	1085	502	365	193
BOD($mg.l^{-1}$)	-	-	646	570	-	879	634	780	832	797	786	723	775	325	222	87
TKN($mg.l^{-1}$)	17,4	17,6	21,8	19,6	55,4	67,8	65,8	65,5	31,6	35,0	48,2	33,2	26,9	10,4	21,6	-
PO_4-P($mg.l^{-1}$)	4,7	5,1	5,1	7,1	10,5	10,1	13,1	18,2	10,1	7,9	9,0	8,4	9,7	5,0	6,1	-
Effluent pH	7,9	7,6	8,1	8,0	7,6	7,8	7,5	7,4	7,4	7,5	7,7	7,9	7,7	7,6	7,5	8,0
COD($mg.l^{-1}$)	120	314	310	223	471	486	436	323	453	566	502	385	391	162	214	150
BOD($mg.l^{-1}$)	-	179	130	124	-	266	220	149	208	256	253	230	209	66	85	20
% Removal COD	80,3	71.5	76,9	84,6	63,9	64,1	63.4	73,7	65,7	57,8	60,5	64,0	64,0	67,7	41,4	22,3
BOD	-	-	79,9	78,3	-	69,7	65,3	80,8	75,0	67,9	67,8	68,2	73,0	79,7	61,7	77,0
Loading kg COD.m^{-3}.day^{-1}	0,99	1,87	2,25	1,98	2,59	3,62	3,19	2,44	2,63	3,59	3,74	3,85	3,94	1,82	1,31	0,70
kgBOD.m^{-3}.day^{-1}	-	-	1,09	0,78	-	2,35	1,70	1,55	1,65	2,35	2,31	2,62	2,81	1,18	0,80	0,32

NOTE : MEDIA VOLUME = 956 m^3

TABLE 17 : MASS LOADING AND REMOVAL RATE RELATIONSHIPS FOR SECONDARY FILTER

Date	COD applied	COD removed		BOD applied	BOD removed	
	k/m^3/day	kg/m^3/day	%	kg/m^3/day	kg/m^3/day	%
28/1	0,99	0,79	80,3	-	-	-
4/2	1,87	1,34	71,5	-	-	-
11/2	2,25	1,73	76,9	1,09	0,87	79,9
18/2	1,98	1,68	84,6	0,78	0,61	78,3
4/2	2,59	1,66	63,9	-	-	-
11/3	3,62	2,32	64,1	2,35	1,64	69,7
18/3	3,19	2,02	63,4	1,70	1,11	65,3
25/3	2,44	1,80	73,7	1,55	1,25	80,8
2/4	2,63	1,73	65,7	1,65	1,24	75,0
8/4	3,95	2,28	57,8	2,35	1,60	67,9
15/4	3,74	2,26	60,5	2,31	1,57	67,8
22/4	3,85	2,46	64,0	2,62	1,79	68,2
29/4	3,94	2,52	64,0	2,81	2,05	73,0
13/5	1,82	1,23	67,7	1,18	0,94	79,7
20/5	1,31	0,54	41,4	0,80	0,49	61,7
27/5	0,70	0,16	22,3	0,32	0,25	77,0

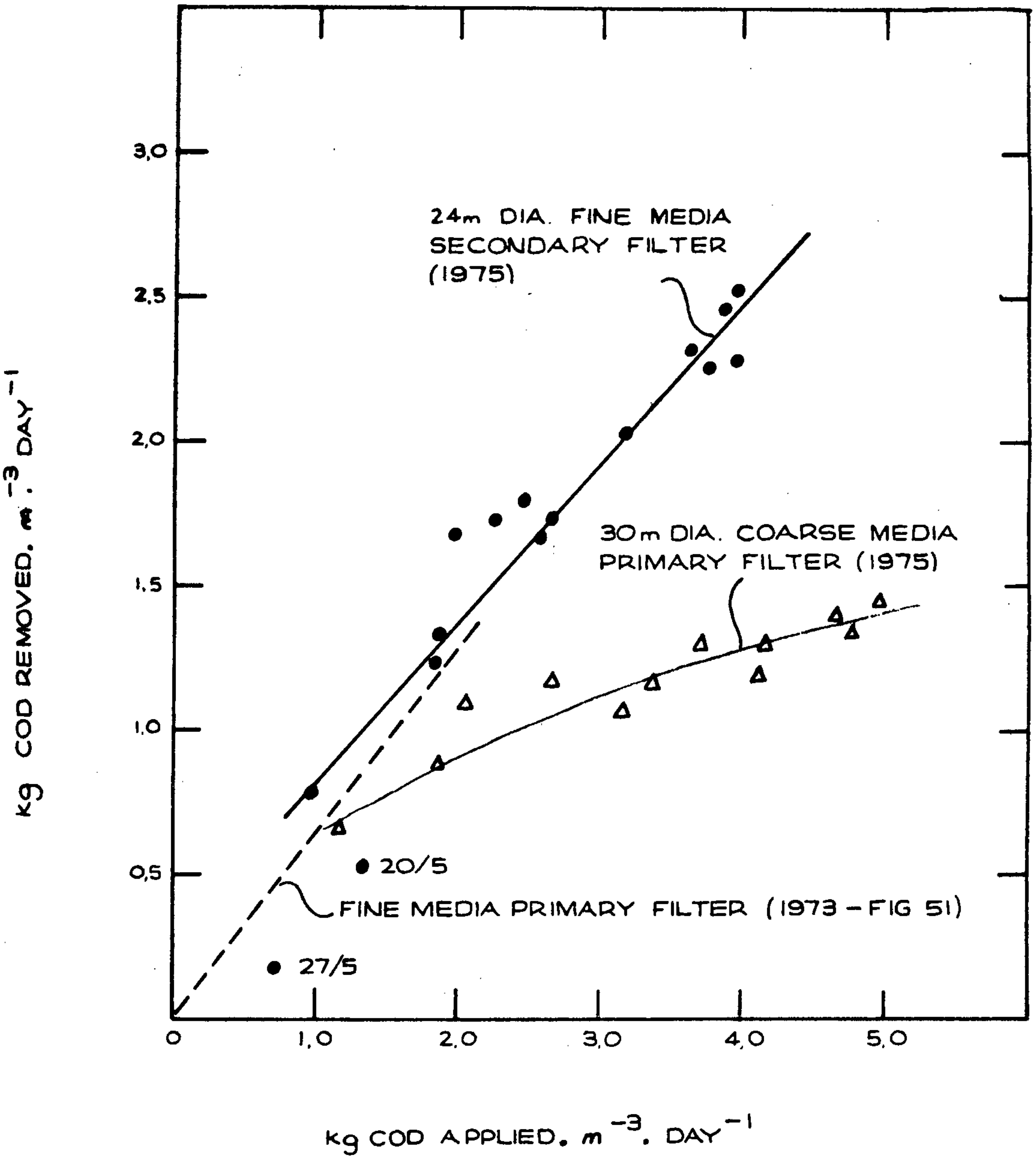

FIGURE 52: COD MASS LOADING/REMOVAL RATE RELATIONSHIPS

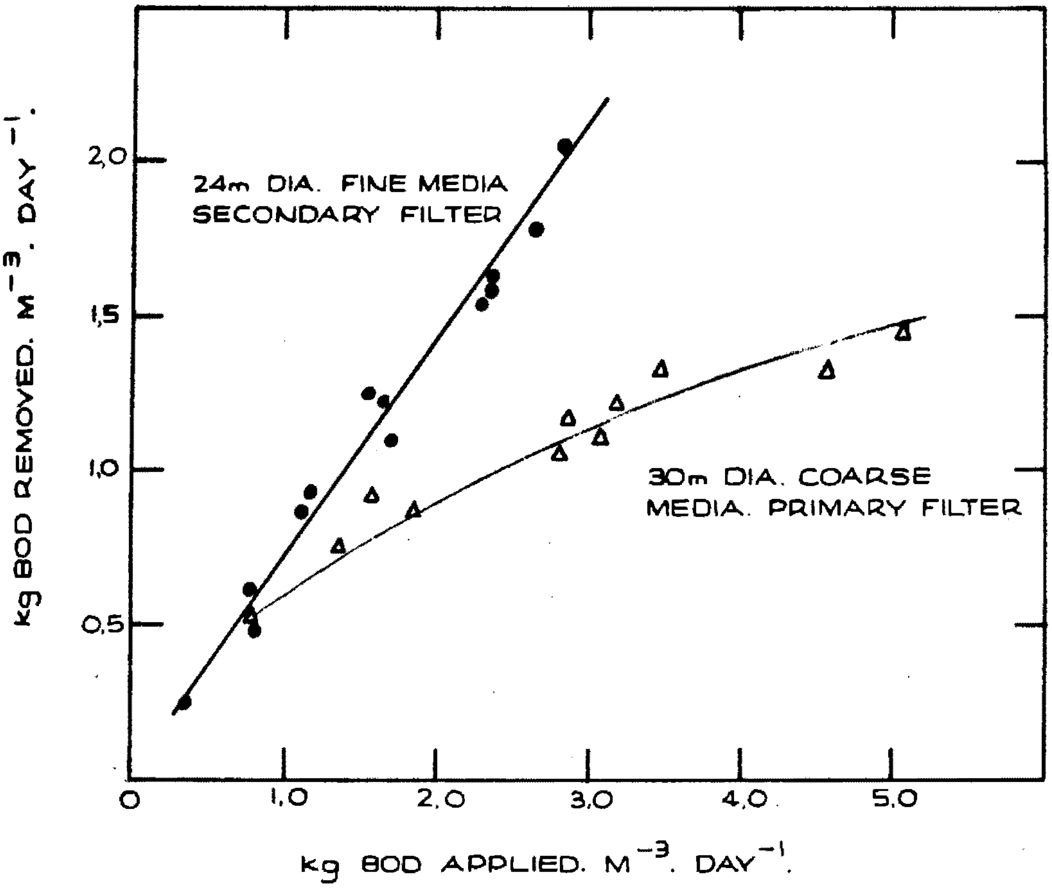

FIGURE 53 : BOD MASS LOADING / REMOVAL RATE RELATIONSHIPS

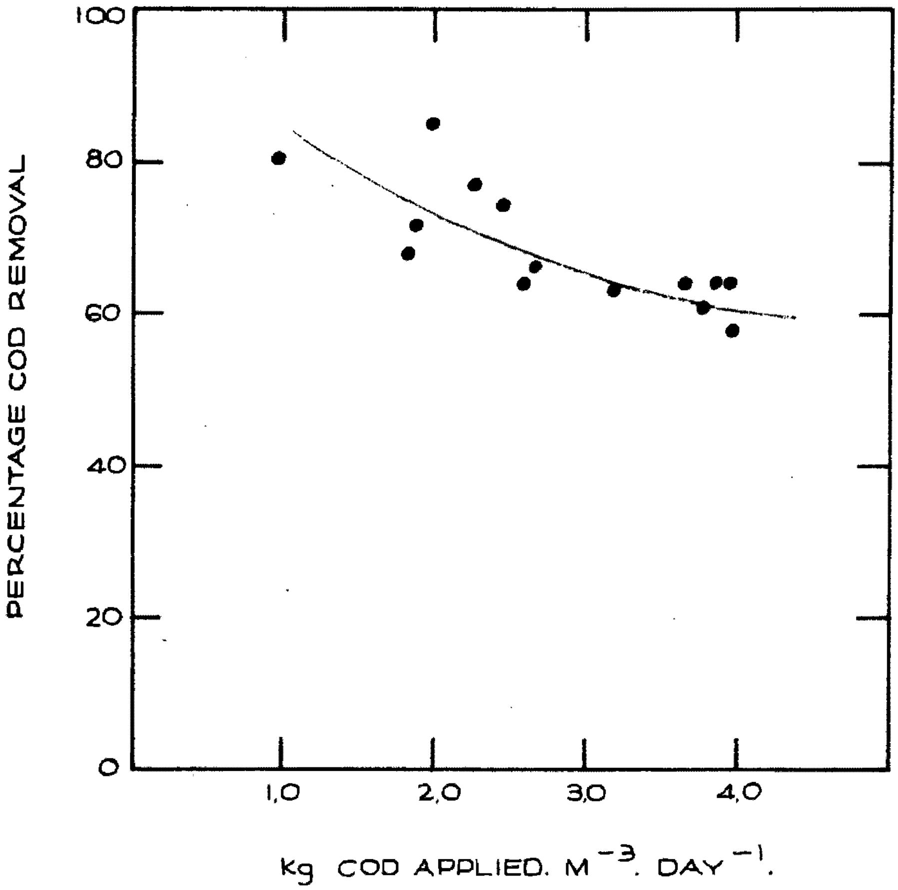

FIGURE 54: COD MASS LOADING vs PERCENT COD REMOVAL

5,3 kg COD.m^{-3}.day^{-1} and 3,2 kg BOD.m^{-3}.day^{-1}. As Figs. 52 and 53 show no decline in the mass removal rates over the secondary filter, extrapolation of the trend lines show that the corresponding maximum mass removal rates would be 3,2 kg COD and 2,3 kg BOD.m^{-3}.day^{-1}.

It is of interest to note that when the 30 m diameter coarse media primary filters were loaded at 5,3 kg COD and 3,2 kg BOD.m^{-3}.day^{-1} the corresponding mass removal rates were 1,4 kg COD and 1,2 kg BOD.m^{-3}.day^{-1}.

The greater removal efficiency of the fine media secondary filter cannot be attributed to a difference in the quality of the respective filters' influents, as the fine media filters, when operating as primary filters, gave approximately the same removal relationship (refer to Fig.52).

Table 18 shows the hydraulic loading, in terms of m^3.m^{-3} media volume.day^{-1} and m^3.m^{-2} filter area.day^{-1}, for the coarse and fine media filters.

TABLE 18 : HYDRAULIC LOADINGS OF FILTERS.

	COARSE, PRIMARY	FINE SECONDARY
Media Volume (m^3)	2002	956
Filter Area (m^2)	707	452
Flow (m^3.day^{-1})	3262 to 6282	1309 to 4369
m^3.m^{-3}.day^{-1}	1,6 to 3,1	1,4 to 3,6
m^3.m^{-2}.day^{-1}	4,6 to 8,9	2,9 to 7,7

The data in the Table shows that the hydraulic loading of both filters was of the same order hence the large difference in the mass removal efficiency can only be explained by one - or both - of the following :

(a) Filter depth - 3 m as opposed to 1,8 m. The greater depth of the coarse media 30 m diameter filter could result in inadequate ventiliation of the entire filter media volume, there by impairing the filters' performance.

(b) Specific surface area of the filter media. Bruce (1970) reports that the removal efficiency of a high rate biological filter is directly proportioned to the specific surface area of the filter media. It would therefore be expected that the removal efficiency of the fine media filters (specific surface area = 136 $m^2.m^{-3}$) would be greater than that of the coarse media filters (specific surface area = 80 $m^2.m^{-3}$).

The ratio of the available surface area for the 1,8 m deep fine and 3 m deep coarse media filters is :

$$\frac{\text{Fine}}{\text{Coarse}} = \frac{136 \times 1{,}8}{80 \times 3}$$

i.e. Approximately 1 : 1

The equality in the available media surface area would therefore indicate that the filter depth was responsible for the poor COD removal performance of the coarse media filters in that ventilation was perhaps impaired.

(ii) COD mass loading rate - Percentage COD removal relationship over the secondary filter.

Fig. 54 shows that as the COD mass loading rate was increased from 1 to 4 kg $COD.m^{-3}.day^{-1}$, the percentage COD removal decreased from 82 to 60 per cent.

These values indicate that in order to obtain greater than an 85 per cent COD removal, mass loading rates of less than 1 kg $COD.m^{-3}.day^{-1}$ would have to be applied to the secondary filters.

CONCLUSIONS FROM SECONDARY BIOLOGICAL FILTRATION

The plant scale investigation into the application of secondary biological filtration as the form of secondary treatment gave rise to the following conclusions :

(i) If the secondary treatment must effect an 85 per cent COD removal, from 1 450 $m.l^{-1}$ to 200 $mg.l^{-1}$, then the secondary filters should be loaded at less than 1 kg $COD.m^{-3}.day^{-1}$ during the canning season.

At this loading rate the filter volume required to enable a flow of 23 $Ml.day^{-1}$ to undergo secondary treatment - prior to discharge to maturation ponds - would be 34 000 m^3 (volume of four existing fine media filters, 3 834 m^3).

Employment of biological filtration, with this low loading, as a form of secondary treatment would not appear to be feasible as the filter volume required is unrealistic.

(ii) The maximum COD mass loading that may be applied to the fine media filters is 5,3 kg $COD.m^{-3}.day^{-1}$, with the resulting COD mass removal being 3,2 kg $COD.m^{-3}.day^{-1}$. This high mass removal efficiency of 60 per cent indicates that fine media secondary biological filtration could be employed as a 'secondary roughing' stage.

CHAPTER 8

CONCLUSIONS OF INVESTIGATION

With regard to the secondary treatment of the high rate filter effluent, and the roughing treatment of the neat industrial waste at the Paarl sewage works, the following conclusions are formed :

SECONDARY TREATMENT

(i) Nature of Effluent

The COD of the effluent from the high rate filters at Paarl during the 1974 season ranged from 1 200 to 1 400 $mg.l^{-1}$. The COD:N:P ratio varied from 100:1,4:0,48 to 100:3,8:0,75 indicating that there was at times an apparent nutrient deficiency.

(ii) Biodegradability of the Effluent

The effluent was approximately 88 per cent biodegradable, with the unbiodegradable COD fraction varying from 145 to 175 $mg.l^{-1}$.

(iii) Activated Sludge Process

At short sludge ages the effluent is not treatable by the activated sludge process due to 'bulking'. However, if the sludge age is greater than 20 days the settling characteristics are satisfactory and the activated sludge process can be employed.

When operating with a sludge age of 20 days the activated sludge process will produce an effluent COD of approximately 180 $mg.l^{-1}$ – an 87 per cent reduction.

If it is intended to employ the activated sludge process, the following kinetic constants should be used:

$Y = 0{,}39$ mg $VSS.mg^{-1}$ COD removed.
$K = 0{,}04\ mg.l^{-1}.day^{-1}$.
$b = 0{,}24\ day^{-1}$.

Note : Both K and b are temperature dependent – the values shown are for 20°C. For temperature corrections refer to

Marais (1973).

As nitrification is not required in the form of secondary treatment, employment of long sludge ages solely to obtain efficient liquid-solid separation in the secondary settling tank would not appear to be economically feasible.

(iv) Rotating Biological Disc Process.

A three stage rotating biological disc system could be employed as the form of secondary treatment. The first stage would consist of 8 000 x 3 m diameter discs (total area = 11 ha) loaded at a maximum rate of 300 g $COD.m^{-2}.day^{-1}$, with the COD removal being 70 per cent. The additional two stages of discs (8 000 discs in each stage) would be required to increase the overall COD removal to 85 per cent - i.e. an effluent COD of 180 to 210 $mg.l^{-1}$.

(v) Secondary Biological Filtration

Fine media secondary biological filtration (media nominal size 44 mm) will effect an 85 per cent COD removal on the effluent from the high rate filters - i.e. remaining COD 180 to 210 $mg.l^{-1}$. However the filters would have to be loaded at less than 1 kg $COD.m^{-3}.day^{-1}$ and the media volume required at this loading (34 000 m^3) would appear to be unrealistically high.

The high mass removal efficiency (60 per cent) of the fine media filters, when loaded at a maximum rate of 5,3 kg $COD.m^{-3}day^{-1}$, indicates that the filters could be employed as a 'secondary roughing' stage.

ROUGHING TREATMENT OF INDUSTRIAL WASTE

(vi) Rotating Biological Disc Process

A one stage rotating biological disc system could be employed as a form of 'roughing' treatment on the neat industrial waste. The system would, with a disc loading of 300 g $COD.m^{-2}.day^{-1}$, effect a 30 to 40 per cent COD removal. Approximately 7 500 x 3 m diameter discs would be required for a flow of 8 000 $m^3.day^{-1}$ (COD = 4 000 $mg.l^{-1}$)

The disc loading of 300 g $COD.m^{-2}.day^{-1}$ represents the maximum at which the performance of the disc system is still competitive with that of the conventional plastic media filtration.

The costs of the discs, together with all the appertaining equipment, would render this an uneconomical alternative.

CHAPTER 9

POSSIBLE FORM OF SECONDARY TREATMENT.

Initially it was considered that one of the three systems investigated, i.e. activated sludge, rotating biological disc or secondary biological filtration, would serve adequately to reduce the COD load to the maturation ponds. The investigation showed that it would not be feasible to employ any of these systems.

Secondary biological filtration, however, has possibilities as a form of 'secondary roughing' treatment if used in conjunction with an aerated lagoon as the form of final treatment before discharge to the maturation ponds.

The system of further roughing treatment is attractive as a further load reduction would be realised with existing plant. The aerated lagoon offers a 'running cost' intensive scheme which is ideal for the situation in which the pollution load is highly seasonal - as at Paarl.

The four existing fine media filters when loaded at 5,3 kg COD.m^{-3}.day^{-1} would effect a 60 per cent COD reduction on a maximum flow of 13 800 m^{3}.day^{-1}. An additional three fine media filters would enable the total expected flow of 23 000 m^{3}.day^{-1} to undergo 'secondary roughing' treatment before discharge to the aerated lagoon.

Table 19 shows the reduction in COD load to the aerated lagoon (i) if 13 800 m^{3}.day^{-1}, of a total of 23 000 m^{3}.day^{-1}, underwent 'secondary roughing' treatment on the four existing fine media filters, and (ii) if three additional fine media filters were constructed to accommodate the total 23 000 m^{3}.day^{-1}.

TABLE 19 : COD LOAD TO AERATED LAGOON.

		kg COD.day^{-1}.	Percentage Reduction.
	23 000 m.^{3}day^{-1} of Primary Filter effluent (COD = 1 450 mg.l^{-1}) to aerated lagoon.	33 350	-
(i)	13 800 m^{3}.day^{-1} through 'secondary roughing' stage, then full 23 000 m^{3}.day^{-1} to aerated lagoon	21 344	36
(ii)	23 000 m^{3}.day^{-1} through 'secondary roughing' stage, then to aerated lagoon	13 340	60

The Table shows that the COD load to the aerated lagoon would be reduced by 36 per cent if the four existing fine media filters were operated as a further roughing stage, and by 60 per cent if three additional fine media filters were constructed to accommodate the full 23 000 $m^3.day^{-1}$.

No extensions to the 'primary roughing' stage are required for the 23 000 $m^3.day^{-1}$ flow.

A detailed economic analysis would indicate whether the savings in aeration costs in the lagoon would justify constructing three additional fine media filters.

The details of the proposed aerated lagoon did not form part of this Thesis, but it has been proposed that the lagoon should be of a faculative nature. It is suggested that pilot plant studies be undertaken during the 1976 canning season to ascertain design and performance characteristics.

CHAPTER 10

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APPENDIX I

METHODS OF ANALYSIS

1. Standard Methods, 13th Edition, 1971, published by the American Public Health Association, Washington D.C. was consulted for the following tests :-

(a)	Chemical Oxygen Demand	page 501
(b)	Total Kjeldahl Nitrogen	page 402
(c)	Free and Saline Ammonia	page 186
(d)	Total and Volatile solids	page 538
(e)	Sludge Volume Index	page 561

2. Nitrite and Nitrate Nitrogen were analysed by an autoanalyser (Technicon) according to the Technicon Auto-Analyser Methodology.

3. Dissolved Oxygen was measured using a 'Yellow Springs' oxygen meter, model 54, and probe.

4. Oxygen Absorbed was measured by the method set out in the Government Gazette Extraordinary, Vol. 4, June 22nd, (1962).

5. pH was measured using a 'Radiometer' pH29 meter.

6. Total Phosphorus was analysed by a spectrophotometric method developed in the Water Research Laboratory, Civil Engineering Department, University of Cape Town.

APPENDIX II

RAW AND CALCULATED DATA

Table A.1 COD Removal in single-stage operation.

*disc area = 0,3630m^2, otherwise disc area = 0,1815m^2

BATCH NO.	FEED	Q (l/day)	R_H (hrs)	Soluble COD in (mg/l)	Soluble COD out (mg/l)	COD Loading Rate (gCOD/m^2/day)	COD Removal Rate (gCOD/m^2/day	Soluble COD Reduction
1	Guava +	11,6	5,95	1795	883	110	56	51
	Sewage	16,7	4,14	1680	1070	154	56	37
		18,5	3,74	1720	953	175	78	45
		23,0	3,00	1616	1017	205	76	37
		29,4	2,35	1650	1147	267	83	31
		34,6	2,00	1634	1140	311	94	30
2	Beet +	23,8	2,9	611	229	80	50	62
	Sewage	29,2	2,4	611	262	98	56	57
		37,6	0,89	590	269	122	66	54
	*	84,5	0,80	590	250	137	79	58
		46,9	1,54	590	245	152	89	59
		36,0	0,93	537	241	106	59	56
	*	86,6	1,02	537	220	128	75	59
		35,4	2,03	537	232	105	59	56
		33,1	1,02	530	254	97	51	53
	*	77,2	0,87	530	252	113	59	52
		36,1	2,00	530	249	105	56	53
3	Beet	35,0	0,96	1040	793	200	48	24
	*	75,2	0,90	1040	735	215	63	30
		34,9	2,06	1040	739	200	58	29
		35,0	0,96	1027	682	198	66	33
	*	75,2	0,90	1027	662	208	76	37
		34,9	2,06	1027	747	198	54	27
		35,5	0,95	1094	825	214	53	25
	*	78,6	0,86	1094	715	232	82	35

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BATCH NO.	FEED	Q	R_H	COD in	COD out	Loading Rate	Removal Rate	% COD Reduction
3 (cont.)	BEET	37,0	1,95	1094	763	222	66	33
		35,5	0,95	943	717	185	44	24
	*	78,6	0,86	943	737	204	45	22
		37,0	1,95	943	723	192	45	23
		35,0	0,96	927	650	179	53	30
	*	77,2	0,87	927	653	197	58	29
		36,4	1,98	927	655	186	55	30
4	BEAN	33,4	1,00	1360	1063	250	55	22
	*	74,0	0,91	1360	1080	277	57	21
		35,2	2,04	1360	1063	264	58	22
		35,3	0,95	1447	1140	281	60	21
	*	78,8	0,85	1447	1109	304	72	24
		35,2	2,04	1447	1140	280	60	21
		32,5	1,03	1489	1173	266	57	21
	*	74,1	0,91	1489	1182	304	63	21
		32,0	2,25	1489	1116	262	66	25
		32,5	1,03	1395	1054	250	61	24
	*	74,1	0,91	1395	1078	284	65	23
		32,0	2,25	1395	1077	246	56	23
5	BEAN	17,3	1,94	1124	881	107	34	32
	*	44,3	1,52	1124	835	137	36	26
		17,9	4,00	1124	721	111	40	36
		18,1	1,86	1207	850	123	36	29
	*	46,4	1,45	1207	884	154	41	27
		18,4	3,92	1207	759	122	45	37
		18,0	1,87	1125	797	111	33	30
	*	45,0	1,49	1125	815	140	38	27
		18,1	3,98	1125	773	112	35	31

A-3

BATCH NO.	FEED	Q	R_H	COD in	COD out	Loading Rate	Removal Rate	% COD Reduction
6	Pea	18,4	1,82	1111	854	113	26	23
	*	44,7	1,50	1111	872	137	30	22
		17,9	4,02	1111	721	110	38	35
		16,2	2,07	1008	450	88	50	57
	*	47,3	1,42	1008	461	131	71	54
		20,3	3,54	1008	530	111	53	48
		31,7	1,06	1025	625	179	70	39
	*	66,9	1,01	1025	535	189	90	48
		34,8	2,07	1025	670	197	68	35
		25,2	1,33	916	533	127	53	42
	*	75,0	0,90	916	453	190	95	50
		36,1	2,00	916	513	182	80	44
7	Pea	12,0	2,80	932	436	62	33	53
	*	23,1	2,91	932	332	59	38	64
		13,7	2,45	940	332	71	46	65
	*	25,0	2,69	940	347	65	41	63
		19,2	1,75	871	407	91	49	53
	*	35,1	1,92	871	396	84	45	54
		18,4	1,83	853	461	87	40	46
	*	35,0	1,93	853	343	82	49	60
		29,2	1,15	790	323	127	75	59
	*	51,6	1,54	790	324	112	66	59
		28,6	1,17	680	280	107	63	59
	*	53,0	1,27	680	296	100	58	58
		29,5	1,14	811	533	132	45	34
	*	46,8	1,43	811	470	104	44	42

A–4

BATCH NO.	FEED	Q	R_H	COD in	COD out	Loading Rate	Removal Rate	% COD Reduction
8	Pea	24,0	1,40	549	406	73	19	26
	*	49,0	1,37	549	278	74	37	50
		24,9	1,35	638	355	87	39	45
	*	51,1	1,32	638	363	90	39	43
		21,4	1,57	891	596	105	35	33
	*	45,2	1,49	891	563	111	41	37
		20,4	1,65	888	522	100	41	41
	*	44,8	1,44	888	510	110	47	43
		22,0	1,53	752	480	91	33	36
	*	43,0	1,56	752	412	89	40	45
		17,5	1,92	881	529	85	42	49
	*	31,7	2,12	881	453	77	44	57

Table A.2 COD Removal in two-stage operation

BATCH NO.	FEED	Q (l/day)	STAGE 1 (A = 0,36 m^2)					STAGE 2 (A = 0,1815m^3)				
			COD in (mg/l)	COD out (mg/l)	COD Loading Rate (gCOD/m^2/day	COD Removal Rate (g/m^2/day	% COD Reduction	COD in (mg/l)	COD out (mg/l)	COD Loading Rate (g/m^2/day	COD Removal Rate (g/m^2/day	% COD Removal
7	Pea	23,1	932	332	59	38	64	332	103	42	29	69
		25,0	940	347	65	41	63	347	159	48	26	54
		35,1	871	396	84	45	54	396	226	77	33	43
		35,0	853	343	82	49	60	343	196	66	28	42
		51,6	790	324	112	66	59	324	190	92	38	41
		53,0	680	296	100	58	58	296	179	85	34	40
		46,8	811	470	104	44	42	470	371	121	26	22
8	Pea	49,0	549	278	74	37	50	278	222	75	15	20
		51,1	638	363	90	39	43	363	286	102	22	22
		45,2	891	563	111	41	37	563	476	140	22	16
		44,8	888	510	110	47	43	510	374	126	34	27
		43,0	752	412	89	40	45	412	264	98	35	36
		31,7	881	453	77	44	57	453	221	79	41	52

APPENDIX III

ESTIMATION OF SLUDGE AGE FOR BIODISC.

In an activated sludge process operating at 12 days sludge age, 1,0g COD removal results in the accumulation of 2,1g VSS. (Marais, 1975). Sludge yield is therefore 2,1/12 = 0,175g VSS.g COD removed^{-1}. For approximately 75 per cent volatile sludges as obtained in this study, the equivalent sludge yield is 0,175/0,75 = 0,233g MLSS.g COD removed^{-1}. This agrees well with the observed mean sludge yield of 0,224g MLSS.g COD^{-1}.

Based on typical sludge composition figures of (i) 12 per cent NH_3 - N by mass and (ii) 2 per cent PO_4 - P by mass, nutrient requirements per g of COD removal in the activated sludge process at 12 days sludge age may be calculated as follows :

Mass of NH_3 N = 12 per cent of 0,175 g VSS = 0,0210 g NH_3 - N
Mass of PO_4 - P = 2 per cent of 0,175 g VSS = 0,0035 g PO_4 - P

Theoretical nutrient requirements are thus in the ratio COD : N : P = 1 : 0,021 : 0,0035, i.e. 100 : 2,10 : 0,35. Observed nutrient uptake in the Biodisc system was COD : N : P = 100 : 2,1 : 0,6.

Comparing the observed sludge yield and nutrient requirements of the Biodisc with the theoretical values predicted for the activated sludge process, it would appear that the equivalent mean sludge age in the Biodisc unit was approximately 12 days. This figure represents an average over the system since (i) cell wash-off is greater from the outside layers of the film and (ii) the sludge age of the solids suspended in the mixed liquor is equal to the hydraulic residence time in the disc chamber while the sludge age of the film on the discs is clearly much longer.