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Thus says the Lord:

 "Let not the wise man glory in his wisdom,
 Let not the mighty man glory in his might,
 Let not the rich man glory in his riches;
But let him who glories glory in this,
 That he knows and understands me,
 That I am the Lord who practise
 Steadfast love, justice, and righteousness in the earth;
 For in these things I delight."

. Jeremiah 9 v 24

STUDIES IN ANAEROBIC/AEROBIC TREATMENT

OF

DAIRY SHED EFFLUENT

A thesis presented in partial fulfilment of the
requirement for the degree of

DOCTOR OF PHILOSOPHY

in

Agricultural Engineering

At Massey University

Palmerston North

New Zealand

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1977

A B S T R A C T

Increases in herd size and enforcement of water quality regulations have created an effluent disposal problem for the New Zealand dairy industry. Spray disposal to land and lagooning are commonly used but mechanical failures, management requirements and pressure on land have limited their suitability in many situations. This project was established to consider an alternative system.

Initial studies revealed that anaerobic treatment in unmixed, non-insulated tanks, followed by trickling filter aeration, might be suitable. Two laboratory scale and one field treatment plant (1/15 - 1/20 full scale) were constructed to investigate the system. A factorial experimental design allowed investigation into three anaerobic treatment levels with a 3 x 3 aerobic treatment interaction nested within each anaerobic treatment.

Anaerobic residence times of 5, 7.5 and 10 days provided loading rates of 1.35 - 0.63 kg COD/m³-day and 1.36 - 0.67 kg TS/m³-day. Removals between inlet and outlet averaged 71% and were insensitive to loading rate. Total solids accumulation rates of 40-50% TS input rate suggests that anaerobic tank design should be based on solids accumulation rate and cleaning frequency.

The stone media trickling filter was loaded at approximately 0.61 kg COD/m³-day. Aeration periods of 1, 2 and 3 days and hydraulic loads of 2.8, 10.1 and 18.2 m³/m²-day were studied to determine their influence on treatment efficiency. Multiple regression analysis indicated that the longer residence times and higher recycle rates improved treatment efficiency. Removals varied with the measured parameters but ranged from 42-66% for COD. Design alterations to allow the final discharge to be taken from the bottom of the filter, after settling, would increase aerobic treatment efficiency above 75% COD removal. Prediction of treatment efficiencies beyond the monitored operating conditions suggested that only marginal improvements could be made. The TS accumulation rate in the aerobic phase was approximately 13% of the TS input rate or 56% of the BOD removal rate.

Overall plant treatment efficiencies of 80-89% were obtained. Removals in excess of 92% could be achieved with minor design alterations. Maintenance and operational requirements were minimal. The only problem with the system was an average 15 fold increase in $\text{NO}_3\text{-N}$ and 4 fold increase in DIP under conditions for optimum removal of the other parameters. Intermittent land disposal could reduce this problem.

Treatment comparison between similar laboratory plants, and between laboratory and field plants which varied by a scale factor of 56, suggests that identically designed plants would give a similar performance and that there is little scale effect. Increasing the scale only improved treatment efficiencies under unstable aerobic conditions, i.e., high recycle rates and low residence times. Increasing scale gave some decrease in maintenance and operational problems.

Design of a full scale plant, based on daily pollution loads from a 250 cow dairy shed, suggests that the system is a viable proposition.

- Mr I.R. Hughes, Statistician, Dairy Research Institute; for his assistance in statistical analysis.

- Staff of the Printery and Photographic Departments, Massey University; for their assistance in producing this thesis.

- Mobil Oil New Zealand Ltd.; for the grant of \$1,000 to assist in the construction of the field treatment plant.

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A B B R E V I A T I O N S

BOD	= biochemical oxygen demand	Mg	= magnesium
C	= carbon	ml	= millilitre
°C	= degrees Celsius	MLVSS	= mixed liquor volatile suspended solids
Ca	= calcium	mm	= millimetre
CH ₄	= methane	mV	= millivolt
CMD	= coefficient of multiple determination	N	= nitrogen
CO ₂	= carbon dioxide	Na	= sodium
COD	= chemical oxygen demand	Na ₂ O ₂	= sodium peroxide
DIP	= dissolved inorganic phosphate	NaOH	= sodium hydroxide
DKN	= dissolved Kjeldahl nitrogen	NH ₄ -N	= ammoniacal nitrogen
DM	= dry matter	NO ₃ -N	= nitrate nitrogen
DO	= dissolved oxygen	O ₂	= oxygen
DOP	= dissolved organic phosphate	P	= phosphorus
F/M	= food to microorganism ratio	ppm	= parts per million
g	= gram	RBD	= rotating biological disc
h	= hour	rpm	= revolutions per minute
ha	= hectare	s	= second
I.D.	= internal diameter	S.T.P.	= standard temperature and pressure
K	= potassium	TDN	= total dissolved nitrogen
kg	= kilogram	TDP	= total dissolved phosphate
kW	= kilowatt	TEMP	= temperature
l	= litre	TKN	= total Kjeldahl nitrogen
m	= metre	TN	= total nitrogen
max.	= maximum	TP	= total phosphate
mg	= milligram	TPN	= total particulate nitrogen
		TPP	= total particulate phosphate

TS = total solids

VS = volatile solids

VFA = volatile fatty acids

yr = year

CHAPTER 1

INTRODUCTION

1:1) THE NEW ZEALAND DAIRY INDUSTRY

The N.Z. Dairy Industry has an annual export earning in excess of \$391 million per year (210)* which is approximately 20% of the Country's export earnings (211).

The increases in farm size and intensification to provide the raw materials for both consumption and export are shown in Tables 1:1 (212), 1:2 (215) and 1:3 (213), and have been investigated by other workers (214). Herds of up to 900 cows are now being milked in N.Z.

The almost total dependence on grazed pasture as a feed source reduces the concentration of animals within a confined area. The herd is only brought to the dairy shed, for 1-2 hours, morning and evening to be milked. It is the treatment and disposal of effluent produced at the shed during this period that is one of the major problems within the industry.

1:2) DAIRY EFFLUENT TREATMENT

Historically, dairy shed effluent, consisting of dung and urine, milk, detergents and washing water from plant cleaning, has been discharged into a natural water course or transferred to a sacrifice area. The increasing volume of effluent resulting from larger herd sizes, in conjunction with the current legislative requirements and greater awareness of environmental conservation, has now made these practices unacceptable from a legal and social standpoint.

To meet these requirements within the economic restraints of the production unit, two major methods of treatment and disposal have been used; namely, spray irrigation and lagoons. Though both systems have many advantages there are limitations which may restrict the farmers' operation. The continual shifting of sprinklers, deterioration in pasture quality, special management, disease risks, spray drift, and the maintenance of equipment, are making the operation of the spray system marginal in many situations. Lagoons have less maintenance and operating problems than spray disposal, but the design criteria being used require relatively large areas of land close to the dairy shed.

* Numbers in parentheses refer to appended references.

TABLE 1:1

STATISTICS FOR FACTORY SUPPLY DAIRY FARMS IN N.Z.

Year	1960/61	1970/71	1974/75
Total no. of cows (millions)	1.9	2.3	2.5
Average no. cows/herd	57	97	112
No. of factory supply herds	30,700	23,700	17,695

TABLE 1:2

THE NUMBER OF FACTORY SUPPLY HERDS
WITH MORE THAN 300 COWS

Season	1969/70	1971/73	1974/75	1975/76
No. of herds	74	115	125	133 ⁽¹⁾

(1) Provisional figure

TABLE 1.3

STATISTICS FOR TOWN SUPPLY DAIRY FARMS IN N.Z.

Year	1960/61	1970/71	1973/74
Total no. of farms	2,530	1,876	1,743
Productive farm area (ha)	41.3	63.5	73.0 ⁽¹⁾
Average no. of cows/herd	54	91	100

(1) For comparison total farm area was 31.7 ha.

This has a high opportunity cost which will increase with time and intensification. Furthermore, it presupposes the existence of a suitable site for the lagoon.

The limitations of these systems, along with the trends in the industry, suggested the need for considering other methods for treatment and disposal. It became apparent that development of an anaerobic/aerobic biological treatment was the most suitable alternative.

This project was therefore established with the following objectives:-

- (a) To evaluate the treatability of a high fibre dairy shed effluent.
- (b) To determine the feasibility of high loading rates to anaerobic ponds followed by trickling filter aeration.
- (c) To consider the relevance and implication of this treatment system in regard to the future of the dairy industry.

CHAPTER 2

DAIRY SHED EFFLUENT TREATMENT - A REVIEW

2:1) EFFLUENT PRODUCTION AT THE DAIRY SHED

It has been estimated that once stocking rates rise above 2.5 cows/ha effluent disposal becomes a problem (1). The characteristics of dairy shed effluent are reviewed in Appendix I and summarized in Table 2:1. These figures should be used with care owing to the wide variation in values reported. The national implications of this effluent production have been outlined (23).

Although many workers have analysed the effluent produced by dairy cattle, and many more have investigated systems for treatment and disposal, little, if any, work has been reported on methods of reducing the total volume of effluent to be handled.

2:2) TREATMENT METHODS AND THE LAW

2:2.1) The Water and Soil Conservation Act

The Water and Soil Conservation Act plus amendments (216) sets out regulations for the control of fresh and saline water quality. The law is based on the concept that present and future uses of the water will determine its required quality. To cater for these uses, all natural waters are classified into four main categories. The criteria for classification are summarized in Table 2:2. The law states that no discharge should cause the water to fall below its classification.

On application, the Regional Water Board who administer the Act, may issue a 'Right to Discharge'. The 'Right' specifies the characteristics of the effluent acceptable to the Board and will vary depending on the receiving water classification. All 'Rights' are revised by the Water Board, either by default when the receiving water is reclassified, or at the Board's discretion. The ability to revise the 'Right to Discharge' is necessary to accommodate unforeseen water quality requirements.

At present, pollution of underground waters through infiltration is not actively policed. Although a producer does not require a 'Right to Discharge' for land distribution, assuming no direct runoff, it appears from the law that he may be prosecuted for polluting underground water if the source of the pollution can be traced (4).

TABLE 2:1EFFLUENT PRODUCTION PER COW-DAY

Parameter	Total Effluent Production	Estimated Effluent from the Dairy Yard
Volume (l/cow-day)	40	70
BOD (kg/cow-day)	0.8	0.07
Solids (kg TS/cow-day)	4.8	0.40
Solids (kg SS/cow-day)	3.5	0.28
Nitrogen (kg/cow-day)	0.14	0.010
Phosphorus (kg/cow-day)	0.06	0.003
Potassium (kg/cow-day)	0.11	0.005

TABLE 2:2

A SUMMARY OF FRESH WATER CLASSIFICATION IN N.Z.

Class	Temp °C	DO ppm	pH	Faecal Coliform /100 ml	Total Coliform /100 ml	Use	Aquatic Life	Colour Turbidity
A				No waste discharge permitted				
B	±3 ⁽¹⁾	6	6.0-8.5	2,000	10,000	Human	No toxicity	No change ⁽¹⁾
C	±3	6	6.5-8.3	200	NS ⁽²⁾	Human	No toxicity	No change
D	±3	6	6.0-9.0	NS	NS	Livestock	No toxicity	No change

NOTES: (1) These values are based on the prevailing conditions.
Specific limits are not set because of wide variations experienced.

(2) NS = not specified

Pressure is being applied to the industry to update its effluent treatment systems with the inducement of a \$2,000 fine with \$100/day for each day the offence continues. Legal action has been taken against several dairy farmers and the number of prosecutions is expected to increase (218).

2:2.2) Dairy Regulations

The dairy farmer is also subject to regulations within the industry which are enforced by the Dairy Division of the Ministry of Agriculture and Fisheries (5). The regulations are primarily concerned with the production of a high quality product. To ensure this, guidelines have been laid down for:

- (a) the design and siting of dairy sheds
- (b) the installation of milking machinery
- (c) the cleaning of milking plants
- (d) the siting of effluent collection pits, pump units, lagoons and sprayed areas.

These controls cover the design and operation of the dairy shed, both directly and indirectly, and affect the nature of the waste and its method of treatment and disposal.

2:2.3) National Surveys of Dairy Shed Effluent Treatment

Since these regulations were introduced some simple disposal methods have been used to circumvent the law. Transferring waste to sacrifice areas or 'blind gullies' has been popular and prosecutions have been avoided.

A number of surveys have been made on the treatment methods used within the dairy industry (107, 110-112). A summary of these results is presented in Table 2:3. The 10% reduction in unsatisfactory treatment systems is encouraging but it is expected that some marginal, and all unsatisfactory, treatment systems will have to be modified as Catchment Boards and the Dairy Division apply the regulations more rigorously.

TABLE 2:3A SURVEY OF DAIRY SHED EFFLUENT TREATMENT SYSTEMS

Type of System (1)	% of Farms Using System (2)		Acceptability (3)
	1971/72	1975/76	
Spray irrigation	5.5	21.0	Satisfactory
Lagoons	6.1	5.6	Satisfactory
Tankers	3.3	3.4	Satisfactory
Piping	6.2	9.1	Marginal
Waste land	23.9	15.4	Marginal
Open drains	55.2	36.0	Unsatisfactory
Blind drains		7.2	Unsatisfactory
Other		1.8	Unsatisfactory

- NOTE: (1) The criteria for defining treatment systems into any category is not clear.
- (2) Regional variation is large and must be considered when applying this data.
- (3) The acceptability rating is the author's. The classification is subjective and indicates the areas of concern within the administrative bodies.

2:3) LAND DISPOSAL

2:3.1) Introduction

Land disposal of dairy effluent has been widely used (7-34, 172). Soil has the capacity to adsorb and decompose waste by chemical reaction and by the action of indigenous organisms. Land disposal can therefore reduce the organic loading on natural waters. It also provides a source of irrigation and fertilizer.

New Zealand's favourable climate allows the daily application of effluent to pasture throughout the year, providing adequate drainage is present to cope with the wetter months (7). This contrasts with overseas practice where severe winters often require waste to be stored in holding ponds for land application prior to spring ploughing (26, 27, 120, 121).

2:3.2) Design and Loading Rates

Comprehensive bulletins on the design of spray irrigation systems in N.Z. have been published (11, 12, 14, 15, 304). These include pump and sprinkler selection, siting and area requirements, piping and system design and management guidelines.

High loading rates are detrimental (9, 19, 25-27, 120) to:

- (a) soil structure through the breakdown of stable soil aggregates
- (b) plant growth due to anaerobic conditions in the root zone and excessive solid deposits
- (c) treatment efficiency as a result of solid and nutrient accumulation
- (d) animal health including metabolic disorders, pathogen infections and possibly reduced feed intake due to lowered pasture palatability.

The overall effluent loading is determined by considering the relative contributions of the hydraulic, solid and nutrient loads.

2:3.2,1) Hydraulic Loads -

The application rate should not exceed the infiltration rate. Values vary from 3mm/h to more than 30mm/h, depending on the prevailing conditions (12, 122, 152). The total volume per application is

limited by the soil's field capacity (16). Hydraulic loads may be increased by sub surface drainage (16). However, residence times can be unduly decreased by excessive use of this procedure.

2:3.2,2) Solid Loads -

Annual applications of effluent, prior to soil tillage for cropping, range from 6 to more than 350 tonnes dry matter (DM)/ha. Greater than 200 tonnes DM/ha is not regarded as suitable (19, 26, 27, 120, 121, 123-125). Loadings for repeated effluent irrigation are 2.1-3.5 tonnes total solids (TS)/ha/3-4 week cycle (19, 25, 120).

2:3.2,3) Nutrient Loads -

Nitrogen (N) is a key element because of its mobility in the soil (20), its dominance in plant growth (126) and its high levels in dairy shed effluent (Appendix I). Comparison of published data (19, 20, 22, 24, 120, 121, 123, 126, 127, 129) suggests that, even allowing for losses, loadings in excess of 700 kg N/ha-yr should not be applied. Nitrogen loadings above this level may be obtained with anaerobic pretreatment of the waste. The increased proportion of ammoniacal nitrogen ($\text{NH}_4\text{-N}$) both decreases nitrogen mobility in the soil (119) and increases losses through volatilization (20, 24, 123).

Other nutrients such as phosphorus (P) and potassium (K) are not usually considered in design as their lower concentration in the effluent (Appendix I) and ease of binding by soil and plant reduce their significance relative to N (19, 119, 126, 130). Sodium (Na) levels may be detrimental to soil structure (119, 121).

Optimization of nutrient loading has been reported (183, 197).

2:3.3) Treatment Efficiency

Variations in effluent, climate, soil, plant cover, design and management contribute to the variation of treatment efficiency reported.

2:3.3,1) Runoff and Infiltration Quality -

Results of runoff monitoring are summarized in Table 2:4.

Standardization of reported infiltration loads is difficult (18, 20-22, 121, 128, 133, 136, 138, 139). Biochemical oxygen demand (BOD) levels in ground water are generally less than 10 mg/l (18).

TABLE 2:4

RUNOFF QUALITY FROM LAND DISPOSAL AREAS

Parameters	BCD	NO_3^-	PO_4^{--}	K^+	Faecal Coliform
Concentration (mg/l)	45-100	7-50	10-20	100-300	$10^3 \rightarrow 10^5$ (Organism/100 ml)
Level Above Control	1-5 Times	1-5 Times	1-3 Times	-	1.5 - 2.0 Times
References	18, 19, 120, 137.	18, 19, 120, 129, 133, 134, 136, 137, 139.	18, 19, 129, 134, 136, 137.	129, 139.	18, 19, 129.

Monitoring of tile drains from a disposal area gave 25-100% BOD removal, with nitrate nitrogen ($\text{NO}_3\text{-N}$) levels 4-5 times those of the control area (133). Phosphorus movement is minimal with 99% removals reported (17). A 98% TS removal may also be expected (18).

2:3.3,2) Soil Quality -

Land disposal of organic wastes generally improves soil structure (139) though some reports of decreased infiltration rate over the long term have been published (26, 27). Nutrient accumulation occurs within the soil (121, 127, 128) which increases soil conductivity (139).

2:3.4) Plant Growth Responses

An increase in crop dry matter, of 0.15-2.00 times the control, is usually shown in effluent disposal areas (22-25, 94, 120, 134, 139-141). Yield reductions under high loadings have occurred (25, 121, 127, 142).

Palatability, digestibility and nutrient levels are not significantly affected by land disposal, providing good management is obtained (22, 25, 140).

2:3.5) Animal Health

2:3.5,1) Disease Transmission -

Although many workers (9, 17, 19, 29-32) have reported on the possible disease problems arising from land disposal, it is difficult to prove the relationship between the pathogens detected and the corresponding diseases in stock and men.

2:3.5,2) Metabolic Disorders -

The accumulation of nitrate in crops is influenced by the applied nitrogen loads (120, 121, 125, 146). Associated toxicity problems have been reported (144) and $\text{NO}_3\text{-N}$ levels in livestock feeds greater than 0.2% (DM basis) are viewed with concern (145).

A potassium/(calcium and magnesium) ratio ($\text{K}/(\text{Ca} + \text{Mg})$) greater than 2 is undesirable, particularly under low Mg conditions (120, 145). Investigation of these salts in the effluent (10, 119, 138) indicates

potential problems, particularly with pretreatment prior to land disposal as solid/liquid separation could remove much of the bound Ca leaving the soluble K to further increase the $K/(Ca + Mg)$ ratio.

2:3.6) Pretreatment for Land Disposal

Pretreatment of effluent prior to land disposal has been used extensively overseas (24, 117, 125, 128, 131, 132, 147, 149) and is being introduced in N.Z. (148, 299). The reasons for pretreatment include; improved handling characteristics, increased loading rates, reduced runoff and simplified management.

The two main alternatives are ponding, to allow periodic discharge (24, 117, 125, 128, 147, 148), or solid/liquid separation, to allow the use of conventional irrigation equipment and concentrated solid storage (128, 131, 149).

2:3.7) Economics of Land Disposal

Overseas literature (33, 35) indicates that the cost of land disposal is greater than any returns obtained from increased dry matter production and must be justified on something other than fertilizer value. Some N.Z. operators also see spray disposal as an expensive substitute for inorganic fertilizers (28).

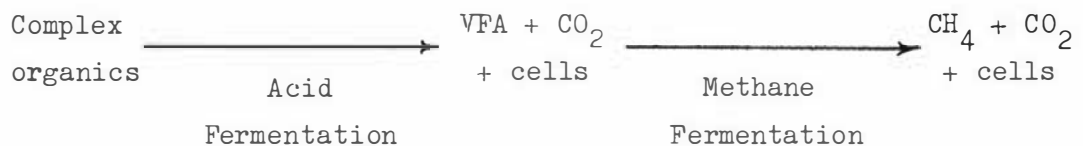
Phillips (34) suggested that the increased dry matter yield balanced the capital and running costs of spray disposal on a well managed system. This was a short term study and did not consider the utilization of any dry matter produced. Dakers (110), in a more recent analysis, showed that spray irrigation has a net annual cost of \$375 for a 100 cow town supply herd. Clarke (300) indicated that these costs could be substantially increased when considered over the long term, due to high maintenance problems.

The scale of operation, the quality of management, and the location of the farm will all affect the final costing. Individual analysis of each situation is the only realistic method of evaluating the suitability of a land disposal system.

2:4) ANAEROBIC TREATMENT

2:4.1) Introduction

Anaerobic digestion is a powerful biological method of stabilizing organic matter and reducing its mass. It is a two-stage process converting complex organics via intermediate volatile fatty acids (VFA's), carbon dioxide (CO_2) and cell matter to methane (CH_4), CO_2 and additional cell matter. The two stages should operate concurrently as shown:



The process has been the subject of a vast amount of investigation, much of which has been condensed in comprehensive reviews (37, 153-157).

The major advantages and disadvantages of anaerobic treatment are summarized below.

Advantages:

- (a) Low nutrient requirements, applicable to a wide variety of wastes.
- (b) Solids reduction, stabilization and improved dewatering characteristics.
- (c) Reduction in pathogen levels.
- (d) Reduction in the COD of the effluent.
- (e) Sludge removal improves subsequent aerobic treatment.
- (f) Suitable for concentrated effluents due to operation in the absence of oxygen.
- (g) Low net cell production due to low energy levels in the overall reaction.
- (h) Production of methane.

Disadvantages:

- (a) High temperature requirement to achieve satisfactory reaction rates.
- (b) Low environmental flexibility due to the stringent requirements of the methane producing bacteria.

- (c) Inability to degrade some organic compounds such as aromatic moieties used in detergents.
- (d) High level of technology and operator skill for efficient operation.

2:4.2) Principles of Anaerobic Treatment

2:4.2,1) Biochemical Reactions -

Hydrolysis of the complex organic compounds is generally executed by extra-cellular enzymes. This process may be rate limiting with lignified or similarly resistant products (156, 158). The hydrolysed components are absorbed by the cell and degraded via standard biochemical pathways (37, 153, 155).

The methane producing bacteria have simple nutritive requirements, most of which are the products of acid fermentation. The biochemical details of the conversion from VFA's to CH_4 have not been fully determined (153-156). However, the overall reaction rate is slow and methane generation is the rate-limiting reaction in most digestion processes.

2:4.2,2) Environmental Requirements -

Despite their simple nutritive requirements, methane producing bacteria are sensitive to their environment, and traditionally anaerobic digesters have been operated under strictly controlled conditions for maximum methane output.

Digester loading rates and effluent properties can affect the environment by controlling alkalinity, microbial residence time, substrate input, temperature and the degree of endogenous respiration.

The conditions reported for each stage of the digestion process are summarized in Table 2:5 (160).

2:4.3) Anaerobic Lagoons

Anaerobic lagoons are excavated ponds with earth embankments giving an average depth of 3m. Their low capital and operating costs have suited them for dairy shed effluent treatment (43-45, 135, 149, 164-166, 168-171). Raw effluent is discharged directly into the lagoon,

TABLE 2:5ENVIRONMENTAL REQUIREMENTS FOR ANAEROBIC DIGESTION

Variable	Acid Fermentation (1)	Methane Fermentation ⁽²⁾
Temperature (°C)	20 ± 5	37 ± 2
pH	5.5 - 6.5	6.8 - 7.5
Alkalinity (mg/l)	1,000	>1,500
Redox potential (mV)	-100	-300
VFA's (mg/l)	-	< 2,000 ⁽³⁾
Max. growth rate (generations/h)	1.25	0.14

NOTE: (1) These values have been reported when the acid fermentation phase was optimized in isolation from methane fermentation.

(2) Values shown reflect the environmental conditions of a traditionally operated methane digester.

(3) VFA toxicity interacts with pH and cation levels (154).

the performance of which is governed by loading rates, method of operation and the environment.

2:4.3,1) Loading Rates -

- (a) BOD load: Hart and Turner (44) suggested that $\text{kg BOD/m}^3\text{-day}$ was the most suitable loading parameter. The relatively low BOD/volatile solids (VS) ratio experienced with dairy waste supports this.

Loading rates for various effluents range from $0.013\text{--}0.540 \text{ kg BOD/m}^3\text{-day}$ (44, 48, 119, 161). Design loadings for dairy cattle effluent have been as high as $0.14 \text{ kg BOD/m}^3\text{-day}$ (47), but Bhagat and Proctor (48) estimated operational loadings of $0.32 \text{ kg BOD/m}^3\text{-day}$, allowing for the accumulated solids in the lagoons. N.Z. design figures range from $0.02\text{--}0.05 \text{ kg BOD/m}^3\text{-day}$ (52-55, 167) or $0.29 \text{ kg chemical oxygen demand (COD)/m}^3\text{-day}$ (57).

- (b) Solids load: Loads of $0.07\text{--}5.10 \text{ kg VS/m}^3\text{-day}$ have been quoted (44-46). The normal design loadings range from $0.012\text{--}0.20 \text{ kg VS/m}^3\text{-day}$ (47, 49, 57, 164, 166, 169) with levels of $1.12 \text{ kg VS/m}^3\text{-day}$ if allowance is made for volume reduction due to accumulated solids (48). TS loadings are similar, allowing for a 75-80% VS content (165).
- (c) Hydraulic load: There is little mixing in lagoons and this allows solid sedimentation, reducing the influence of hydraulic loads on solids residence time. High hydraulic loads can lead to a reduction in treatment, followed by overloading of the aerobic lagoons (173). Design values for residence times vary from 7.5-65 days (46, 47-49, 57, 166, 169) with a mean of 25-30 days. Design values will decrease as settled solid accumulates (48).
- (d) Animal load: Using data from Table 2:1 and the above loading rates, an average lagoon size of $2\text{--}3 \text{ m}^3\text{/cow-day}$ would be used for effluent from the dairy shed. This would provide a residence time of 30 days.

2:4.3,2) Lagoon Operation -

Although a significant proportion of lagoon treatment is achieved through settling, some mixing is required to provide satisfactory microflora/waste contact for decomposition (119, 161, 169). This is achieved naturally by:

- (a) the currents produced by waste entry (163)
- (b) the evolution of gas through microbial activity (119)
- (c) the result of thermal gradients (161-163)
- (d) the effect of wind (161-163).

Pumped recycling would improve the solids dispersal within the lagoon and could be incorporated into a hydraulic recycle system for cleaning, solids removal and land disposal (94, 117, 137, 149, 169). Mixing would also reduce the problem of short circuiting through thermal stratification (161). However, some problems with odours, disease and chemical precipitates have been encountered (175-180).

Temperature affects design loading rates as methane generation almost ceases below 13-15°C (119, 161). For this reason 'start up' is recommended over the summer months (161-163). The increased microbial activity during spring, particularly in acid fermentation, may cause an increase in VFA's and odour.

Surface solid is often formed on anaerobic lagoons. The presence of this fibrous mat provides insulation during cold weather, but it also reduces wind mixing. Accumulation of rising solid lifts part of the fibrous mat above the liquid surface, decreasing its contact with the microflora and thus reducing its decomposition.

Details for design, construction and maintenance of anaerobic lagoons have been presented (54-58). The practice of installing central discharges above surface level may not be ideal as this could cause short circuiting (161). Raw waste discharge in one end of the lagoon has shown satisfactory solid distribution (166).

2:4.3,3) Treatment Efficiency -

BOD removal for anaerobic lagoons varies from 88% at 29°C, to 20% at 2°C (47). Similar values have been recorded by other workers (48, 49, 161, 164). BOD discharge levels range from 150 mg/l to more than

400 mg/l (47, 167). TS and VS removal follow similar trends (48, 49, 161). For dairy waste more than 60% of the BOD and TS removal can be attributed to settling (Chapter 2:6.1,1). It should be noted that TS removal does not imply decomposition, but storage in the lagoon. The insensitivity of lagoon discharge to variation in loading rate has been reported by some workers (46).

Total Kjeldahl nitrogen decreases (48, 164), but $\text{NH}_4\text{-N}$ can rise by 25% to yield more than 70% $\text{NH}_4\text{-N}$ (48). $\text{NO}_3\text{-N}$ shows a 7% increase (49). The change in N forms is affected by temperature. There is an estimated 25-55% decrease in total phosphate through the anaerobic lagoon (48, 49). Microbial reduction is greater in summer, with 99% faecal coliform removal (47, 161). The discharged liquor may have an odour.

Infiltration from lagoons to ground water is of concern. Davis et al. (56) showed that lagoons were effectively self sealing in 4 months. Other workers (164, 168) suggested that 6-8 months were required before sealing. However, Nordstedt et al. (49), monitoring ground water samples at 4.6-30.0m from the lagoon, showed the respective BOD levels to be 8-1 times those of the control. $\text{NO}_3\text{-N}$ showed a 5 fold increase of the control at 4.6m. Sewell et al. (168) reported similar $\text{NO}_3\text{-N}$ and chloride increases prior to sealing. Hills (57) demonstrated that the degree of infiltration was dependent on soil type and the hydraulic gradient. Infiltration rates were approximately 1% of the pollutant load measured as COD, N and total VS. Provided the soil contained more than 7.5% clay or 30.5% silt, and was compacted to the maximum Proctor Density, little infiltration was experienced. The mechanisms of sealing have been reported (57, 168, 174).

2:4.3,4) Solids Accumulation and Disposal -

Of the VS added to a lagoon, 40-60% may be destroyed (44-47, 166). Bhagat and Proctor (48) stated that only 29% of the settled VS was biodegradable. The inert solids also accumulate, giving a TS accumulation of $0.32\text{-}4.00 \text{ kg/m}^3\text{-day}$ over a loading range of $0.8\text{-}4.8 \text{ kg VS/m}^3\text{-day}$ (45). The volume of TS accumulated depends on sludge density. Loehr (46), and Nordstedt and Baldwin (166, 169) showed that increasing the solids loading rate increased the sludge density.

Values quoted range from 4.6-12.0% TS at 50-70% VS. An increase in temperature increased the biological activity in the sludge and tended to reduce sludge density (169). As a result of these conditions the sludge accumulation rate on a volume basis was relatively constant, irrespective of loading rate or operating conditions. A loading rate of $0.115 \text{ kg VS/m}^3\text{-day}$ resulted in a sludge accumulation rate of $0.0033 \text{ m}^3/\text{kg TS added}$ or $0.0038 \text{ m}^3/\text{kg VS added}$. The annual sludge accumulation was 15-17% of lagoon volume (166, 169).

Lagoon sludges are commonly distributed on the land. Nordstedt and Baldwin (169) suggested pumping, or perhaps dredging, as the most efficient method of removal. The cleaning operation could be done on a batch (i.e., every 5-6 years), a periodic (i.e., every 6-12 months), or on a continuous basis, depending on preference and available equipment. Whichever system is employed, care should be taken to avoid emptying the ponds below the level of the surrounding water table, and at a rate which could cause bank erosion.

The only available loading rates for land application are presented in Chapter 2:3.2. Additional attention should be given to pathogen levels (46, 135). At least one quarter of the sludge should be left in the lagoon to act as "seed" for future treatment (45). Brown (54, 55) suggested cleaning once the lagoon contained 50% accumulated sludge.

2:4.4) Capped Anaerobic Digestion

Anaerobic digestion rates can be improved by controlling the environment. The increased decomposition may produce sufficient methane to warrant its collection and storage as a high energy fuel. This system has had wide application in agriculture (43, 88, 119, 124, 184-186, 189, 316, 317), particularly with piggery effluent (187, 188, 190-192).

2:4.4,1) Loading Rates -

Digesters may be loaded at $0.5\text{-}8.0 \text{ kg VS/m}^3\text{-day}$ depending on the degree of mixing and temperature control (153-157). Laboratory digesters, receiving dairy cattle waste, were loaded at $1.6\text{-}3.8 \text{ kg VS/m}^3\text{-day}$ (39, 40, 193). Solids levels within a digester are maintained at 2-3% TS. Lower values require increased digester

capacity. while higher levels result in solids handling problems (194).

Although theoretical hydraulic residence times may be less than 6 days (119), in practice values of 10-30 days are employed (39, 40, 86). At the shorter holding times, solid recycle is usually used to avoid microbial washout.

2:4.4,2) Treatment Efficiency and Gas Production -

Dairy cattle waste VS removals of 11-53% have been reported with a mean of approximately 20% (39, 40, 186, 193). BOD removals range from 59-89%, with effluent concentrations still in excess of 1,000 mg/l (39). COD reductions are significantly less (40).

Gas production, consisting of 52-68% methane, ranges from 0.25-1.00 m³/kg VS destroyed (39, 40, 124, 186). Collection and storage should include condensate and flame traps, and scrubbers to remove other gases (185, 195, 196). The energy value of methane is 37.23 MJ/m³ at S.T.P. (195). The net energy yields are considered marginal with dairy cattle wastes (301, 302).

The nutritional value of the digested sludge has been considered by various authors (186, 198), but the sludge is generally disposed of by land application (186, 195, 196).

2:4.4,3) Design and Development -

Design of anaerobic digesters has been documented (41, 42, 185, 192, 195).

Improved technology, using anaerobic upflow filters (119, 153) and split phase digestion (159, 160), has significantly improved domestic treatment systems. Loading rates of 80 kg VS/m³-day into an acid digester have been reported (160). These systems have not been widely used in agriculture.

2:5) AEROBIC TREATMENT

2:5.1) Introduction

The reactions within aerobic treatment systems and the microflora responsible for them have been reviewed (119, 195, 198, 199). The optimum pH range is 6.5-8.5 (198). The nutrient requirements for N and P relative to organic waste oxidation are given as BOD:N:P = 100:3:0.5 (119, 198). Reaction rate constants are affected by temperature changes, as are fluid properties such as density, surface tension, gaseous diffusion and solubility. Mixing is important to maintain nutrient and oxygen distribution and to reduce thermal gradients and effluent short circuiting.

A minimum of 1-2 ppm dissolved oxygen (DO) must be maintained to sustain aerobic decomposition (119, 195, 198). The oxygen supply should match the demands exerted by the organic wastes (BOD) and endogenous metabolism (119, 199, 200, 217).

Aerobic sludge yields may be calculated (195, 198) but are largely influenced by the nature of the waste. The cell yield, the cell endogenous rate and the food to microorganism ratio (F/M) all affect sludge production.

2:5.2) Oxidation Ponds

Oxidation ponds are the simplest aerobic treatment systems. They rely on natural air/surface contact and photosynthesis to maintain a supply of DO. They may be facultative in operation since some anaerobic digestion occurs in the settled secondary sludge.

2:5.2,1) Design Considerations -

Pond design procedures are reported by Gloyna (162), Thirumurthi (203) and Eckenfelder (204). Hydraulic overloads have been the cause of lagoon failure (163, 205). Retention times of 20-30 days are common (161).

The BOD removal rate is of primary importance. Thirumurthi (203) suggested that this is influenced by organic load, toxicity, insolation rates, temperature and pond structure. Assuming no toxicity problems with dairy wastes, the effects of the other

variables can be briefly summarized.

- (a) BOD Load: Decreasing the organic load reduces the rate of BOD removal. This should not be confused with percentage BOD removal and effluent quality which may well improve with reduced organic loading rates.

BOD loadings range from 8-670 kg BOD/ha-day (119, 161, 162) with 84 kg BOD/ha-day being used under N.Z. conditions (55, 58).

- (b) Insolation Rates: Algae are the main contributors to the DO supply in lagoons. Stoichiometrically, the ratio of oxygen production to algal synthesis is 2:1 on a weight basis (119) though in practice values of approximately 1.6:1 are obtained (119, 161, 162, 204). Algal synthesis is dependent on photosynthetic efficiency. Reported values range from 2-12% (119, 161, 162, 204).

Neel et al. (206) suggested that a minimum of 1.68 Langleys of total radiation per day are required per kg BOD/ha applied.

- (c) Temperature: In addition to its effect on biological reaction rates, temperature change will cause thermal stratification in the absence of wind for mixing. This leads to poor oxygen and algal distribution, low temperatures at the bottom of lagoons and short circuiting (163).

- (d) Pond Structure: Details of pond design have been reported (161, 162). Ideally, large shallow ponds are required but restraints on area, minimum depth requirements to avoid insect breeding and the need to maintain an active bacterial population, result in lagoons approximately 1m deep (119, 161-163). Surface dimensions of less than 3:1 (length: breadth), and orientation to prevailing winds, are recommended to obtain maximum wind mixing. Inlets at one end of the lagoon are recommended (163).

2:5.2,2) Treatment Efficiency -

Effluent quality ranging from 2-350 mg BOD/l has been reported (52,

119, 161) with the quality largely reflecting the extent of algal removal. Treatment efficiencies of 70-90% BOD reduction may be expected (119, 161, 162).

A linear die-off rate of pathogenic organisms has been reported, resulting in 95-99% removal of E. coli (161). Consequently, ponds in series are more effective than single large ponds as they reduce short circuiting (161, 163).

Some accumulation of sludge will occur but this is not a problem.

2:5.3) Aerated Lagoons

Forced aeration was introduced to reduce lagoon area, increase loading rates and decrease environmental effects on lagoon performance (61-71). Aeration is achieved with floating turbines or submerged spargers releasing compressed air.

Oxygen uptake rates vary from 3-30 mg/l-hour and aerators are selected to provide approximately twice the BOD load of 0.06-0.16 kg/m³ (61, 65). Typical aerator performances are 0.9-1.2 kg O₂/kW-hour (38, 43, 60, 119).

The mixed liquor volatile suspended solids (MLVSS) level of 2-3% requires mixing velocities of 0.15 m/s and power inputs of up to 8 kW/1000m³ (43, 60, 64, 119).

2:5.4) Trickling Filters

2:5.4.1) Introduction -

The media within a trickling filter provides a large surface area to volume ratio and an inert base for the development of a biological slime.

It is the active biological film which absorbs and oxidises the pollutants in the effluent, thus reducing its BOD. Hence filter design and operation is directed to maximizing the mass of active biological film in contact with the effluent.

The advantages of trickling filters have been discussed by other

workers (9, 246, 268) and may be summarized as;

- (a) Simple operation
- (b) Low operating costs
- (c) The ability to handle shock loads with rapid recovery
- (d) Minimum land area occupied.

These advantages make the trickling filter suitable for;

- (a) Small populations
- (b) Shock loadings
- (c) Roughing, i.e., removal of approximately 50% BOD prior to further treatment or discharge
- (d) Polishing - this may be either through moderate loadings to obtain a good (20-30 ppm BOD) discharge, or at low loadings for nutrient removal.

2:5.4,2) Design Considerations -

Various permutations of filter design and operation are reported (246, 246, 256, 293).

Aside from the effects of effluent composition and pretreatment, the main factors in filter design are:

- (a) Hydraulic Load - Low rate filters are loaded at 0.9-3.75 m^3/m^2 -day (248) and high rate filters at 8-94 m^3/m^2 -day (253, 254). The higher flow rates are generally with plastic media. Hydraulic loads have been shown to reach an optimum for any given set of conditions (255, 256).

The flow may be applied continuously or intermittently.

Dosing frequency with intermittent discharge varies widely (79, 268, 284, 288). The advantages of flush feeding include; film erosion, nutrient penetration into the filter and greater endogenous respiration (79, 252). These advantages are less significant at high hydraulic loadings and with plastic media (252). Alternative methods of flush feeding have been summarized (195).

- (b) BOD Load - BOD loads are related to hydraulic loading (271). Increasing the BOD load will decrease the percentage removal by the filter, but will increase the total weight of BOD

removed per unit volume (246, 255, 265).

Filter loading rates range from 0.08-0.40 kg BOD/m³-day for low rate filters to 0.41-5.80 kg BOD/m³-day for high rate filters.

(c) Recirculation - The advantages of recycling the effluent through the filter have been stated (246, 248) and are listed below:

- (i) Improved effluent/film contact. This is effected by improved liquid distribution, uniform thickness with filter depth and increased contact time due to the greater number of passes.
- (ii) Continual reseedling of the filter influent.
- (iii) Increased stability of flow and BOD load applied to the filter.
- (iv) The reduction of filter blockage by increasing the sloughing of the film.
- (v) Improved fly control, particularly during summer.

The disadvantages of recirculation are:

- (i) Increased costs from larger pipes, pumps and power requirements.
- (ii) Larger settling tanks if the recycle flow is passed through one or both of the primary and secondary settling tanks (293).
- (iii) Increased heat loss in the winter.
- (iv) The possibility of greater sludge production due to increased sloughing.
- (v) A decrease in nitrification due to increased competition by heterotrophs flushed down the filter (254).

Kinetic studies indicate that recycle ratios greater than 5:1 are of little advantage in large scale municipal treatment systems (80, 246, 249, 251, 252, 258).

(d) Filter Media - The characteristics of the media may be summarized after Fair et al. (195) and Loehr (119) as follows:

	<u>Stone media</u>	<u>Plastic media</u>
Specific surface area (m^2/m^3)	80 - 110	90 - 100 (217 max)
Void volume (%)	45 - 55	90 - 98
Size (mm)	37 - 50	Varies with type
Weight (kg/m^3)	1440	96

Details of the properties of the various plastic media and their relative effectiveness can be obtained from the literature (255, 262, 265, 266, 286).

The improved ventilation, increased microbial slime, longer residence times per pass and reduced media weight allow trickling filters with plastic media to be built to greater depths and operate at higher BOD loadings/unit volume.

The higher specific surface area of plastic media requires a higher minimum irrigation rate to maintain a satisfactory liquid film over the entire microbial surface. It is difficult to determine how this "minimum" value is attained but values quoted vary from $35 \text{ m}^3/\text{m}^2\text{-day}$ to more than $70 \text{ m}^3/\text{m}^2\text{-day}$ (262, 265). Plastic media is also significantly more expensive than stone.

Although filter media is generally thought to be a stable, chemically inert material capable of supporting its own weight and the weight of the slime and liquid on it, experiments have been done using brushwood, straw and other degradable compounds (273, 289). Brushwood, with a specific surface area of $35 \text{ m}^2/\text{m}^3$ and 91.5% voids, provided significant removals over the monitored period (289). The problems of compacting and blocking of the media, and its final disposal would limit its application in the longer term.

- (e) Filter Depth - Filter depth varies from 4m, for high rate stone media filters, to 12m for plastic media filters (119, 243). There is no agreement on optimum filter depth (265, 266) and it remains one of the major variables considered in the kinetics and optimization of trickling filter design. It affects a wide range of factors including; filter volume,

liquid contact time, heterotrophic/autotrophic microbial balance, pumping heads and structural design.

- (f) Sludge Removal - Sludge production ranges from 15-70% of the BOD removed (253, 255, 286, 287), with agricultural wastes yielding 50% sludge/unit BOD removed (273). Sludge production per unit BOD removed increases as BOD removal increases (266) and as the soluble BOD fraction decreases (265).

Hopper bottom settling tanks with up-flow rates of 2.4 m/h or overflow rates of 20-21 m³/m²-day are satisfactory, producing settled sludge containing 3-5% solids depending on settling time (292). Dewatering characteristics are good and the sludge has a specific resistance to filtration of approximately 10-20 x 10⁹ s²/g (262, 265).

Settling is improved with chemical precipitants (282, 290, 292). The performance of sedimentation tanks, based on BOD and suspended solids (SS) removal, may be estimated from empirical equations (284, 293).

2:5.4,3) Temperature Effects -

The influence of temperature is well documented. Velz (80) showed that the limiting load for maximum efficiency was temperature dependent and related to the reaction rate constant (K) by;

$$K_T = K_{20} \times 1.047^{(T-20)}$$

Schulze (249) reduced this temperature conversion constant to 1.035, but still considered that the expression over-exaggerated temperature responses.

The trickling filter does not follow the Van't Hoff rule ($Q_{10} = 2$) characteristic of many biological systems. A number of reasons have been given to explain this phenomena;

- (a) Increasing temperature increases the percentage of energy consumed for maintenance reducing microbial growth rates (251 - Hernandez's discussion).

- (b) Increasing temperature increases respiration rate and decreases oxygen solubility, creating an oxygen deficit. Measurements revealed a 0.32% increase in BOD removal per °C temperature rise (252).
- (c) Decreasing temperature produces a large decrease in macrofauna activity, resulting in a 1.5 to 2.0 fold increase in biological film thickness. The greater microbial mass has an increased maintenance requirement off-setting the temperature effects (284).
- (d) Increasing BOD and hydraulic load decreases temperature effects (243).

Other authors (269, 283, 285, 287) suggested that 7-10°C is a critical temperature for both macro and microfloral activity as the change in the structure of water alters enzyme activity and thus reduces oxidation.

Solbe et al. (284) compared the Arrhenius, Howland and Wuhrmann equations for temperature correction of the reaction rate constants. Of the three, it was felt that Howland's equation, although the simplest, gave the greatest scatter.

The decrease in sedimentation with temperature (284, 290) affects the total treatment of the trickling filter. Fortunately the decrease in humus production during low temperatures off-sets this limitation.

2:5.4,4) Kinetics and Optimization -

Trickling filter design has centered on BOD removal. The problems faced in developing comprehensive kinetic equations for plant optimization include:

- (a) The type of waste - The degree and rate of decomposition will affect the percentage BOD removals, thus influencing maximum permissible loadings to obtain desired effluent standards.
- (b) The stage of treatment - In general, the difficulty of removing BOD increases as the amount of BOD remaining decreases.

- (c) Temperature effects.
- (d) Media type and packing - these variables alter filter hydraulics for the same total flow.
- (e) Biological variations such as changes in microbial film composition, film thickness and reaction rates.

These variations have led to the development of kinetic equations from a number of standpoints, namely; empirical considerations (246, 253, 256, 293), first order reactions (80, 249, 252, 291, 293), linear regression analysis (251, 258, 275), mass transfer theory (259-261, 270, 272, 274, 280) and Monodian kinetics (267, 269, 276).

Although each worker compared his own equations with field data, and most attempted to correlate their findings with other researchers, some (257, 293) tried to evaluate the different equations under equivalent conditions.

Baker and Graves (257) compared designs on a "volume required" basis and suggested that the NRC (246) and Eckenfelder (252) equations were similar, but the Galler and Gotaas (251, 258) equations specified a slightly lower volume.

Brown et al. (293), comparing the NRC, Eckenfelder, and Galler and Gotaas equations made the following comments:

- (a) Varying BOD load showed the NRC to be the poorest.
- (b) Varying temperature left all the models with a wide scatter. None accounted for the lag between temperature change and effect on removal.
- (c) Flow was not a part of the NRC equation, but the other two showed a decrease in treatment with increased flow.
- (d) All three equations showed an increase in treatment with increasing recycle up to 5/1. The NRC equation showed the smallest effect with recycle.

In summary, Brown et al. (293) suggested that models give long term averages for plant treatment but do not adequately handle short term fluctuations.

2:5.4,5) Nutrient Removal -

Sorrels and Zeller (250) made the following observations on nitrogen:

- (a) Within limits, the amount of nitrogen lost increased as the amount of BOD removed increased.
- (b) The lost nitrogen was thought to be removed as N_2 gas (localised anaerobiosis), or as organic N in the settled sludge.
- (c) Nitrification decreased with increasing BOD and increased as nitrogen loss decreased.
- (d) Nitrification was more predominant in secondary filters.

Nitrification occurs in the lower portion of the filter where there is less competition for available oxygen (79, 254). Nitrate conversion of 70-90% N can occur at loadings of 0.2-0.4 kg BOD/m³-day (264, 285), flows of 15-30 m³/m²-day (283) and temperatures above 7°C (279, 283, 287). The kinetics of nitrification are given by Balakrishnan and Eckenfelder (264).

Subsequent denitrification, using 3.5 mg methanol/mg nitrate, achieved 95% nitrate removal with an overall N removal of 85%, leaving 1-3 ppm N in the effluent (279).

Jebens and Boyle (278), studying P removal, achieved levels of 15-45% total removed, which was in line with their reviewed literature. This was in excess of that estimated for microbial growth. Flow, dilution and recirculation had little effect on P removal.

2:5.4,6) Trickling Filters in Livestock Waste Treatment -

Despite widespread use in domestic and industrial waste treatment, the application of trickling filters to livestock waste treatment has been limited (81, 119, 247, 263, 281, 289, 296-298).

Correlation of published results is difficult due to the variation in effluent composition, filter media and operating conditions. Within these limitations, available data is summarized in Table 2:6. Effluent BOD seldom falls below 100-300 mg/l (81, 247, 281) with some authors (289) quoting values in excess of 3,000 mg/l.

Treatment was regarded as satisfactory as the total load on a receiving water would be small (296). The simplicity of operation

TABLE 2:6

SUMMARY DATA - LIVESTOCK WASTE TREATMENT USING A TRICKLING FILTER

Waste	Filter media	Hydraulic load m ³ /m ² -day	BOD load kg/m ³ -day	COD load kg/m ³ -day	BOD IN mg/l	COD IN mg/l	BOD REM. %	COD REM. %	Temp. °C	Remarks	Ref.
Cattle	Stone	0.07-0.13 (1)	0.03-0.18	0.02-0.12 (2)	200-770	120-490	90-74	82-32 (2)	-	Field plant	(247)
Cattle	Stone	0.05-0.26 (1)	0.02-0.10	0.01-0.04 (2)	170-300	98-117	94-91	69-57 (2)	-	Lab plant	
Dairy	Stone	18.71	0.11-0.32	-	1511	-	95-51	-	18.3-7.2	Significant temp. effect TS removal = 30-50%	(81)
Pig	Plastic or wood	57.06-57.89	-	0.1-1.5	-	14,900 (3)	-	93	-	TS removal = 99% after settling	(296)
Pig	Plastic	72.76-81.86	1.32-3.87	-	430-505	-	41-38	-	-	TS removal = 14-17%	(281)
Pig	Plastic	44.5	9.8	23.7	35,000 (3)	81,000 (3)	71	83	17.3-5.7	SS removal = 98% on settling No significant temp. effect	(297) (298)
Pig	Brushwood	-	1.00-1.67	-	281	-	85-89	-	-	Some brushwood compaction problems	(289)
Cattle	Brushwood	6.55	0.846	-	13,984	-	90-45	-	-		
Pig	Brushwood	20	1.66	-	12,000	-	85	-	-		
Dairy	Stone	19.2	0.2	0.7	670	2350	70	68	15.7	Two day residence	(82)

- Notes: (1) Assume 1.83m deep
(2) Permanganate values corrected for nitrite
(3) Diluted with recycle

and minimum maintenance costs have been reported (281, 297, 298).

2:5.5) Rotating Biological Discs

Rotating biological discs (RBD) consist of a series of closely spaced discs running on a single shaft. The unit is placed above a trough so that approximately one third of the disc bearing the biological media is submerged in the effluent as it slowly rotates. These discrete treatment units can be expanded in size or number to cope with a given loading (83-85).

Treatment principles are closely related to trickling filters, and RBD's are being used for domestic effluent treatment at loadings of approximately $0.02 \text{ kg BOD/m}^2\text{-day}$ (84, 85, 222-226). Their application in agriculture is limited (83, 227, 228, 315). Miner and Verley (228) are the only reported workers to have used dairy wastes in a combined rotary solids/liquid separator with a biological treatment system. Approximately 90% BOD and 60% TS removal was reported.

2:5.6) Oxidation Ditches

The use of a continuous oval channel, containing a rotor to pump and aerate the effluent, was initially developed by Basveer, using municipal wastes (207). It has since been applied to agricultural effluents (88, 119, 199, 318).

The units are suitable for below floor treatment and have been widely used in piggeries (72, 75, 199, 208) and to some extent with housed cattle (76, 77, 209, 319, 320). Their application to dairy waste treatment is limited (132).

2:5.6,1) Design of Oxidation Ditches -

Data for the design of oxidation ditches has been documented (38, 43, 60, 119). Loadings range from $0.15\text{-}2.50 \text{ kg BOD/m}^3\text{-day}$ with an average of $0.5 \text{ kg BOD/m}^3\text{-day}$. The oxygenation capacity of the rotor should be twice the input BOD and pumping rates should be sufficient to maintain a liquid velocity of $0.3\text{-}0.5 \text{ m/s}$. Rotor spacing should not be greater than 90m. Their performance is affected by operating conditions (60, 219, 220), but 37 kg oxygen/m or $0.86 \text{ kg oxygen/kW-h}$ may be expected.

MLVSS are maintained at 1-3% giving a low F/M ratio of 0.01:1 or less. This is at variance with municipal treatment plants which maintain a MLVSS of approximately 0.4%.

2:5.6,2) Operation of Oxidation Ditches -

Oxidation ditches may be operated as;

- (a) Aerobic storage vessels with intermittent discharge to the land
- (b) Treatment units with solids separation and recycle resulting in a dischargeable liquor
- (c) Closed processes with the liquid removed by evaporation and the solids extracted mechanically (221).

The major problem is the development of anaerobic conditions causing odours and foaming. Start up, shock loadings, rotor failure and settled solids may result in anaerobiosis.

The maintenance of rotor bearings and the monitoring of MLVSS are the only requirements for regular attendance.

Solids reduction of 34% after 143 days treatment, and a supernatant BOD of less than 200 mg/l, have been reported with beef cattle wastes (119).

2:5.7) Composting

Composting is a thermophilic aerobic process. The requirements for, and results of, the treatment in agricultural applications have been widely reported (43, 86-90, 199, 217, 229-233).

A C/N ratio of 30:1, a moisture content of 40-70%, and the addition of P and K at rates of 9 and 4 kg/tonne respectively, should produce stable compost in 20-30 days provided aerobic conditions and a 60-70°C temperature are maintained (86-88).

Aerobic conditions, moisture loss and temperature control can be obtained by mixing every 2-7 days (87) or by forced aeration at 0.06-0.20 m³/minute-tonne at S.T.P. (89). High rate mechanized composting, using forced air and mixing, in long ditches has produced satisfactory compost in 10-15 days (90, 229).

Loss in VS of approximately 50-60% (230) and volume reduction of up to 45% (37) can be expected. COD may be decreased by 30-50% (89, 230). Conservation of N is important in maintaining the fertilizer value of the compost. Wilson and Hummel (230) showed that these losses were increased under anaerobic conditions and in the absence of other nutrients such as P. Although N losses of 20-30% were measured (230), nitrate levels rose significantly up to about 1,000 ppm (89).

Liquid composting with slurries of 10-15% TS has been attempted (231, 232). It is generally regarded as a high energy system because temperature, oxygen and mixing requirements are power demanding. As such, it is not economic (231).

2:5.8) Odour Control

Borth et al. (242, 243) and Ifeadi et al. (244) have studied the odorous components of dairy manure. Odour is generally controlled with aeration, though chemical oxidation may be used (245).

2:6) PHYSICAL AND CHEMICAL TREATMENT

2:6.1) Solid/Liquid Separation

Solid/liquid separation in the early stages of treatment is advantageous in that it;

- (a) Reduces wear and blocking problems in hydraulic equipment
- (b) Effectively streams the waste allowing specialized handling of the separate fractions.

2:6.1,1) Sedimentation -

Although the principles of sedimentation are based on Stokes' and Newton's settling laws, variations in particle size, shape and interference result in settling characteristics being primarily influenced by solids concentration (217).

Settling curves for dairy waste at various TS levels have been presented (94, 95, 236, 237). After 10 minutes quiescent settling, with 1% TS slurry, 60-65% TS and COD removal can be expected with a maximum of 70-75% after 17 hours. Decreasing TS levels will reduce this performance.

2:6.1,2) Solid/Liquid Separators -

Three principles of mechanical separation have been tried extensively. These are screening (rotary, vibratory and brushed), centrifugation, and filtration. A significant volume of literature is available on these systems (96, 106, 128, 131, 149, 228, 238-241) and has been briefly summarized by the British Agricultural Research Council (190).

The solids produced by the separators ranged from 8-26% TS and were produced at approximately 1,200-110 kg/hour respectively. Solids levels greater than 10% were generally "stackable" though still had some drainage liquid.

2:6.2) Chemical Treatment

Chemical methods for sewage treatment have been used (321). Ludington (97), using agricultural wastes, outlined the possibilities of incineration and wet air oxidation. Neither of these systems are economically viable and have received little consideration.

2:7) WASTE RECYCLE

The reuse of effluent may improve the economics of the treatment system and reduce the total volume of waste discharged.

The application of compost or slurries to the land maintains the nutrient cycle, while the collection and use of methane may reduce the demand for other expensive forms of energy.

Hydraulic recycle of the treated supernatant has been investigated (66, 71, 125, 149). Small increases in BOD and TS have been measured but no changes in Coliform and Streptococci levels are reported. The treated effluent would be of sufficient quality to clean yards, while the accumulation of N, P and K during recycle would improve fertilizer value for final discharge to land.

Limited work has been done on recycling waste as a feed supplement (99-101). Most work is related to animals on high concentrate feeds. Manure, after washing, was fed at 40% of total feed. Live weight gains were slightly less than those on all concentrated feed and the carcass composition was slightly poorer. The waste-fed animals

showed an improved feed conversion efficiency with few health problems. Wastelage (effluent plus dried grass at a ratio of 57:43 and stored) reduced the infection problem but required some supplements, mainly vitamins.

This work was based only on fattening and live weight gain in cattle. Although the digestive process is similar, an investigation of waste recycle as a feed supplement to milking cows would be useful. The harvesting of microorganisms produced in treatment plants can provide a protein rich supplement for dairy cattle, but methionine deficiencies have been reported when the microorganisms constituted 20% of the ration (240).

Other studies (102) attempted chemical treatment of the waste to improve its utilization. In general, the addition of NaOH and Na_2O_2 gave approximately a 50% increase in digestibility of cell wall fractions. The disease risks of this and other forms of recycling must always be considered.

Utilization of the dairy waste fibre has been suggested as substitution for wood in the pulp and paper industry or as firewood for domestic heating (241). Consideration has been given to its use as an insulator. However, the accumulation of sufficient fibre to maintain an industry would be difficult.

CHAPTER 3

PROJECT DEVELOPMENT

3:1) INTRODUCTION

The selection criteria for a dairy shed effluent treatment system were:

- (a) The treatment plant should remove 80-90% of the applied load.
- (b) The treatment plant must be within the economic framework of the dairy unit.
- (c) The operational skills must not be beyond the ability of farm staff.

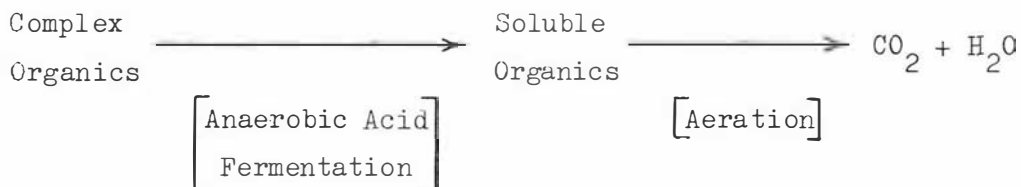
The high fibre content of effluent from pasture fed dairy cattle suggested that anaerobic treatment would be advantageous for partial decomposition of the waste. However, the faster reaction rates of the aerobic microflora favoured the inclusion of an aerated system. Alternative physical and chemical treatment systems considered failed to meet the selection criteria from an economic and operational standpoint.

It was therefore decided to investigate a combined anaerobic/aerobic biological treatment system.

3:2) BIOLOGICAL TREATMENT

Wide variations in anaerobic lagoon loading rates, showing no corresponding trends in treatment efficiency (Chapter 2:5), suggested that investigations into high lagoon loading rates may be beneficial. Pohland and Ghosh (160) discussed the advantages of dividing the anaerobic process into acid fermentation and methane generation. They suggested that this procedure would enable optimization of each process, resulting in higher loading rates and improved treatment efficiencies.

The economics of methane production, based on 1972 data, excluded it as a suitable system. However, the use of the acid fermentation phase to convert the complex organics to simpler soluble compounds was desirable. If coupled to an aerobic treatment plant allowing the rapid oxidation of the soluble organics, the total process reaction would be:



This coupling of anaerobic acid fermentation and aeration has been reported since the commencement of this project (314).

Temperature control and mixing were not considered due to their effect on the plant's economic and operational viability. Although this lack of environmental control would reduce the digester's efficiency, the lack of mixing would allow solid sedimentation, increasing its residence time above the mean hydraulic residence time. This should improve solids decomposition.

Aerobic reactions with soluble substrates were expected to be rapid. Aeration in oxidation ponds was not considered as the large areas required had a high opportunity cost. Costs also excluded the use of oxidation ditches and activated sludge plants, leaving trickling filters or cascade aerators as feasible alternatives. Ease of solids control favoured the cascade aerator, however, consideration of the surface area to volume ratio out-weighed this advantage and it was decided to use a trickling filter which should comply with the selection criteria.

3:3) IMPLEMENTATION OF CONCEPTS

The lack of work in livestock waste treatment systems in N.Z. required initial investigations into the suitability of mechanical equipment, e.g., pumps, valves and flow control, and the operational problems of dairy shed waste treatment. In order to carry out these investigations and develop a practical anaerobic/aerobic treatment plant, the method of approach was to:

- (a) Fabricate small scale plants for short term experiments to determine the feasibility of the system and the suitability of equipment.
- (b) Design laboratory plants which would allow longer term studies on treatment effects.
- (c) Construct a field plant, with similar loading rates, to investigate scale effects and estimate operational problems

of a full size plant.

The development and conclusions of these stages are outlined in the following chapters.

CHAPTER 4

PLANT DEVELOPMENT - INITIAL STUDIES

4:1) SELECTION OF EFFLUENT SOURCE

The Number One Dairy Production Unit at Massey University was selected as it is a town supply farm and provides a continuous source of effluent. The unit is typical of those seen in the industry, except for the use of greater volumes of washing water at the cow shed.

The farm consists of 93 ha of predominantly rye/clover pasture, with some cropping for supplement feeding. It supports a 200-cow Friesian herd plus replacements. The peak milking number of approximately 150 cows occurs from November to January. The animals are pasture grazed, with pasture and maize silage supplement as required.

4:2) SINGLE TANK TREATMENT

4:2.1) Introduction

To achieve minimum cost and simple operation, it was decided to use a single deep storage tank with a trickling filter mounted above it (Figure App. III:1). The proposal was to allow the bottom of the tank to become anaerobic while the top would be aerated by recycling over the filter. It was visualized that this would remove odours from anaerobic decomposition and provide a final discharge with 1-2 mg/l DO.

Raw waste would be loaded to the bottom of the tank, allowing anaerobic treatment and solids settlement. Successive loadings would displace the liquor upwards allowing its aeration prior to final discharge through the overflow.

4:2.2) Initial Pilot Plant

4:2.2.1) Design and Construction -

A trickling filter and holding tank were used to investigate the suitability of this proposal. The unit consisted of a 195 litre drum with a 2.4 x 0.3m diameter trickling filter, containing 60mm stone media, mounted above it (Plates 4:1 and 4:2, Appendix II, 311).

The daily raw effluent input provided a loading rate of 1.41 kg COD/m³-day and an 8 day mean hydraulic residence time. The influent pump



PLATE 4:1 Single 195 litre tank and trickling filter unit.

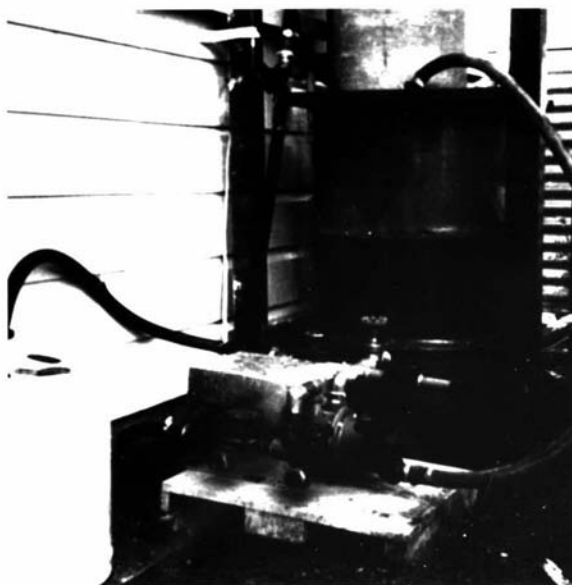


PLATE 4:2 Loading and recycle pump for the single tank unit.

was used to recycle the effluent over the trickling filter, providing a hydraulic loading of $8.55 \text{ m}^3/\text{m}^2\text{-day}$. This loading could only be maintained at a 26/1 recycle rate due to the low loading volumes.

4:2.2,2) Plant Operation -

Pumps that could accommodate solids while maintaining low, accurate flows are difficult to obtain. A series of centrifugal and positive displacement pumps were tested. Small pumps tended to block, while the throttling of larger pumps, with gate and diaphragm valves, also caused solids to accumulate, thereby reducing flow rates. The only suitable pumps were helical rotor (Mono) and rubber impeller (Jabsco) units. Variable speed drive for flow control was obtained with a 0.18 kW DC motor, controlled to give motor speeds of 100 to 1,500 rpm. The controller had feed-back circuitry to compensate for variations in motor load.

Operational problems included air entrapment during loading and the accumulation of solids in the holding tank. The presence of a floating fibrous mat made it difficult to maintain stable flow rates to the filter (Appendix II). Of greatest concern was the lack of a definite microbial film on the filter media. The absence of this film was thought to be the result of a large population of grazing organisms.

An average of 68.7% COD removal was achieved over the 2 months of operation (Appendix II). This was below the selection criteria (Chapter 3).

4:2.3) A Glass Column Filter

A laboratory treatment plant was constructed (Appendix II) to determine whether dairy shed waste could support an active biological film in the trickling filter if the grazing populations were controlled. The recycle rate over the filter (26/1) was satisfactorily maintained by a Hughes variable-stroke piston pump.

The plant was only operated for 4 weeks, as a build up of film on the filter was recorded after one week's operation.

4:2.4) Conclusions from the Single Tank Treatment Plants

The following conclusions were drawn from the single tank studies:

- (a) Dairy shed effluent is amenable to biological treatment and no microbial seeding is required to initiate the process.
- (b) Positive displacement pumps, with flooded suctions and variable speed drives, are the most suitable for loading and flow control.
- (c) Solids accumulation is the major operating problem and the floating fibrous mat made the implementation of the single tank system impractical.
- (d) The treatment efficiency was not satisfactory.

4:3) TWIN TANK TREATMENT

4:3.1) Introduction

The solids accumulation problem experienced in the earlier plants was best solved by separating the anaerobic and aerobic phases. This procedure had the additional advantages of minimizing loading fluctuations to the aerobic phase, as a result of the buffering capacity of the anaerobic tank, and allowing independent analysis of both the anaerobic and aerobic systems.

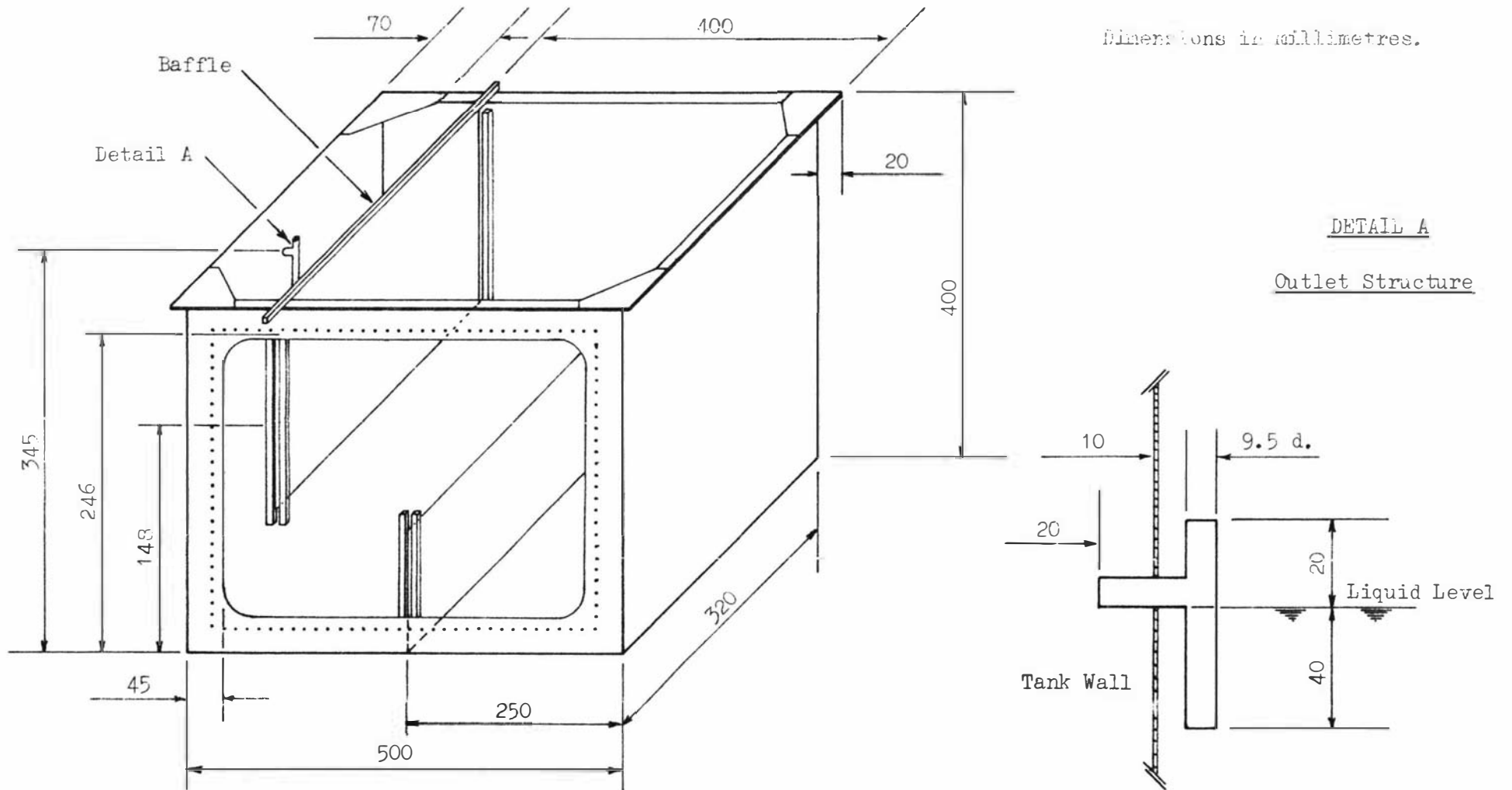
4:3.2) Design and Construction

The reported 3 day residence times for acid fermentation (160) were considered to be optimistic. However, anaerobic residence times of 3, 5 and 7 days were selected to determine their effect on treatment. In an effort to minimize plant size, longer residence times were not considered. Assuming twice daily loadings of 4 litre, the anaerobic tank dimensions were 0.05 x 0.32 x 0.40m (l x b x h, Figure 4:1). The tank was constructed from galvanised sheet metal with a perspex front to allow visual inspection of the accumulating solids. Discharge tappings had a 'T' structure (Figure 4:1) and were placed to give the required volumes in the tank. The 'T' structure reduced the amount of floating solids being discharged from the anaerobic tank, i.e., the take off point was 0.04m below the surface, while breaking the syphon to maintain the desired liquid level.

Aerobic residence times of 1, 2 and 3 days were selected. The selection was based on economic and effluent treatment considerations

FIGURE 4:1

ANAEROBIC TANK STRUCTURE



in association with reported data (64, 65, 68, 69). Tank construction was similar to the anaerobic tank with dimensions of 0.35 x 0.25 x 0.30m (l x b x h). The 'T' outlet structures were modified so that the take off point was only 0.02m below the liquid surface (Figure 4:1).

A 1.8 x 0.14m diameter perspex tube was used to house the trickling filter. The unit was on a 32mm angle iron frame above the aerobic tank (Figure App. II:3 and Plate 4:3). A medium of 19mm stones was selected for economic reasons. It was also readily available. The filter was covered with aluminium foil to prevent algal growth. A Hughes variable-stroke piston pump maintained the recycle flow over the filter.

An adjustable collecting tray was mounted on the aerobic tank directly below the trickling filter (Figure 4:2). This simplified the measurement of the recycle flow rate and the sampling of effluent coming off the filter.

4:3.3) Operation of the Twin Tank Plant

The plant was operated from May to September 1974, with a 5 day anaerobic tank residence time and a 2 day aeration period. Loading rates were 1.23 kg COD/m³-day to the anaerobic tank and 0.68 kg COD/m³-day to the trickling filter, with a recycle flow of 19.2 m³/m²-day (37/1 recycle rate). Other loading variables are presented in Appendix II.

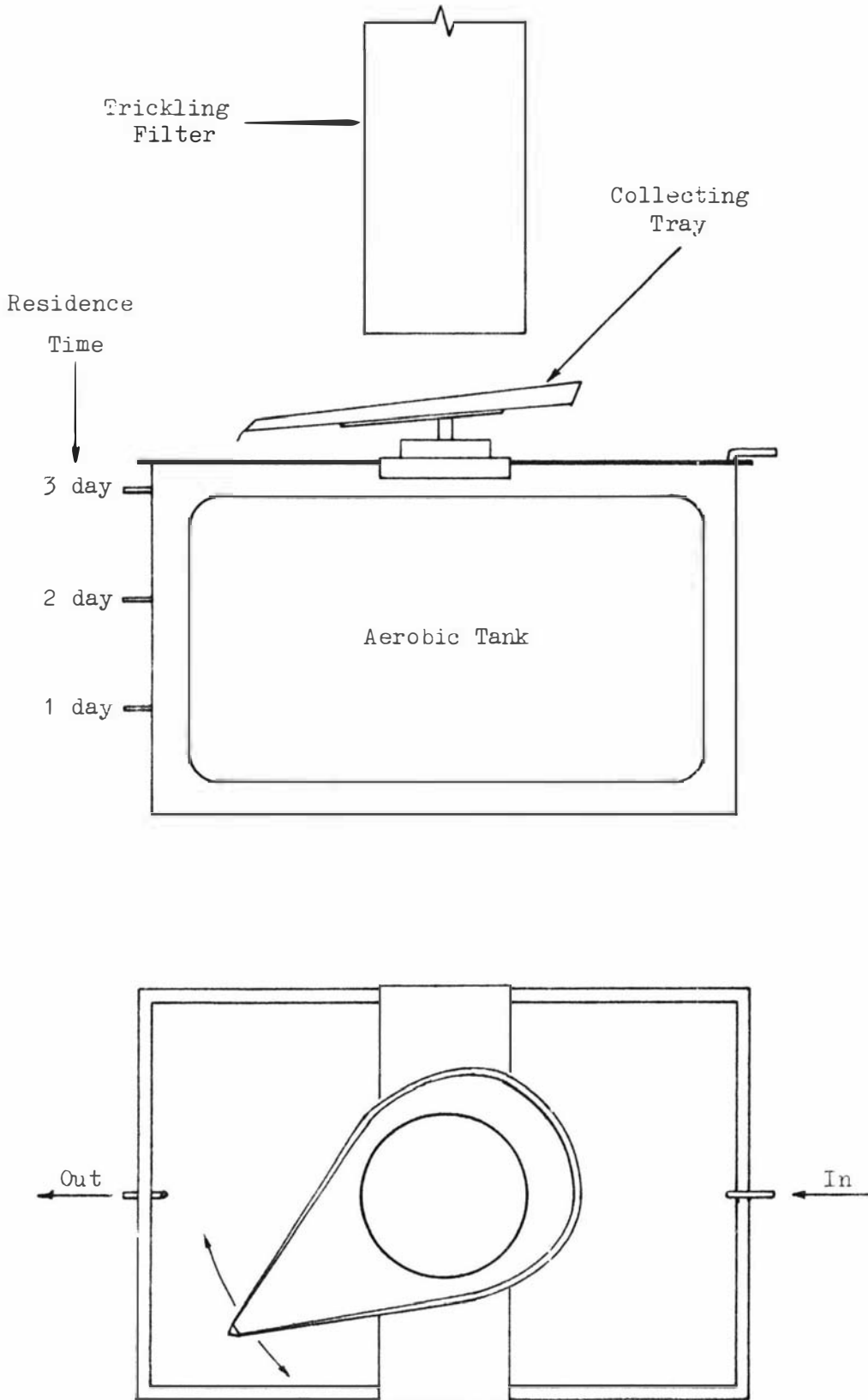
The effluent was gravity fed from the anaerobic to the aerobic tank with little difficulty. The 6.5mm tubing used for connecting the two tanks, and for the trickling filter recycle line, blocked twice as a result of solids accumulation and microbial growth. This was not considered to be a significant problem.

It was difficult to determine when equilibrium had been achieved. Solids dispersal and gassing was not evident in the anaerobic tank until 8 weeks had elapsed. After this time the gassing continued at a slow rate. A biological film was evident on the trickling filter medium after 5 days of operation. Visual observation suggested that the film thickness stabilized after approximately 3 weeks. This is



PLATE 4:3 Twin tank anaerobic/aerobic treatment with the perspex trickling filter mounted above the aerobic tank.

FIGURE 4:2

SCHEMATIC DIAGRAM OF TRICKLING FILTER COLLECTING TRAY

in agreement with reported values (81).

The microbial activity formed long filamentous strands from the bottom of the filter. Their appearance after 7 weeks of growth is shown in Plates 4:4 and 4:5. The potential for filter blockages from this growth was of some concern. However, the slime was removed 2 months after start-up and did not reappear. No filter blockages were experienced over the experimental period.

Maggots from the bot fly appeared in the anaerobic tank after 7 weeks of loading. Their presence was short lived as the development of a fibrous crust over the surface of the tank prevented their emergence for pupation. A small population of flies (*Psychoda* and *Sylvicola* (312)) developed at the same time. These lived in the trickling filter and in the anaerobic surface crust. They caused no problems in the laboratory.

Odour from the treatment plant was negligible except when cleaning out the anaerobic solids. Results from the solids cleaning and plant monitoring are presented in Appendix II.

Overall treatment efficiencies for this twin tank system averaged 87% COD removal and 92% TS removal. The accumulated solids were cleaned from the anaerobic tank on two occasions and calculations showed that approximately 50% of the input solids (TS) accumulated (Appendix II).

4:3.4) Conclusions from Twin Tank Treatment System

The following conclusions were drawn from the twin tank studies:

- (a) Separate tanks for anaerobic and aerobic treatment greatly simplified plant operation. Little maintenance was required.
- (b) Treatment efficiencies were within the required guidelines (Chapter 3).
- (c) Solids loading and accumulation rate could be the primary criteria in sizing anaerobic holding ponds.
- (d) With the 5 day anaerobic residence time a 40 day anaerobic solids cleaning frequency was calculated (Appendix II). This was considered to be the maximum acceptable frequency. Thus the 3 day anaerobic residence time was not feasible.



PLATE 4:4 Filamentous growth from the bottom of the trickling filter.

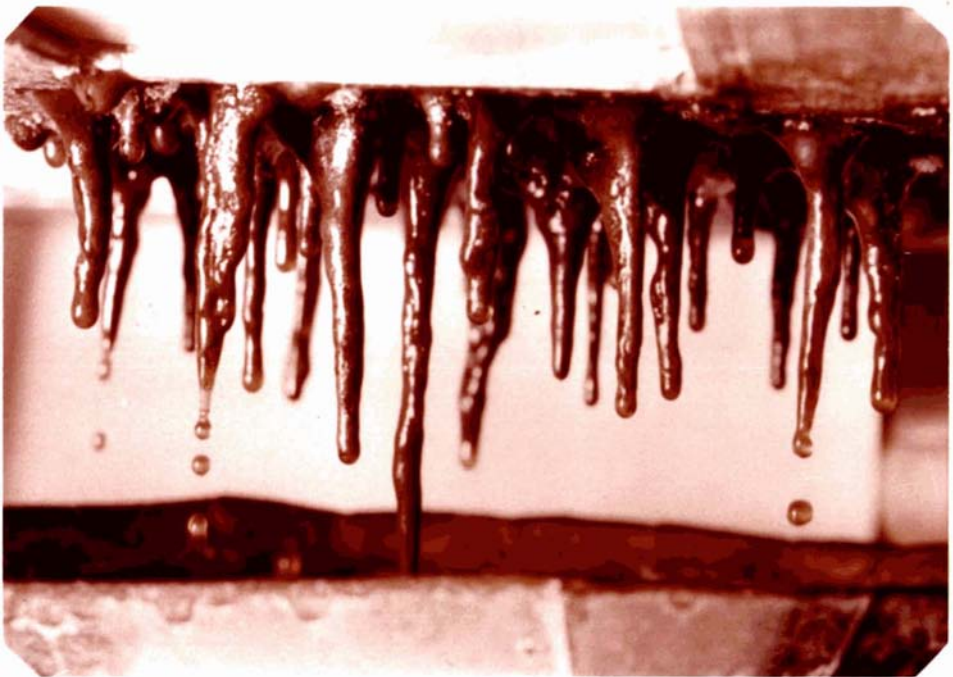


PLATE 4:5 Close-up of the filamentous growth.

- (e) Results from the 2 day aerobic residence time suggested that there would be no difficulties with the 1 and 3 day aeration periods.
- (f) It was decided to terminate this experiment and construct laboratory and field scale treatment plants, with increased anaerobic residence times, to allow a complete analysis of the treatment system.

CHAPTER 5

PLANT DEVELOPMENT - FINAL DESIGN

5:1) LABORATORY PLANT CONSTRUCTION

The selected anaerobic residence times were 5, 7.5 and 10 days. The lower value was controlled by the solid accumulation rate while the upper limit was set to keep the plant size to a minimum. Tank construction was the same as outlined in Chapter 4:3, except that the dimensions were increased to 0.5 x 0.32 x 0.56m (l x b x h).

The design of the aerobic stage was unaltered. The aerobic residence times were 1, 2 and 3 days, with recycle ratios over the trickling filter of 5/1, 20/1 and 35/1. The high recycle ratios were required to maintain an adequate flow over the filter, as the daily loading was only 8 litre. They corresponded to hydraulic loadings of approximately 2.5, 10 and 18 m³/m²-day.

Two identical laboratory plants were constructed to satisfy the requirements of the experimental design (Chapter 7). The final layout is shown in Plate 5:1.

5:2) FIELD PLANT CONSTRUCTION

The maximum anaerobic tank capacity was governed by the availability of a 4,500 litre tank. This set the daily loading volume to 450 litre/day, approximately 56 times that of the laboratory plants. All other design criteria were scaled to maintain similar operating conditions. Siting and design details of the field plant are presented in Appendix III and Plates 5:2 - 5:6. All concrete structures were part of the shed yard and sewerage system and placed restraints on some of the design variables.

The loading pump was a "Mono CP 25". It was used to transfer the raw effluent sample from the collection tank to the input metering tank and from the input metering tank to the anaerobic tank (Figure App. III:3). Each phase was controlled by Omron probe switches. Collection of the raw effluent required two controllers in series. The first Omron controlled pumping from the collection tank to the input metering tank. The second Omron over-rode the first once the required volume was obtained. The collection tank was emptied approximately 2.5 times before this volume was obtained. Conversion of the circuitry for loading the anaerobic tank was done manually.



PLATE 5:1 General arrangement of laboratory plant.

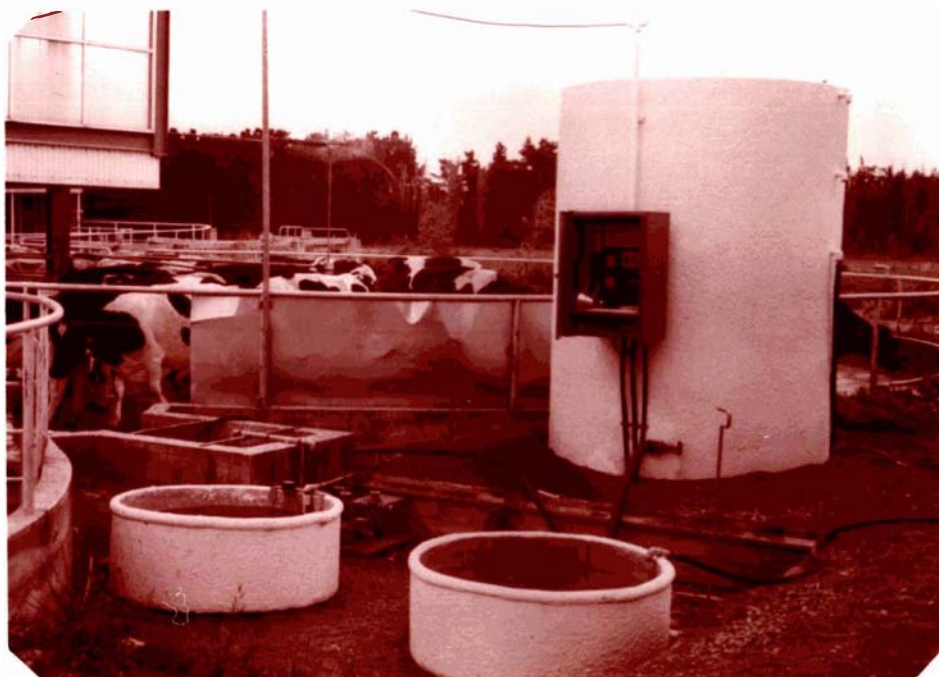


PLATE 5:2 Anaerobic tank, control box and metering tanks of field plant.



PLATE 5:3 Anaerobic tank and trickling filter arrangement for field plant.

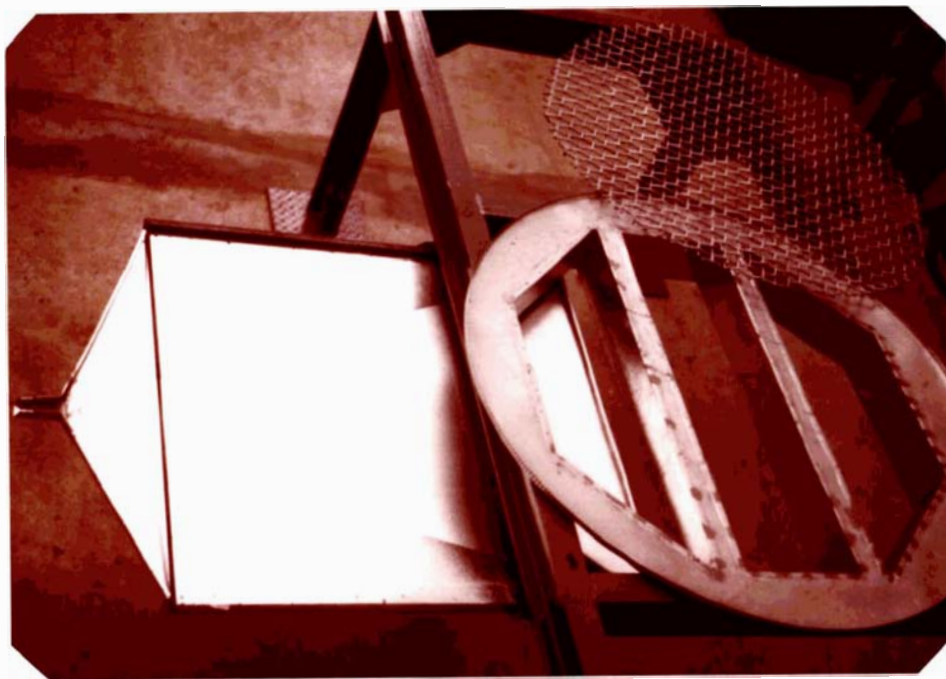


PLATE 5:4 Trickling filter support structure for the field plant.



PLATE 5:5 Rotary tipping bucket distributor on top of the field plant trickling filter.



PLATE 5:6 Field plant trickling filter, aerobic tank,
recycle pump housing and motor control.

Two pumps were used for the trickling filter recycle flow during the experiment. Initially, two "9.5mm Jabsco" pumps were mounted in parallel. Due to unsatisfactory performance (Chapter 9) these were changed to a double ended 140mm diaphragm pump geared through a 50:1 reduction box to achieve the desired flows. The frictional headloss of the single 12mm I.D. supply line to the top of the filter was too great once a microbial film had developed on the internal walls. A second identical line was placed in parallel to eliminate this problem.

The flow was distributed over the top of the filter by a rotating tipping bucket. Design details are presented in Appendix IV.

CHAPTER 6

EXPERIMENTAL METHODS

6.1) SAMPLE COLLECTION

6.1.1) Raw Waste

The collection of a representative sample of effluent from the dairy shed proved difficult. The use of large volumes of water throughout the milking routine, and changes in labour, compounded the natural variations in effluent quality (Appendix I).

6.1.1.1) Manual Collection -

Initially, samples were collected manually at the shed during the evening cleaning cycle. Although this allowed some visual inspection of the collected effluent, it was unsatisfactory for the following reasons:

- (a) The procedure was time consuming.
- (b) It resulted in selective rather than proportional sampling.
- (c) Samples were sometimes missed due to variation in milking time.
- (d) Once daily collection was atypical of normal operating conditions.

This procedure was terminated after 2 months.

6.1.1.2) Automatic Collection -

A simple automatic sampler was developed to collect and store a proportion of the effluent from the yards, initially, to maintain lab plants and finally, to provide sufficient effluent for both lab and field plants. Proportional sampling was difficult to arrange since a fixed volume was required each day in spite of alterations in yard flow. This was particularly true if hoses were not turned off between milkings. Furthermore, the maximum sample size was only 470 litre/day which was approximately 4% of the yard flow.

The design, construction and installation of the sampler is given in Figure App. II:4, Figure App. III:3 and Plates 6:1 and 6:2.

Dilute dairy shed effluent, washed from the yard, passed through a 25mm galvanised mesh basket to remove extraneous matter, e.g., pieces of plastic or pipe, soap, afterbirth and stones. The passed slurry fell onto the sampler. Collector channel sizes were designed to transport the material which was passed by the basket. Channel



PLATE 6:1 Effluent collector showing the collecting channels (below basket) and the collecting tank. The cable on the outlet pipe is for pump probe control.

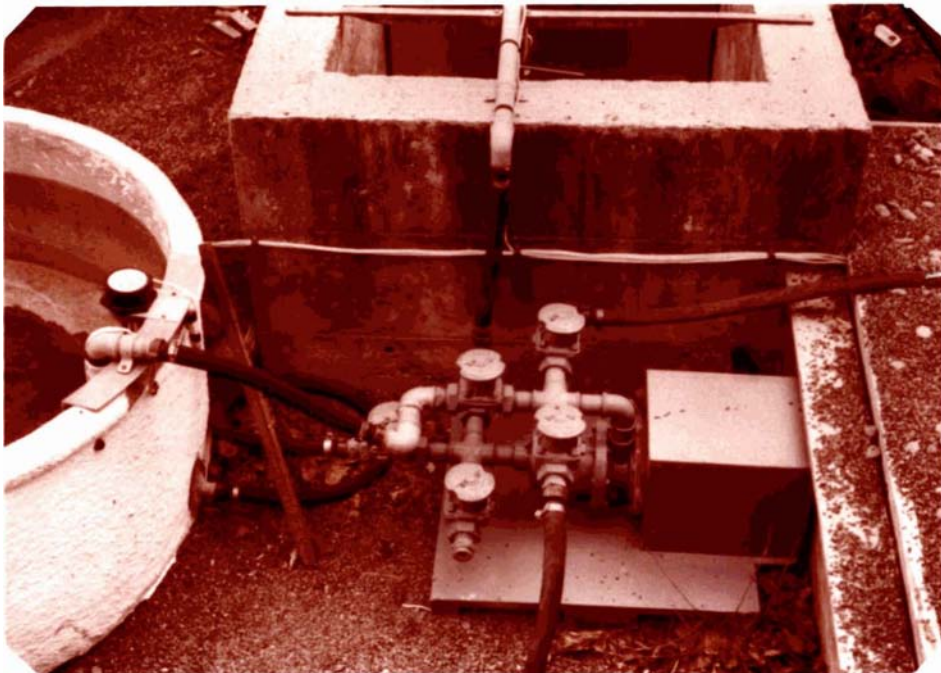


PLATE 6:2 Mono CP 25 loading pump transferring effluent from the collecting tank to the input metering tank (left).

covers allowed adjustment of collector area to achieve the desired sample volume. The remainder of the slurry was discharged into the sewer. The sample obtained was stored, either in an adjacent 100 litre collection tank if only the lab plants were being operated, or pumped to a second 360 litre input metering tank if the field plant was also operating (Figures App. II:4 and App. III:3).

The collection of storm water between milkings was avoided by having an adjustable gap between the end of the collecting channel discharge pipe and the collecting tank. The flow rate of storm water collected in the channels was not sufficient to bridge the gap and be collected (Figure App. III:3).

The operation of the collector and associated equipment was not ideal, but given the nature of the effluent and the difficult operating conditions, their performance was satisfactory. Blocked channels were recorded on 6 occasions and inadequate collector area, resulting in a reduced sample size, was recorded on 10 occasions. Pump failures accounted for 16 lost or incomplete samples, and operator error, e.g., failure to insert the sample tank plug, accounted for a further 4 lost samples. This was over a period of 60 weeks and a total of 810 samples.

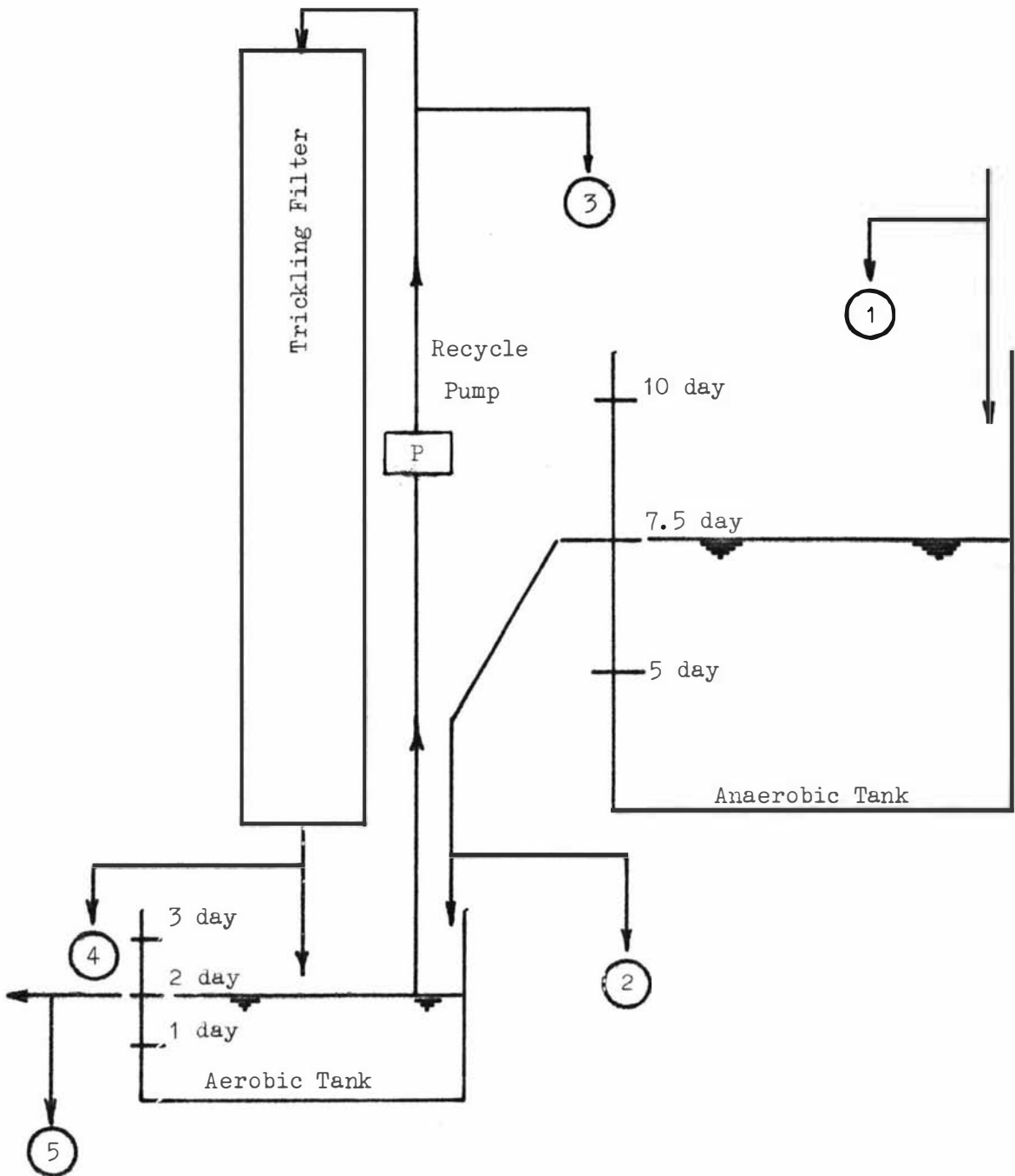
The accumulated sample was mixed and then sub-sampled to obtain 16 litre of raw effluent to load the lab plants and 0.5 litre for analysis. Any short fall in sample size only affected the loading to the field plant, except for 12 occasions when no sample was obtained. All collection equipment was cleaned after loading.

6:1.2) Treated Effluent

Samples were collected throughout the treatment plants at the locations shown in Figure 6:1. At each point 300-500 ml were required for a complete analysis. Larger sample sizes may have improved accuracy and repeatability, however, the scale of the lab plants did not allow this as the samples constituted 15% of the daily input. All samples were collected manually. Collection of a representative treated effluent sample was simpler than for the raw waste because the anaerobic tanks buffered the raw waste fluctuations.

FIGURE 6:1

SAMPLING POSITIONS



- Position 1 = Raw Waste e.g. COD IN
 Position 2 = Anaerobic Outlet e.g. COD AN
 Position 3 = Top of Trickling Filter e.g. COD TTF
 Position 4 = Bottom of Trickling Filter e.g. COD BTF
 Position 5 = Final Discharge e.g. COD OUT

Samples from the top and bottom of the trickling filter were collected prior to loading. The anaerobic and aerobic outfalls were sampled after loading.

6:2) SAMPLE ANALYSIS

6:2.1) Timing of Analyses

Although raw effluent samples were collected twice daily to load the lab plants, analysis was shared between the morning and evening milkings to synchronize with the availability of resources. All samples were analysed immediately after collection.

In the morning a sample of the raw waste and the final discharge of the lab and field plants, a total of 4 samples/day, were collected and analysed for N and P. Resources limited N and P analysis to the input and output for each unit.

In the evening samples throughout each plant were collected (4/plant), as well as duplicate raw waste samples, giving 14 samples/day for analysis during the monitoring periods. Duplicate raw waste samples were taken to reduce errors from sample variation.

6:2.2) Analytical Parameters and Methods

6:2.2,1) Total Sample Analysis -

The complete sample of 300-500 mls was analysed for the following variables:

- (a) pH - A "Radiometer 28" was used with glass and calomel electrodes.
- (b) Redox Potential (E_h) - Platinum and calomel electrodes were used in the same meter.
- (c) Dissolved Oxygen (DO) - A "YSI R54" DO meter was used and calibrated against air as outlined in the operator's manual. Comparison of DO's obtained using this procedure were within 0.1% of the values obtained using the azide modification of Winkler (303).
- (d) Temperature - Temperatures were measured with the YSI DO meter.

6:2.2,2) Sub-Sample Analysis -

Sub-samples were taken from the 300-500 ml and used in the following analyses.

- (a) Chemical Oxygen Demand (COD) - A 20 ml sample was used for each COD. Raw waste sample volumes were measured with a 25ml graduated cylinder. The lower solids concentrations of other samples allowed the use of 20ml bulb pipettes. The pipettes had the tips cut and reground to allow the inclusion of suspended solids in the sample. All samples were thoroughly mixed prior to taking the aliquot. These 20ml aliquots were diluted with distilled water to a final volume of 60-500 ml, depending on their strength.

The procedure carried out on 20ml of this diluted sample is outlined in Standard Methods (200). All chemicals were "Anal R" except sulphuric acid which was commercial grade. The concentration of ferrous ammonium sulphate was increased to 0.25N to allow the use of a 10ml auto-zero burette graduated to 0.05 ml. The two-hour reflux period was controlled by time clocks.

- (b) Biochemical Oxygen Demand (BOD) - Hach manometric BOD meters were held at 20°C and read each day for five days. Sample dilutions for the analysis ranged from zero to 10 fold. This method of BOD determination is quicker and as accurate as the traditional methods (115, 305).

The time required for BOD analysis resulted in one fifth as many BOD analyses as COD. These were sufficient to establish a relationship between the BOD and COD of the samples.

- (c) Solids - Both total solids (TS) and volatile solids (VS) were measured using standard procedures (200). Disposable aluminium foil containers were used to take 90ml samples. The dishes were passed through a muffle furnace prior to initial weighing and were subsequently handled with tweezers.

Lack of equipment prevented VS analysis until one third of the main trials were completed.

- (d) Nitrogen - Total and dissolved nitrogen analyses were carried out. The dissolved fractions were centrifuged at 18,000 - 27,000g max. in a Sorvall and passed through a 0.45μ millipore filter. Analyses of total and dissolved fractions were performed in duplicate by the Soil Science Department (Massey University) according to standard procedures (307-309). The analysis consisted of the following measurements:

Total Kjeldahl Nitrogen (TKN)
 Dissolved Kjeldahl Nitrogen (DKN)
 Nitrate Nitrogen ($\text{NO}_3\text{-N}$)
 Ammoniacal Nitrogen ($\text{NH}_4\text{-N}$)

These parameters allowed the estimation of;

Total Dissolved Nitrogen (TDN)

$$\text{TDN} = \text{DKN} + \text{NO}_3\text{-N}$$

Total Particulate Nitrogen (TPN)

$$\text{TPN} = \text{TKN} - \text{DKN}$$

Total Nitrogen (TN)

$$\text{TN} = \text{TKN} + \text{NO}_3\text{-N}$$

- (e) Phosphorus - Sample preparation was as for nitrogen determination and analyses were performed in duplicate by the Soil Science Department (Massey University) using established methods (306). Values measured were:

Total Phosphate (TP)
 Total Dissolved Phosphate (TDP)
 Dissolved Inorganic Phosphate (DIP)

These parameters allowed the estimation of;

Dissolved Organic Phosphate (DOP)

$$\text{DOP} = \text{TDP} - \text{DIP}$$

Total Particulate Phosphate (TPP)

$$\text{TPP} = \text{TP} - \text{TDP}$$

6:3) OTHER RECORDS

The trickling filter flow was measured at the bottom of the filter

using a bucket (or measuring cylinder) and stop watch. Adjustments were made as required to maintain the desired flow setting.

A systematic diary was kept for each of the treatment units. Records were made of visible changes in feed composition, missed samples, pump breakdowns and other relevant details.

CHAPTER 7

EXPERIMENTAL DESIGN

7:1) INITIAL STUDIES

There was no experimental design or statistical analysis of results for the investigatory experiments.

The data was used to obtain treatment trends and operating procedures for the design of the main treatment plant studies.

7:2) MAIN TRIALS

The three operational variables considered were:

- (a) Anaerobic residence time (A)
- (b) Aerobic residence time (B)
- (c) Trickling filter recycle rate (C)

7:2.1) Operational Procedure

Initial studies (Chapter 4) revealed that 3 weeks operation would ensure equilibrium conditions in the aerobic section after the alteration of a variable. Slower adaptation in the anaerobic tank suggested that 5-8 weeks would be required for equilibrium conditions to be established (Chapter 4, 39, 40). This was considered to be too long to wait between treatment runs.

To cater for this problem it was decided to use a nested factorial design. The anaerobic residence times formed the main blocks with the aerobic residence time and recycle rate confounded within each block (Table 7:1). This design allowed the anaerobic residence times to be held constant over longer periods without affecting the time required for each treatment. Unfortunately, anaerobic treatment and block effects could not be statistically separated. This design limitation was accepted as alternative procedures placed unacceptable demands on resources.

Allowing 3 weeks for aerobic acclimatization and 1 week for monitoring, a total of 4 weeks were required per setting. The procedure is shown in Figure 7:1.

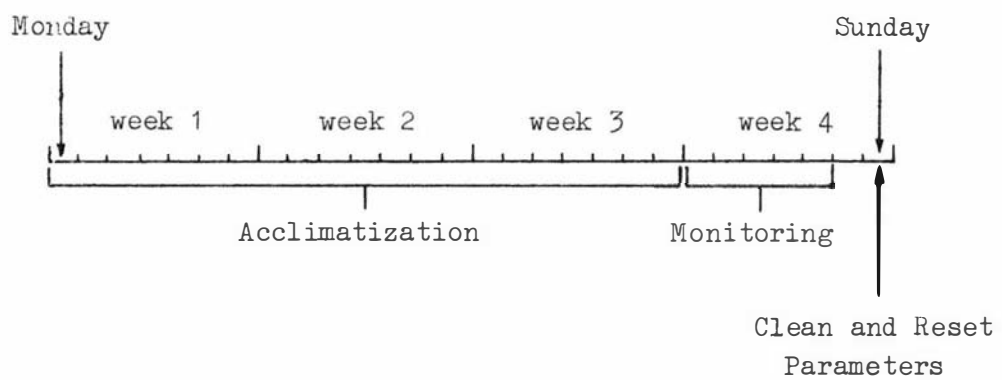
Three settings of each of the variables was considered to be a minimum. Thus the 3 x 3 x 3 factorial design gave a total operating period of 108 weeks. This was unacceptably long, considering the twice daily loadings. Furthermore, it was desired to obtain some

TABLE 7:1

EXPERIMENTAL DESIGN

	BLOCKS					
	I			II	III	
Anaerobic Holding Time (A)	AI			AII	AIII	
Aerobic Holding Time (B)	BI	BII	BIII			
	CI	B_1C_1	B_2C_1	B_3C_1	as	as
Recycle Rate (C)	CII	B_1C_2	B_2C_2	B_3C_2	for	for
	CIII	B_1C_3	B_2C_3	B_3C_3	I	I

FIGURE 7:1

EXPERIMENTAL PROCEDURE PER SETTING

information on the variation in performance of identical treatment plants and scale effects on plant operation.

To meet these requirements a total of three treatment plants were built. Two laboratory plants were identical (Chapter 5). The 9 variables within each block were randomly divided between each laboratory plant. Allowing for one replicate, this gave 5 settings per block per laboratory treatment plant, reducing the total experiment time to 60 weeks.

The two laboratory plants no longer allowed the field plant to measure all parameters. It was therefore necessary to select treatments for the field plant such that all parameters would be confounded. The procedure was based on Snedecor and Cochran (310) and is shown in Table 7:2.

The final allocation of treatment variables to the experimental plants and their order of analysis are presented in Table 7:3.

7:2.2) Data Analysis

Each phase of the treatment was analysed separately. The multiple regression analysis enabled equations to be developed for both the anaerobic and aerobic phases, indicating their respective contributions to the overall treatment. The regression equations were then transferred into contour plots to give a visual appreciation of treatment effects.

Having established the response surfaces for the various treatment variables in each phase, an estimate of the combined treatment efficiencies may be made. These results could then be compared with field plant data to determine scale effects and model suitability.

TABLE 7:2CONFOUNDING OF FIELD PLANT TREATMENTS

Recycle Rate	Aerobic Holding Time		
	I	II	III
I	11	12	13
II	21	22	23
III	31	32	33

Confounding for three blocks:

Block X	Block Y	Block Z
11	12	13
22	23	21
33	31	32

Blocks X, Y and Z were randomly allocated to the experimental Blocks I, II and III.

TABLE 7:3

FINAL TREATMENT ALLOCATION TO EXPERIMENTAL PLANTS
AND TIMETABLE OF ANALYSIS

DATE ⁽¹⁾	ANAEROBIC BLOCKS		AEROBIC TREATMENTS		
	Block Number	Residence Time	Lab. Plant (A)	Lab. Plant (B)	Field Plant (F)
10/1/75			Start-up	Start-up	Start-up
10/2/75	I	5	3/20:1 ⁽²⁾	3/20:1	3/20:1
10/3/75			1/35:1	1/20:1	1/20:1
7/4/75			2/5:1	1/5:1	-
5/5/75			2/35:1	2/20:1	2/35:1
2/6/75			3/5:1	3/35:1	3/5:1
30/6/75	II	7.5	2/5:1	2/5:1	2/5:1
28/7/75			3/20:1	2/35:1	3/20:1
25/8/75			1/35:1	3/35:1	1/35:1
22/9/75			1/5:1	2/20:1	-
20/10/75			3/5:1	2/20:1	-
17/11/75	III	10	1/35:1	1/35:1	-
15/12/75			3/35:1	1/20:1	3/35:1
12/1/76			2/20:1	3/20:1	2/20:1
9/2/76			3/5:1	2/5:1	-
8/3/76			1/5:1	2/35:1	1/5:1

NOTE: (1) The dates given are those for the start of each setting.

(2) Aerobic residence time/recycle rate.

CHAPTER 8

RESULTS AND DISCUSSION

8:1) COLLECTED DATA

A sample of all data collected during one 4 week period is presented in Table App. V:1. This was repeated for all 15 treatment runs and the meaned results of each treatment are presented in Table App. V:2.

8:2) CHARACTERISTICS OF DAIRY SHED EFFLUENT

8:2.1) Measured Characteristics

Mean values of all parameters measured on dairy shed effluent during the experiment are presented in Table 8:1. Seasonal variations in the values are shown in Appendix VII.

COD, BOD and TS show a maximum in November/December, the peak milking period, but monthly fluctuations make this trend insignificant (Figures App. VII:1 and App. VII:2). Temperature and DO (Figure App. VII:3) follow well established seasonal fluctuations (195, 313), while pH remains almost constant. Variations in redox potential are difficult to interpret, but possibly reflect changes in the nature of the waste, the time between collection and measurement, and the difficulty of obtaining stable measurements (Figure App. VII:4). $\text{NO}_3\text{-N}$ levels show a peak in early spring and late summer (Figure App. VII:5). The spring peak could be expected, considering the resumption of calving and the grazing of autumn saved pasture. The high levels in late summer may reflect the greater maturity of the pasture and the use of silage during dry conditions. The increase of $\text{NH}_4\text{-N}$ in spring (Figure App. VII:5) could have resulted from higher temperatures and increased metabolic activity of the indigenous microflora. If this was so, one would not expect a corresponding and significantly greater increase in $\text{NO}_3\text{-N}$. It would appear that the rise in $\text{NH}_4\text{-N}$ reflects feed composition and other seasonal changes. The trends seen in TKN and DKN support this suggestion (Figure App. VII:6). The relative seasonal movements of TKN and DKN show that TPN remains almost constant. The phosphorus data (Figure App. VII:7) gives a peak in spring and a smaller increase in autumn. This may be a reflection of pasture growth and increased cow numbers. Some of the monthly fluctuations probably reflect changes in shed management and personnel.

TABLE 8:1

MEANED DATA FOR DAIRY SHED EFFLUENT

Parameter	Unit	Mean	Std. Deviation
COD	mg/l	6599	1326
BOD	mg/l	1505	469
TS	%	0.717	0.176
VS	% of TS	68.3	5.12
TEMP	°C	17.0	4.40
DO	mg/l	5.04	1.41
E _h	mV	163	49
pH	-	8.24	0.13
NO ₃ -N	mg/l	2.90	1.75
NH ₄ -N	mg/l	26.42	9.86
DKN	mg/l	115	60
TKN	mg/l	205	79
DIP	mg/l	4.51	1.59
TDP	mg/l	6.49	3.15
TP	mg/l	35.20	11.38
(Calculated values based on the above):			
TDN	mg/l	117.9	-
TPN	mg/l	90	-
TN	mg/l	207.9	-
DOP	mg/l	1.98	-
TTP	mg/l	28.71	-

8:2.2) Pollution Loads from Dairy Shed Effluent

The total volume of water used at the dairy shed could not be measured because:

- (a) Limited resources precluded the monitoring of the various water sources to the shed.
- (b) The dairy shed is serviced by two sewer lines, one collecting discharges from the herringbone pit and milking machine cleaning, the second collecting the effluent from the holding yards and cattle access areas. No feasible method of measuring this combined discharge was developed.

The effluent volume discharged from the cattle holding areas, i.e., the monitored effluent, was estimated at 50 litre/cow-day.* Combining this figure with the values presented in Table 8:1, the total pollution load from the dairy shed per cow-day can be calculated (Table 8:2). Comparison of Table 8:2 with Table App. I:4 shows good correlation, considering the variations in data source and laboratory analysis. On this basis, Table 8:2 appears to provide a suitable assessment of pollution loads from a dairy shed.

8:2.3) Correlation of Pollution Parameters

Estimation of the regression equation between pairs of commonly used parameters, e.g., BOD and COD, are useful in design, particularly when complete records of the raw effluent cannot be made.

Regression analysis of the variables listed in Table 8:1, using a Burroughs Advanced Statistical Inquiry System (BASIS) and a Burroughs 6700 computer, resulted in the relationships presented in Table 8:3. All regressions with a coefficient of determination less than 0.70 were discarded, as their prediction value was not considered adequate.

8:3) ANAEROBIC TREATMENT PHASE

The anaerobic and aerobic phases are discussed separately in this and the following section. Chapter 9 discusses full plant treatment,

* The estimate was based on a knowledge of cow numbers, the yard clearing time, and an assessment of other water sources being discharged on to the yard.

TABLE 8:2

POLLUTION LOADS FROM DAIRY SHED EFFLUENT

Parameter	Unit	Pollution Load
COD	kg/cow-day	0.330
BOD	kg/cow-day	0.075
TS	kg/cow-day	0.360
VS	kg/cow-day	0.245
NO ₃ -N	g/cow-day	0.146
NH ₄ -N	g/cow-day	1.321
DKN	g/cow-day	5.750
TKN	g/cow-day	10.250
TDN	g/cow-day	5.896
TPN	g/cow-day	4.500
TN	g/cow-day	10.396
DIP	g/cow-day	0.226
TDP	g/cow-day	0.325
DOP	g/cow-day	0.099
TPP	g/cow-day	1.435
TP	g/cow-day	1.760

TABLE 8:3

CORRELATION OF RAW WASTE PARAMETERS

Dependent Variable	Independent Variable	Variable Coefficient	Constant	Coefficient Determination
COD (mg/l)	TS (%)	9838.3	-296.9	0.87**
BOD (mg/l)	COD (mg/l)	0.229	73.05	0.74**
DKN (mg/l)	TKN (mg/l)	0.672	-22.692	0.79**
VS (%)	TS (%)	0.729	-0.032	0.93**
VS (%)	BOD (mg/l)	0.0003	0.036	0.88**

** Regression significant at the 1% level

operational problems and general suitability of the combined treatment system.

8:3.1) Anaerobic Loading Rates

The average anaerobic loading rates for the three treatment levels are presented in Table 8:4. These are based on initial anaerobic tank volume and could be twice the cited values if allowances are made for volume reduction resulting from accumulating solids. Variation in effluent strength caused fluctuations in loading rates. Apart from using a fixed input volume, no attempt was made to stabilize the loading, as the anaerobic phase would be required to cope with a large variation in loading rate on a commercial dairy farm. Since the anaerobic phase was contained in an unmixed, open, non-insulated tank, the treatment closely resembled that of an anaerobic lagoon. Comparison of Table 8:4 with Chapter 2:4.3,1 shows that the loading rates were 5-8 times reported values at the 5 day anaerobic residence time, and therefore 2-4 times those at 10 day residence times. These higher loading rates allowed correspondingly smaller anaerobic tanks, and consequently a reduction in capital investment and opportunity cost.

8:3.2) Anaerobic Treatment Efficiencies

High treatment efficiencies were not expected across the anaerobic phase, particularly at the lower residence times, as the aim was to produce soluble organics by acid fermentation. These would still produce a significant pollution load.

A paired comparison of the anaerobic tank data from the two laboratory treatment plants showed that the null hypothesis could not be rejected, i.e., the two plants were the same. Hence data from both laboratory plants is combined and summarized in Table 8:5.

Detailed statistical analysis of this data was limited by the experimental design (Chapter 7) and fluctuations in raw effluent data, but visual observation of the means suggested little treatment effect on most parameters. Investigatory analysis supported this view and general conclusions drawn from the data are listed below.

- (a) There was little variation in the average COD and TS removal over the treatments. Since more than 60% of this removal

TABLE 8:4ANAEROBIC TANK LOADINGS

Plant	Hydraulic Residence Time (days)	Loading Volume (l/day)	Load (kg/m ³ -day)			
			COD	BOD	TS	VS
Lab.	5	8	1.346	0.302	1.355	-
	7.5	8	0.967	0.217	1.023	0.663
	10	8	0.627	0.141	0.666	0.474
Field	5	450	1.380	-	1.395	-
	7.5	450	0.863	-	0.938	0.607
	10	450	0.586	-	0.672	0.478

TABLE 8:5

ANAEROBIC TREATMENT IN LABORATORY PLANTS

Variable	5 day	7.5 day	10 day	Mean
COD REM ⁽¹⁾ (%)	71.0	68.0	72.1	70.4
COD AN ⁽²⁾ (mg/l)	1947	2303	1778	2009
BOD REM (%)	47.8	56.8	76.6	60.4
BOD AN (mg/l)	588	809	413	603
TS REM (%)	74.0	70.9	68.9	71.3
TS AN (%)	0.176	0.218	0.204	0.199
VS REM (%)	-	74.0	77.8	75.9
VS AN (%)	-	0.129	0.105	0.117
Anaerobic pH	7.19	6.90	6.89	6.99
Anaerobic E _h (mV)	-50	-40	-47	-46
Temperature (°C)	17.4	16.6	20.1	18.0

NOTES: (1) REM = Removal

(2) AN = Anaerobic discharge

could be attributable to settling (Chapter 2:6.1,1), the anaerobic tank removed approximately 10% of the COD and TS through treatment.

- (b) The BOD removals of approximately 50% were similar for the 5 and 7.5 day residence times, but showed an increase to 76.6% for the 10 day residence time. This increase could be the result of higher mean temperatures for the treatment period and the effect of longer residence time. The 10 day residence would reduce microbial washout, enabling methane producers to increase in the tank liquor, thus providing an increased BOD reduction. These effects were supported by VS removals.

The low BOD removals and wide BOD/TS removal ratios at the low anaerobic residence times suggested an increase in VFA's and other intermediaries due to acid fermentation. The COD/TS removal ratios followed a similar trend, suggesting that some anaerobic pre-conditioning, other than that shown by BOD, COD, and TS removals, was occurring.

- (c) Treatment efficiencies and anaerobic discharge concentrations correspond to those reported in the literature (Chapter 2:4.3,3). Considering the lack of controlled conditions and the high loading rates, particularly if allowances are made for the accumulated solids, the treatment efficiencies were greater than anticipated. The pH and redox potential of the discharge were essentially unaltered by treatment variations.
- (d) The insensitivity of the anaerobic tank discharge to variation in loading rates supports Loehr's suggestion (46) that the performance of anaerobic lagoons is relatively unaffected by loading rate.

8:3.3) Anaerobic Solid Accumulation and Disposal

Solids removal data from the laboratory plants is presented in Appendix VI. In view of the previous solid accumulation rate (Chapter 4:3.4), which required anaerobic tank cleaning every 40 days, it was decided to remove a portion of the anaerobic tank solids at the end of each treatment with a 5 day anaerobic residence time, i.e., every

4 weeks, as a cleaning period of 8 weeks would have resulted in too great a solids accumulation. Increasing the anaerobic residence time to 7.5 and 10 days allowed accumulated solids to be cleaned on an 8 and 12 week cycle respectively. The solids were removed prior to resetting the plants for the next treatment (Figure 7:1).

Making allowances for lost samples (Chapter 6:1.1,2), and using data from Appendix VI, a solids balance can be made for the laboratory plant anaerobic tanks. Tables 8:6 and 8:7 summarize these results for TS and VS respectively.

The TS accumulation rate of approximately 55% of the input solids for the 5 and 7.5 day anaerobic residence times is in agreement with earlier data (Appendix II). The lower accumulation rate (40% of input) at the 10 day anaerobic residence time corresponds with the greater percentage of TS lost, i.e., 30% as opposed to 15-20%. This trend would support the earlier conclusion that the 10 day residence time allowed an improved population of methane generating bacteria in the anaerobic tank, resulting in a greater proportion of the input solids lost through gassing. The higher temperatures, and the longer cleaning periods, would also aid in this process (314). The VS data is in agreement with these trends, although the actual percentage of VS lost (42%) is predictably higher.

The sludge accumulation rate was calculated assuming an 8% TS level in the sludge and an S.G. of 1.00. The former assumption was based on reported values (52, 54, 55) and the measured ~~TS~~ in the removed sludge. The floating mat on top of the anaerobic tank had an average of 12.2% TS and 56% VS, while the pumped slurry, removed mainly from the bottom of the tank, contained 4.1% TS and a similar VS level. Thus a mean value of 8% TS was selected. An S.G. of 1.00 was taken as the anaerobic solids both floated and settled. It was considered that any error in the assumed S.G. value would not significantly affect the calculated sludge accumulation rate.

The rate of sludge accumulation, $0.0050 - 0.0071 \text{ m}^3/\text{kg TS IN}$, is higher than the reported value of $0.0033 \text{ m}^3/\text{kg TS IN}$ (Chapter 2:4.3,4). The higher accumulation rate is probably due to the nature of the effluent, an increase in the amount of inert material, e.g., dirt,

TABLE 8:6

TS BALANCE FOR LABORATORY PLANT ANAEROBIC TANK

	BLOCKS		
	I	II	III
Mean hydraulic residence time (days)	5.0	7.5	10.0
TS loading rate (kg/m ³ -day)	1.36	1.02	0.67
Cleaning frequency (days)	28	56	84
TS IN (kg)/cleaning cycle ⁽¹⁾	1.46	2.76	4.83
TS AN (kg)/cleaning cycle ⁽²⁾	0.38	0.80	1.44
TS CLEANED (kg)/cleaning ⁽³⁾	0.74	1.51	1.89
TS REMAIN (kg) after cleaning	0.04	0.06	0.02
TS LOST (kg)/cleaning cycle ⁽⁴⁾	0.30	0.39	1.48
%TS LOST/cleaning cycle	20.5	14.0	30.5
TS ACCUMULATION (kg)/cleaning cycle	0.78	1.57	1.91
TS ACCUMULATION (kg)/TS IN (kg)	0.53	0.57	0.40
TS ACCUMULATION (kg/m ³ -day)	0.721	0.581	0.268
SLUDGE ACCUMULATION (m ³ /kg TS IN) ⁽⁵⁾	0.0066	0.0071	0.0050

NOTES:

(1) TS IN = TS load into the anaerobic tank

(2) TS AN = TS leaving the anaerobic tank in the liquid discharge

(3) TS CLEANED = TS removed from the anaerobic tank at each cleaning period

(4) TS LOST (kg) = [TS IN (kg)] - [TS AN (kg) + TS CLEANED (kg) + TS REMAIN (kg)]

(5) Sludge accumulation was calculated assuming an 8% TS concentration in the accumulating sludge.

TABLE 8:7VS BALANCE FOR LABORATORY PLANT ANAEROBIC TANK

	BLOCKS		
	I	II	III
Mean hydraulic residence time (days)	5.0	7.5	10.0
VS loading rate (kg/m ³ -day)	-	0.663	0.474
Cleaning frequency (days)	28	56	84
VS IN (kg)/cleaning cycle ⁽¹⁾	-	1.72	3.45
VS AN (kg)/cleaning cycle	-	0.46	0.79
VS CLEANED (kg)/cleaning	-	0.77	1.19
VS REMAIN (kg) after cleaning	-	0.04	0.02
VS LOST (kg)/cleaning cycle	-	0.45	1.45
%VS LOST/cleaning cycle	-	26.5	42.0
VS ACCUMULATION (kg)/cleaning cycle	-	0.81	1.21
VS ACCUMULATION (kg)/VS IN (kg)	-	0.47	0.35
VS ACCUMULATION (kg/m ³ -day)	-	0.312	0.166
SLUDGE ACCUMULATION (m ³ /kg VS IN) ⁽²⁾	-	0.0103	0.0077

NOTES: (1) Abbreviations as for Table 8:6

(2) Calculated using a mean VS% of 57% TS

and the shorter retention times between solids removal. The lower VS levels and removals obtained (Table 8:7) would support these conclusions.

There was no suggestion from the data (Appendix VI) that the sludge density increased with loading rate as had been reported (166, 169). However, the technique used for solids removal did not provide an accurate measure of the sludge density.

Comparison of Tables 8:4, 8:5 and 8:6 suggest that solids loading and accumulation rates are the primary factors in anaerobic tank design. Tank volumes may be best determined on a solids cleaning frequency. Recommended sludge removal, once 50% of the anaerobic lagoon volume has been filled (54, 55), may be conservative when considering treatment efficiencies obtained at low residence times (Chapter 8:3.2). Sludge removal may be better estimated on a minimum mean hydraulic residence time, i.e., the sludge would be removed once the effective lagoon volume reduced the mean hydraulic residence time below a selected value, e.g., 3 days. The accumulated solids would provide a medium for the anaerobic microorganisms to adhere to, thus minimizing the effect of the low mean hydraulic residence time. The anaerobic tank operation would then be comparable to an up flow anaerobic filter (153). The advantage of this system would be a lowered solids cleaning frequency for any given anaerobic lagoon size, providing improved solids decomposition and economic cleaning.

Cleaning the anaerobic tank in the laboratory was messy and unpleasant. It is discussed in more detail in Chapter 9.

8:3.4) Comparison of the Laboratory and Field Plants.

A comparison of loading rates is presented in Table 8:4. Pooling the percentage differences in COD, TS and VS loading rates, the field plant loading was 3.4% below the laboratory plants over the three treatment levels. The greatest single variation was 10%, seen in the COD loading at a 7.5 day residence time. Statistical analysis of plant treatment showed that this was not significant. The lower loading, resulting from the short-fall in effluent volume, only affected the field plant (Chapter 6:1.1,2).

Table 8:8 summarizes treatment efficiencies and anaerobic outlet concentrations for the field plant. Resources did not permit the measurement of BOD on the field plant effluent. Comparison of Tables 8:8 and 8:5 indicates some variation in performance at the various treatment levels. Selecting points showing the largest variation, e.g., COD AN at the 7.5 day residence, and having checked that the two data sets had similar variance, a "t" test on means with pooled variance showed no significant difference in the data. The redox potential was consistently lower in the field plant. This may reflect improved anaerobic conditions in the larger tank, but may also be a function of the larger sample sizes collected. Temperature was lower in the field plant but had little effect on treatment efficiency.

In summary, the data reveals no scale effects in treatment efficiencies despite the variations in environment. It should not be assumed that scale has no effect, as some operational difficulties were experienced with alteration in scale (Chapter 9:5.5).

8:4) AEROBIC TREATMENT PHASE

8:4.1) Aerobic Loading Rates

Aerobic loading rates varied with anaerobic discharge. Taking means for each anaerobic block, the trickling filter loading rates for the laboratory plants are presented in Table 8:9. The BOD loading, compared to domestic standards, classifies the filter as a "low rate" unit. However, if consideration is given to the recycle rate and the concentration of liquid discharge onto the filter, the trickling filter may be classified as a "high rate" unit (Chapter 2:5.4). These loading comparisons are not strictly correct since the 1-3 day residence times used in these experiments influence the actual load being placed on the filter and the time available for treatment. Comparison with livestock waste treatment units shows that the loading rates and operating conditions resemble the work of Bridgham and Clayton (81), and Painter (247).

8:4.2) Aerobic Treatment Results

8:4.2,1) Introduction -

TABLE 8: 8

ANAEROBIC TREATMENT EFFICIENCIES FOR THE FIELD PLANT

Variable	5 day	7.5 day	10 day	Mean
COD REM ⁽¹⁾ (%)	65.4	71.0	67.4	67.9
COD AN ⁽²⁾ (mg/l)	2383	1896	1888	2056
TS REM (%)	72.3	74.3	69.0	71.9
TS AN (%)	0.192	0.180	0.203	0.192
VS REM (%)	-	78.2	76.0	77.1
VS AN (%)	-	0.105	0.110	0.108
Anaerobic pH	7.66	7.69	7.44	7.60
Anaerobic E _h (mV)	-67	-55	-66	-63
Temperature (°C)	14.1	10.1	17.9	14.0

NOTES: (1) REM = Removal

(2) AN = Anaerobic discharge

TABLE 8:9

LABORATORY PLANTS - DAILY AEROBIC LOADING RATES

VARIABLE	BLOCK I	BLOCK II	BLOCK III	MEAN
COD (kg/m ³ -day) (1)	0.590	0.698	0.539	0.609
BOD (kg/m ³ -day)	0.178	0.245	0.125	0.183
TS (kg/m ³ -day)	0.533	0.659	0.618	0.603
VS (kg/m ³ -day)	-	0.390	0.319	0.355
Flow 5/1 (m ³ /m ² -day)	2.81 (0.03) ⁽²⁾	2.81 (0.030)	2.81 (0.030)	2.81
20/1 (m ³ /m ² -day)	10.10 (0.108)	10.19 (0.109)	9.54 (0.102)	9.95
35/1 (m ³ /m ² -day)	18.23 (0.195)	18.33 (0.196)	18.61 (0.199)	18.39

NOTES: (1) Loadings are based on the trickling filter volume of 0.0264 m³.

(2) Figures in brackets give the flow in litre/min onto the filter.

A BASIS package was used to analyze the data. The treatment levels for both aerobic residence time (B) and recycle rate (C) were normalized to improve orthogonality by the following equation:

$$N = \frac{A - Me}{\frac{1}{2}(Ma - Mn)}$$

N = normalized value

A = actual value

Me = mean of actual values (Aerobic = 2, Recycle = 20/1)

Ma = maximum actual value (Aerobic = 3, Recycle = 35/1)

Mn = minimum actual value (Aerobic = 1, Recycle = 5/1)

A step-wise regression analysis was executed with 5% F limits being set for the inclusion or deletion of any term from the equation. The treatment interactions and covariates used in all analyses are presented in Table 8:10.

8:4.2,2) Regression Equations and Contour Diagrams -

The regression equations, based on normalized treatment levels and using data from Table App. V:2, are presented in Table 8:11. Data fluctuations reduced both the number of significant terms in the equations and the coefficients of multiple determination (CMD). The percent removal regressions accentuated this problem as two data values were required for each determination. No significant regression for percent BOD removal was obtained but, given a BOD input value, the percent removal can be estimated from the BOD OUT prediction. Taking a mean anaerobic discharge of 600 mg/l BOD, the range of predicted % BOD removals is 43-73%. Improvement of the CMD's could have been achieved if a greater number of larger samples had been analysed. This was not feasible. An alternative would have been to use settled, rather than fully mixed, samples for analysis. However, settled samples would not provide an accurate assessment of plant performance and final discharge strengths. Determination of actual operating conditions was considered to be of primary importance, hence agitated samples were analysed.

The regression equations were interpreted with the aid of contour diagrams. The X and Y axes of the grid formed the aerobic residence

TABLE 8:10

TREATMENT COMBINATIONS AND COVARIATES
FOR AEROBIC REGRESSION ANALYSIS

TREATMENTS	COVARIATES
<div style="border-left: 1px solid black; border-right: 1px solid black; border-bottom: 1px solid black; padding: 5px; display: inline-block;"> B (1) C (2) BC B² C² B²C BC² B²C² </div>	TEMP AN OUT (3)

- NOTES: (1) B = Aerobic residence time (Chapter 7)
 (2) C = Filter recycle rate (Chapter 7)
 (3) AN OUT = Anaerobic tank outlet concentration, e.g., COD AN. This provides an estimate of the aerobic load, as loading volumes are fixed.

TABLE 8:11

REGRESSION EQUATIONS FOR AEROBIC TREATMENT USING LABORATORY PLANT DATA

Dependent Variable	Constant	Independent Variables and Coefficients	Coefficient of Multiple Determination
COD OUT ⁽¹⁾ (mg/l)	67.446	- 129.073B - 156.964C - 114.967BC + 137.530B ² C + 0.450CODAN	0.92** (2)
COD REMOVAL (%)	51.155	+ 7.157B + 11.432C + 3.931BC - 8.610B ² C	0.72**
BOD OUT (mg/l)	85.940	- 38.836B - 56.011BC + 0.274BODAN	0.70**
BOD REMOVAL (%)	-	-	-
TS OUT (%)	0.009	+ 0.010B ² - 0.005BC - 0.011BC ² + 0.675TSAN	0.97**
TS REMOVAL (%)	27.125	- 4.036B ² + 5.348BC ²	0.51**
VS OUT (%)	-0.017	- 0.005BC - 0.008BC ² + 0.398VSAN + 0.003TEMP	0.93**
VS REMOVAL (%)	56.648	+ 4.580BC + 5.125BC ² + 176.665VSAN - 2.406TEMP	0.83**

NOTES: (1) OUT = Final discharge from the aerobic phase.

(2) ** Regression significant at the 1% level.

time and recycle rate respectively. A series of substitutions into the regression equation gave a complete grid of predicted values. Contours were then drawn to represent common discharge concentrations or percentage treatment efficiencies.*

Contour diagrams were used as they provide a better understanding of the response surface than the use of a family of curves. This is particularly true where second and third order interactions occur in the regression.

Figures 8:1 - 8:7 are the contour diagrams resulting from the regressions presented in Table 8:11. Although the shape of the response surface is controlled by the regression equation, the values given on the contour lines will vary with the limits set for X and Y and the values assigned to any covariate in the equation.

8:4.2,3) Discussion of Aerobic Treatment Results -

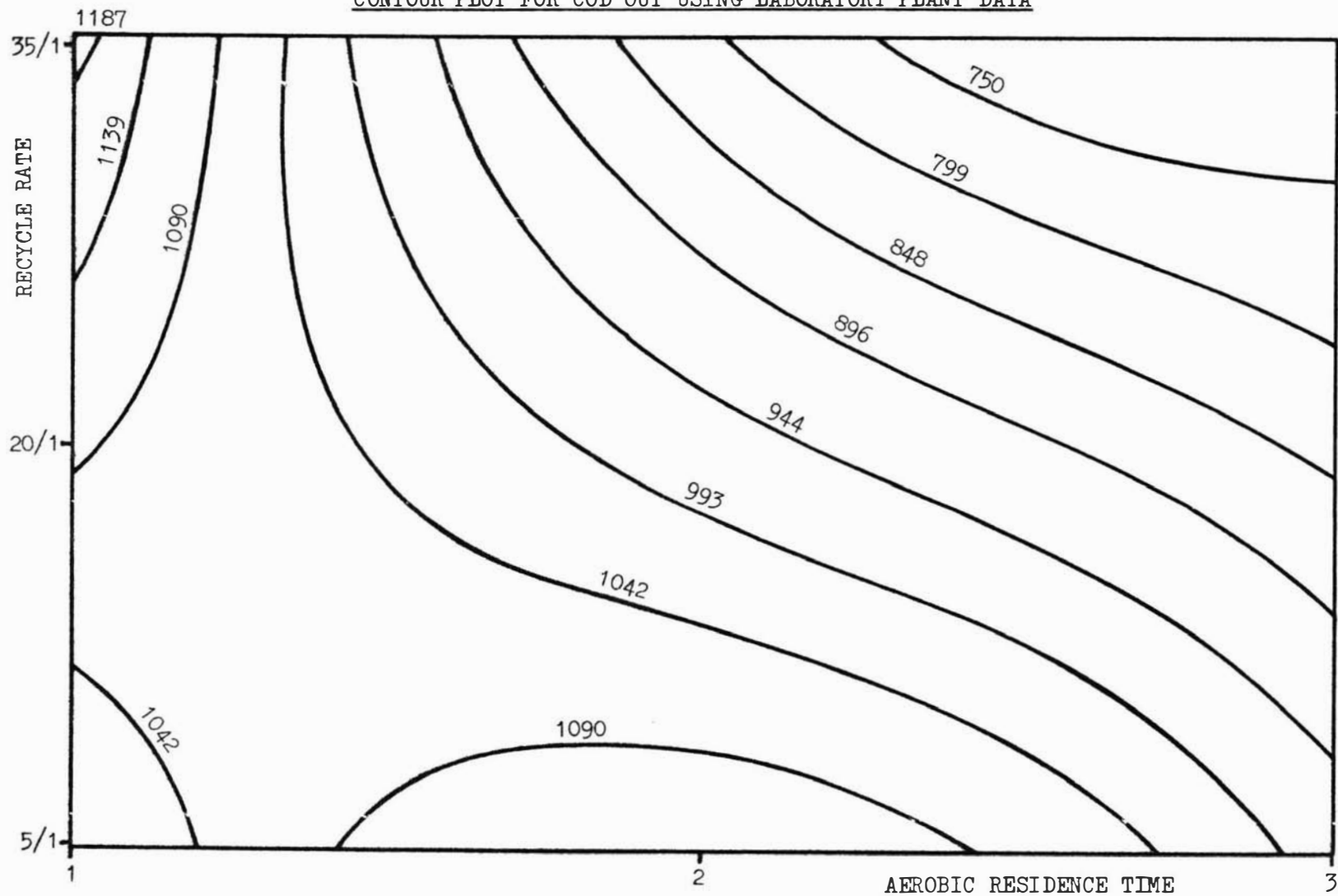
(a) General Treatment Effects: Comparison of the regression equations (Table 8:11) and the aerobic phase response surfaces (Figures 8:1 - 8:7) indicates a strong interaction between aerobic residence time and recycle rate. This is demonstrated by the low treatment efficiency at low aerobic residence times and high recycle rates, and by an increase in treatment efficiency at high aerobic residence times and recycle rates. The large flat area through the middle and lower right of the figures suggests an insensitivity of treatment efficiency to operating conditions. This factor could be of importance when considering plant suitability in the dairy industry.

The absence of temperature effects is at variance with reported work (Chapter 2:5.4) and is probably due to the lack of controlled temperatures and the absence of temperature extremes. Temperature effects only occur in the VS regression where there is a negative coefficient for %VS removal. Although theoretical

* The computer programme, to calculate the 40 x 40 grid positions and draw the contours, was written by Dr I.F. Boag, Industrial Engineering and Management Department, Massey University.

FIGURE 8: 1

CONTOUR PLOT FOR COD OUT USING LABORATORY PLANT DATA



COD AN = 2000 (mg/l)

FIGURE 8:2

CONTOUR PLOT FOR PERCENT COD REMOVAL USING LABORATORY PLANT DATA

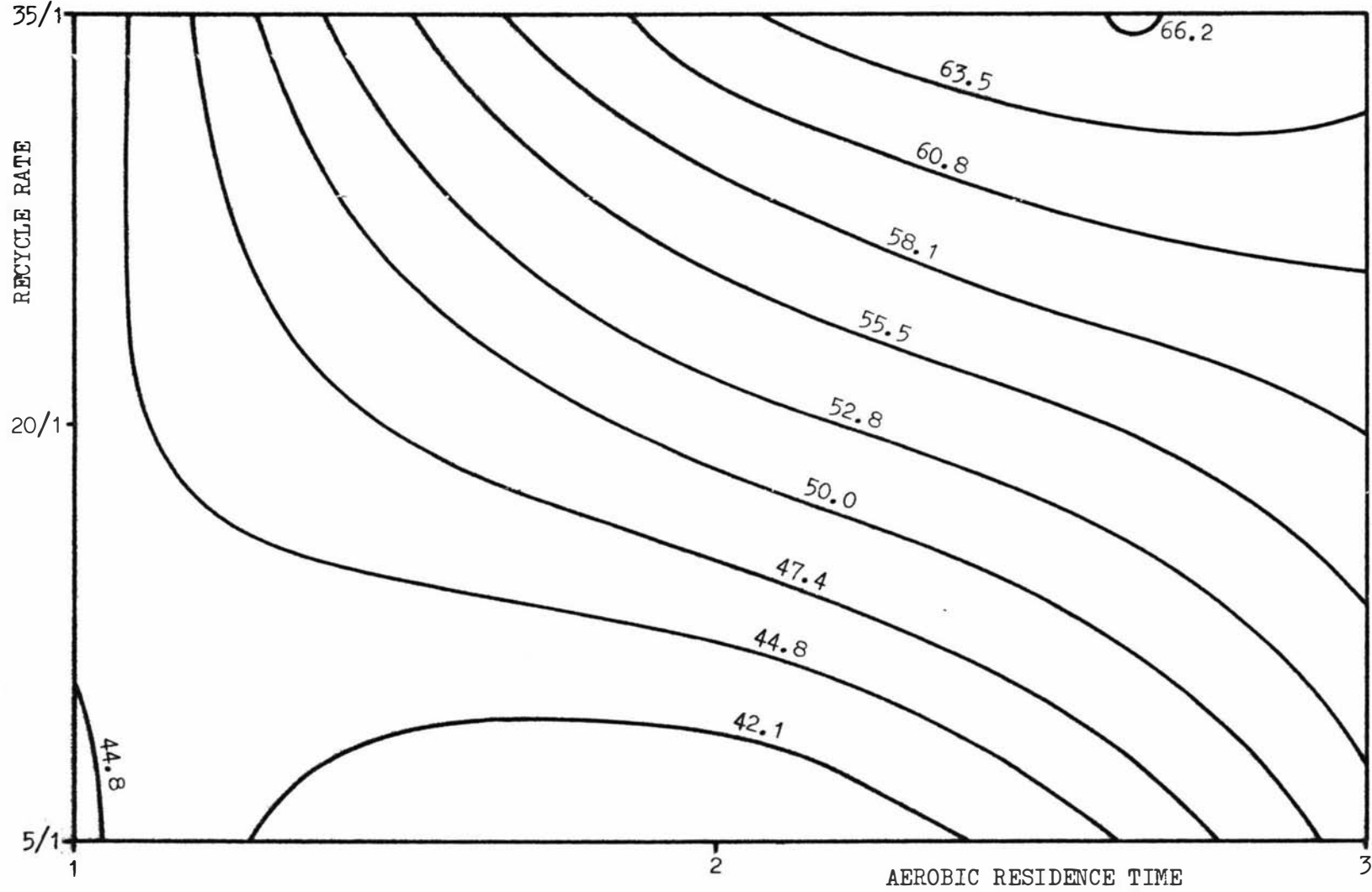


FIGURE 8:3

CONTOUR PLOT FOR BOD OUT USING LABORATORY PLANT DATA

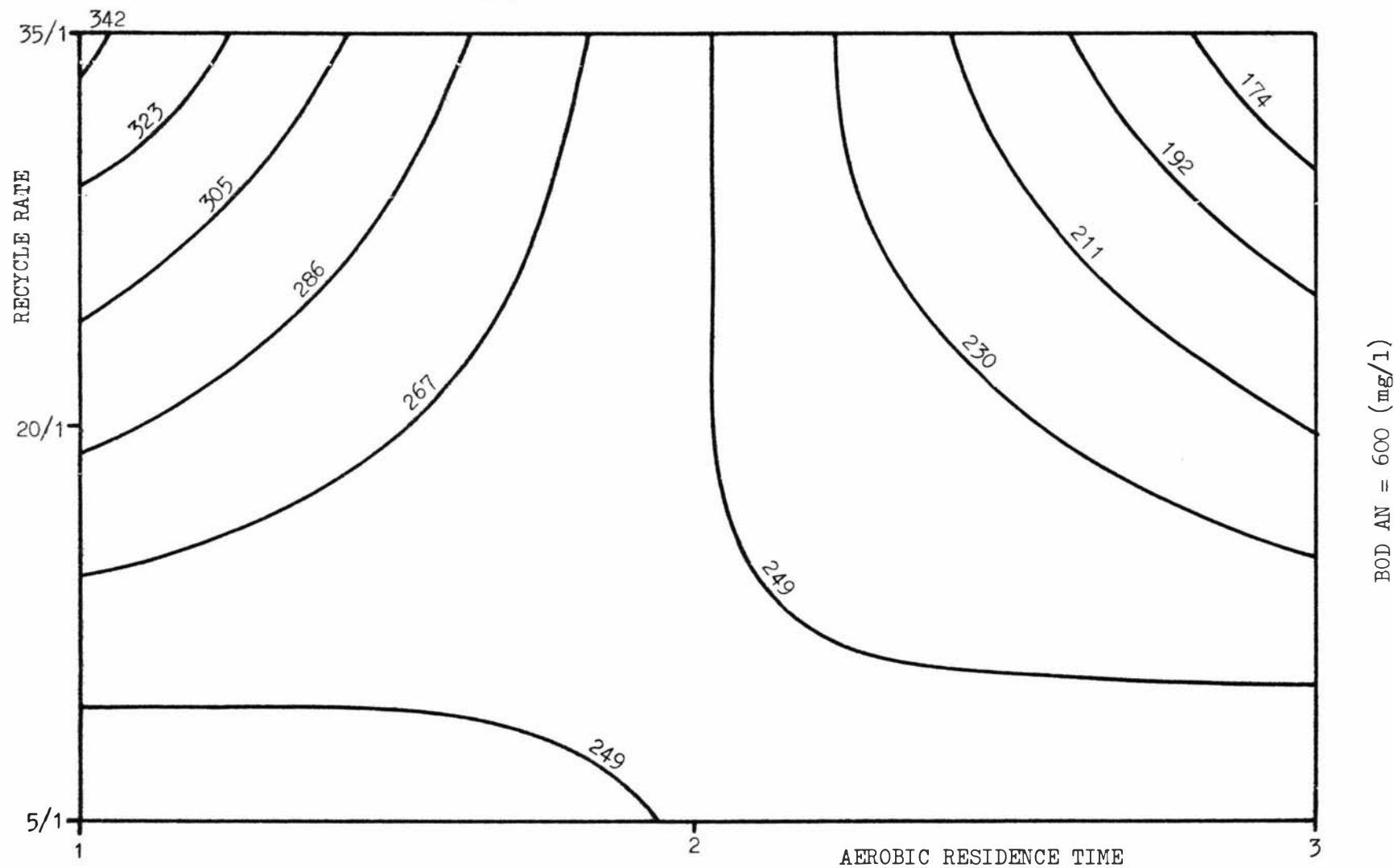
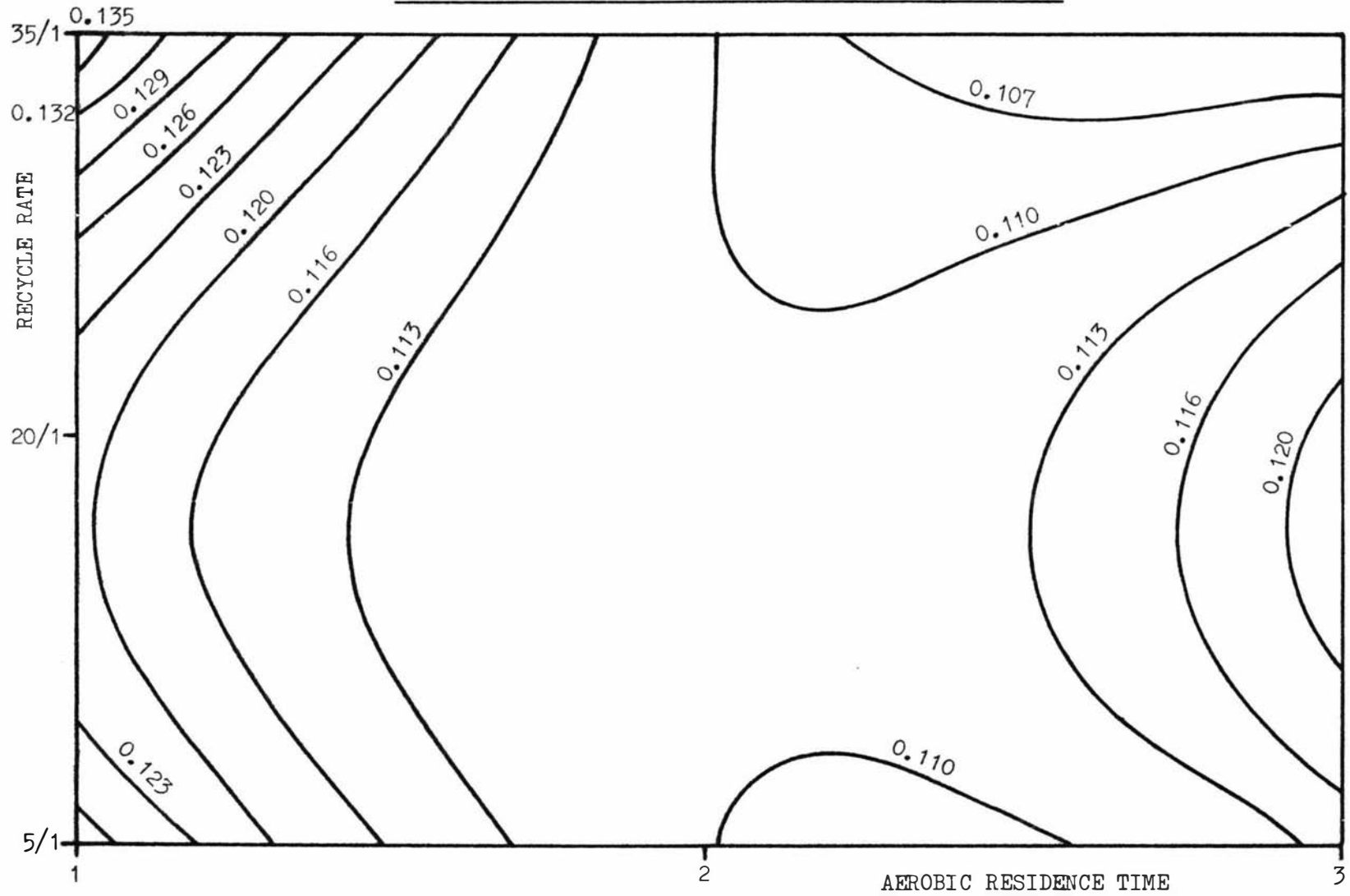


FIGURE 8:4

CONTOUR PLOT FOR TS OUT USING LABORATORY PLANT DATA



TS AN = 0.150 (%)

FIGURE 8:5

CONTOUR PLOT FOR PERCENT TS REMOVAL USING LABORATORY PLANT DATA

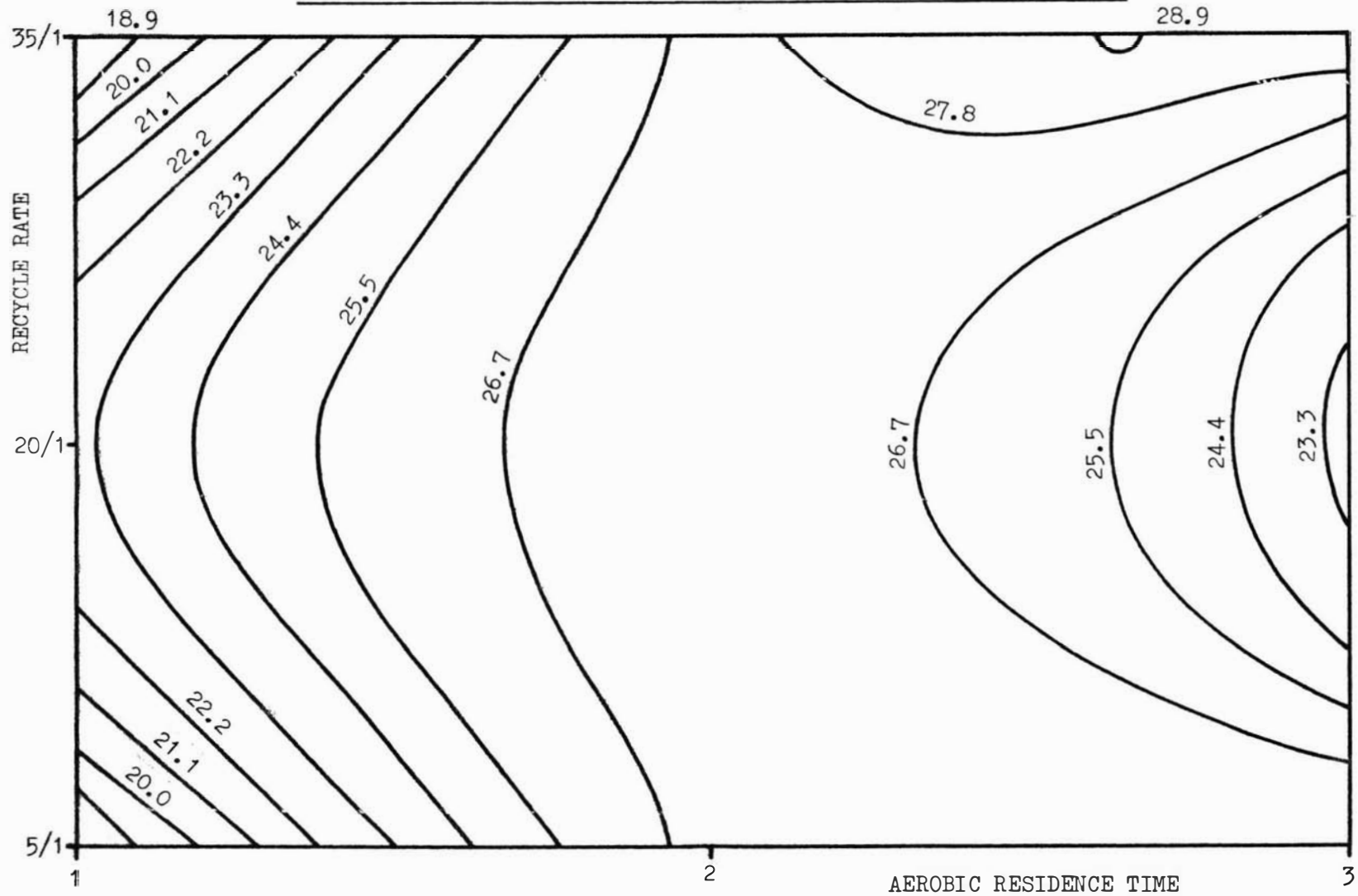


FIGURE 8:6

CONTOUR PLOT FOR VS OUT USING LABORATORY PLANT DATA

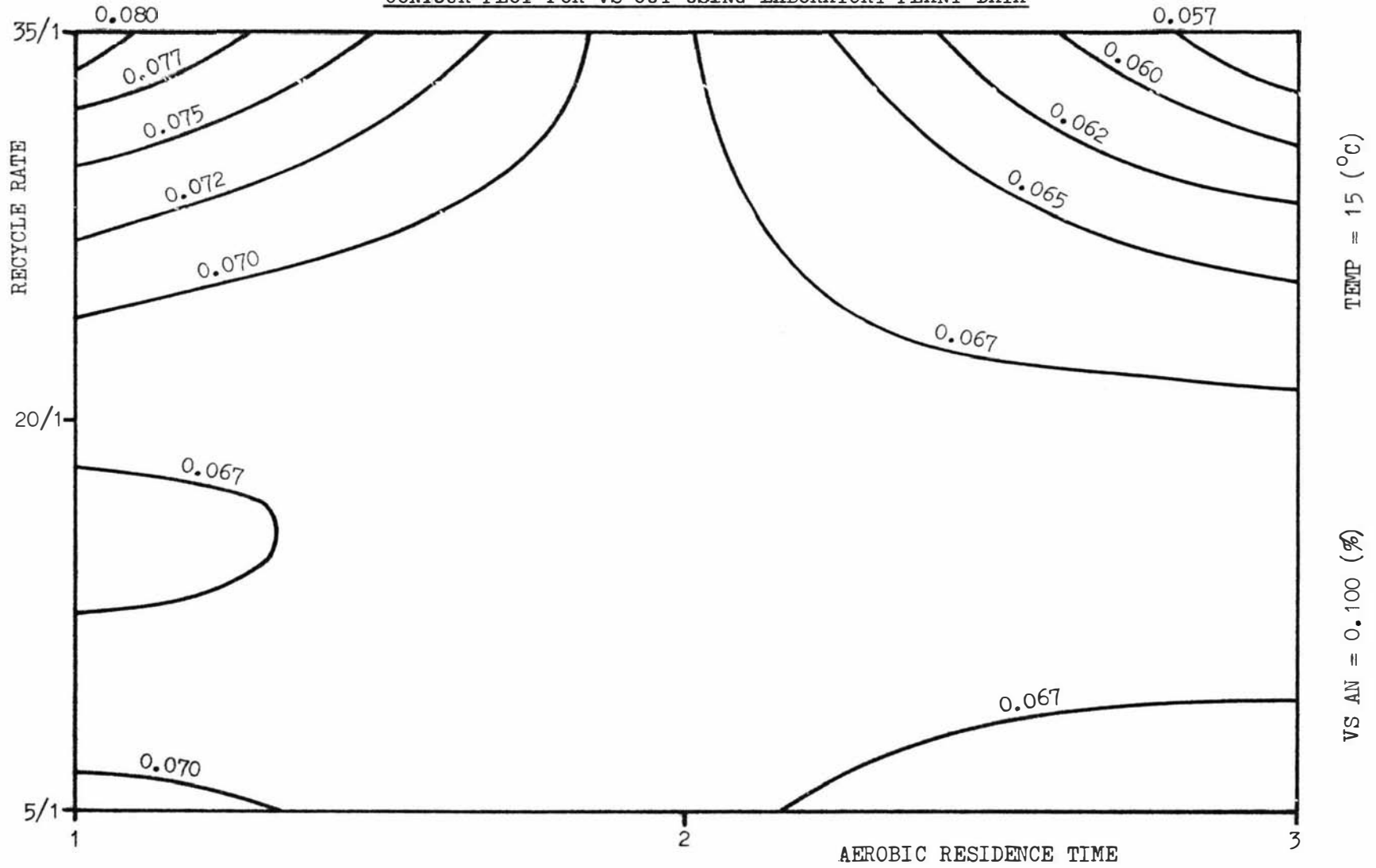
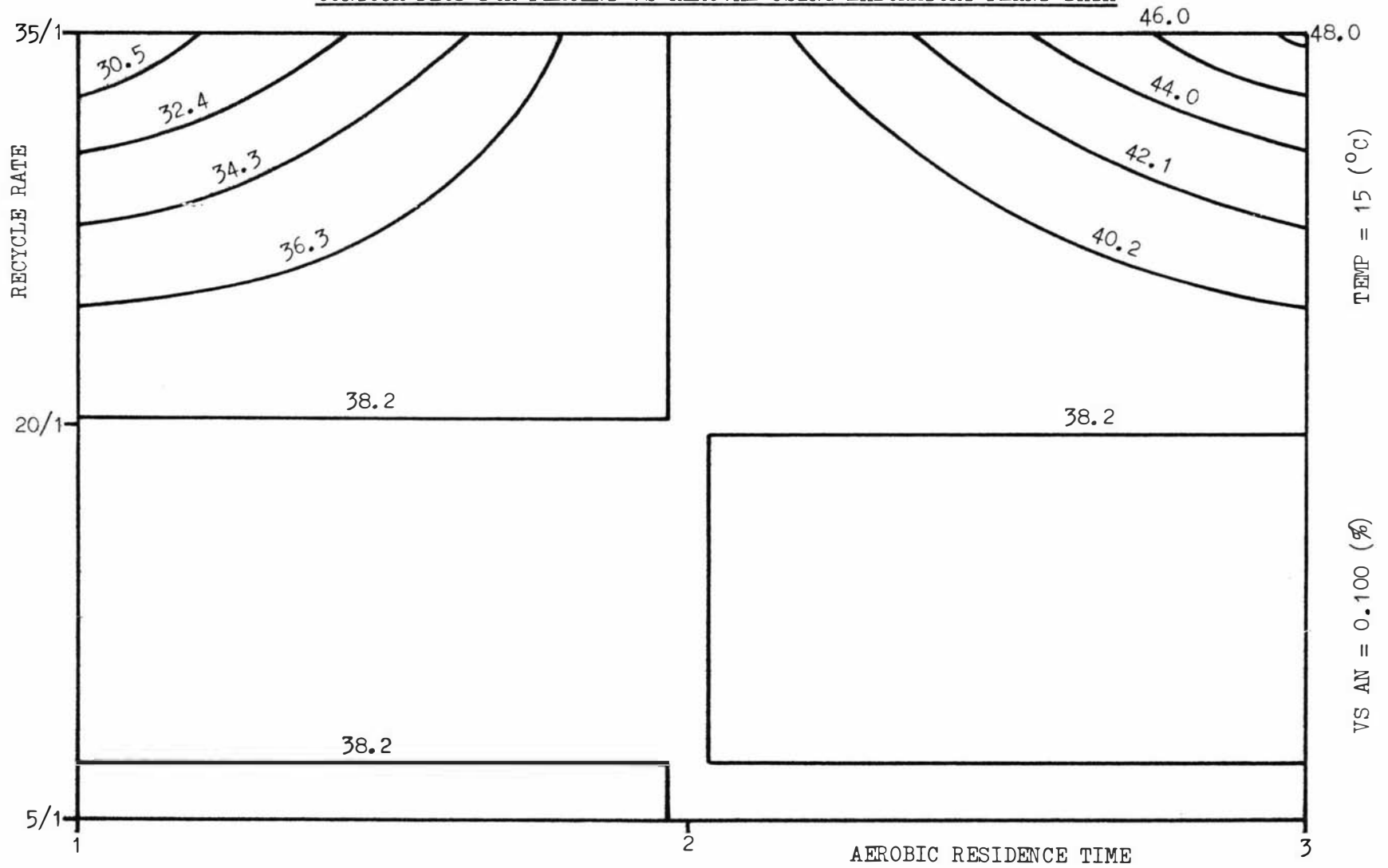


FIGURE 8:7

CONTOUR PLOT FOR PERCENT VS REMOVAL USING LABORATORY PLANT DATA



considerations would not support this, it may result from the influence of higher temperatures increasing the activity of settled floc in the aerobic tank, thus causing gassing and solids dispersion. The dispersed floc would be discharged in the outfall, decreasing treatment efficiencies.

- (b) Aerobic Residence Times: Aerobic residence time had the greatest effect on treatment efficiency. The selected times of 1-3 days were significantly lower than the 20 days used by Bridgham and Clayton (81), although Painter (247) appears to have used a more conventional trickling filter system giving residence times of less than one day.

The data suggests that aerobic residence times of 2.5-3.0 days provide a discharge BOD of less than 200 mg/l. This low residence time, relative to aerobic lagoons, would substantially decrease plant size while still providing effluent of a similar standard.

- (c) Recycle Rate: The advantages and disadvantages of recycling have been listed (Chapter 2:5.4). Unlike trickling filters treating domestic sewage, trickling filters treating dairy shed wastes are loaded twice daily. This makes recycle mandatory if a continuous flow to the filter is to be maintained. Furthermore, the high effluent concentration (BOD in excess of 600 mg/l after anaerobic treatment) requires a high hydraulic load to assist film sloughing and to avoid filter blockages.

The disadvantages are not significant in the dairy farming environment. The low volumetric loadings enable high recycle rates to be maintained without the use of large pumps or settling basins. The possibility of increased sludge should not be a problem if it is returned to the anaerobic tank. Heat losses in winter would only affect a very small percentage of farmers in N.Z., namely, those on town supply in cold districts.

The treatment advantages of the higher recycle rates are only seen for the longer residence times. This is expected as high recycle at low aerobic residence times produces some turbulence

in the aerobic tank, resulting in an increased solids discharge. An alteration in design could improve this feature. The data suggests that recycle rates in excess of 20/1, or hydraulic loadings above $10 \text{ m}^3/\text{m}^2\text{-day}$, would be required to obtain adequate treatment.

- (d) Treatment Efficiencies: Treatment efficiencies obtained in the aerobic plant are in line with the literature. The optimum predicted removals and discharge concentrations are presented in Table 8:12. The lower COD and TS removals probably reflect the absence of a sedimentation tank prior to discharge. BOD removals of $0.13 \text{ kg BOD}/\text{m}^3$ of filter were at the lower range of removals achieved with domestic sewage (249, 250, 273), but similar to those obtained with dairy cattle wastes (81, 247).

The removal of COD per pass through the filter (Table 8:13) showed no significant treatment effect. Further analysis, to estimate rates of removal within the filter was not justified as samples were only collected prior to the evening load (Chapter 6). These values indicated removals after 10 hours of treatment and were not representative of the overall operating conditions within the filter.

Table 8:13 also provides a comparison between COD values at the bottom of the filter and the final discharge. Despite the presence of a sloughed film in the filter outlet, it was of a consistently higher standard than the final discharge. This was particularly evident at the lower residence times and high recycle rates. The poorer quality of the final discharge was due to the presence of a greater concentration of suspended solids and a mixing of treated effluent with the rest of the tank liquor. Some short circuiting probably occurred, resulting in the final discharge being contaminated with the anaerobic outfall. Therefore an alteration in plant design, to allow the final discharge to be taken from the bottom of the filter, would not only improve the aerobic treatment efficiencies to greater than 75% COD removal, but would reduce the significance of aerobic residence time. If settling basins were also included, treatment efficiencies could be further increased. BOD data (Table 8:14)

TABLE 8:12

PREDICTED TREATMENT EFFICIENCIES FOR AEROBIC
TREATMENT USING LABORATORY PLANT DATA

VARIABLE	REMOVAL %	OUTPUT CONC. (mg/l)
COD	66.0	700
BOD	72.0	160
TS	28.9	1040
VS	48.0	550
DO	-	4.5
pH	-	7.29 (units)
TEMP	-	18 (°C)

TABLE 8:13

COD CONCENTRATIONS THROUGH THE AEROBIC TREATMENT PHASE OF THE LABORATORY PLANTS

RECYCLE RATE	POSITION	AEROBIC RESIDENCE TIME					
		1 DAY		2 DAY		3 DAY	
		COD (mg/l)	% Difference	COD (mg/l)	% Difference	COD (mg/l)	% Difference
5/1	3 ⁽¹⁾	617		768		999	
	4	582	-5.7 ⁽²⁾	680	-11.5	892	-10.7
	5	1010	73.5 ⁽³⁾	861	26.6	1122	25.8
20/1	3	785		913		823	
	4	680	-13.4	843	-7.7	710	-13.2
	5	1159	70.4	1132	34.3	747	5.2
35/1	3	758		443		557	
	4	602	-20.6	397	-10.4	535	-3.9
	5	1498	148.8	484	21.9	655	22.4

TABLE 8:14

COMPARISON OF BOD CONCENTRATIONS AT THE BOTTOM OF THE FILTER AND FINAL DISCHARGE OF LABORATORY PLANTS

RECYCLE RATE	POSITION	AEROBIC RESIDENCE TIME					
		1 DAY		2 DAY		3 DAY	
		BOD (mg/l)	% Difference	BOD (mg/l)	% Difference	BOD (mg/l)	% Difference
5/1	4 ⁽¹⁾	86		126		137	
	5	243	183	245	94	304	122
20/1	4	121		133		120	
	5	267	121	331	149	209	74
35/1	4	111		72		82	
	5	410	269	133	85	146	78

NOTE: (1) Positions 4 and 5 refer to sample collection points at the bottom of the filter and the final discharge respectively (Figure 6:1).

emphasizes this point, indicating that BOD removals in excess of 85% could be achieved in the aerobic phase if the final discharge came from the bottom of the filter. TS and VS results show similar trends.

The pH of the aerobic discharge showed little variation and averaged 7.3 throughout the experiment. DO concentration increased with recycle rate and showed no significant trends with alteration in aerobic residence time (Table 8:15). DO levels were consistently higher at the bottom of the filter than in the final discharge, supporting the use of the filter effluent as the final discharge liquor. The decrease in DO in the aerobic tank suggested significant metabolic activity from the suspended flocs. The contribution of this microbial oxidation to the total aerobic treatment could not be estimated.

8:4.2,4) Anaerobic Influence on Aerobic Treatment -

The work of Gerrish et al. (314) supported the concept that anaerobic preconditioning enhanced aerobic treatment. Investigation of this aspect was limited because of the nested design of the experiment. Regression analysis of the anaerobic/aerobic interaction for COD and BOD revealed a significant interaction for %COD removal.

$$\% \text{COD REM} = 51.205 + 7.465B + 11.896C + 3.946BC - 9.026B^2C - 3.455AB$$

The CMD equalled 0.76 and the regression was significant at 1%. The AB interaction was just significant at the 5% level, and the new CMD only slightly improved the original regression (Table 8:11). The equation indicated that increasing the anaerobic residence from 5 to 10 days decreased the %COD removal over the aerobic phase. While contrary to Gerrish et al. (314), this may be possible since the 10 day residence showed an increased BOD removal without a corresponding increase in COD reduction. Therefore, the degradable portion of the anaerobic COD would be reduced, thus decreasing the aerobic treatment effect. The absence of a significant AB interaction in %BOD removal does not refute this possibility as the BOD data gave consistently less significant predictions.

Gerrish et al. (314) also indicated the importance of high temperatures

TABLE 8:15

DO CONCENTRATION (mg/l) IN THE
LABORATORY PLANT DISCHARGE

RECYCLE RATE	AEROBIC RESIDENCE TIME		
	1 DAY	2 DAY	3 DAY
5/1	3.69	2.50	2.35
20/1	4.19	2.47	1.65
35/1	3.87	5.17	4.15

which were not achieved in these experiments. The low temperatures, the lack of environmental control, and the seasonal variation between anaerobic treatment blocks, did not allow further conclusions to be drawn on the influence of anaerobic residence time on aerobic treatment.

8:4.2,5) Prediction of Treatment Efficiencies -

Predictions of treatment efficiency outside experimental limits are often unreliable. The influence of other factors such as solids accumulation, or the increasing difficulty of removal as treatment efficiencies increase, will contribute to variations between predicted and actual values.

Figures 8:8 - 8:11 give predicted output concentrations of COD, BOD, TS and VS with treatment limits of 1-5 days aerobic residence time and 5/1 - 65/1 recycle rates ($2.8-33.8 \text{ m}^3/\text{m}^2\text{-day}$).

Comparison of these predicted response surfaces with those obtained earlier (Figures 8:1 - 8:7) suggests that operation at a 3 day aerobic residence time and 35/1 recycle is relatively stable, i.e., the response surfaces are fairly flat through this area. This insensitivity to treatment variations around the 3 day aerobic residence time confirms earlier conclusions (Chapter 8:4.2,3) that this would be a suitable setting for commercial application.

Some improvement in treatment efficiency may be obtained with increased residence time and recycle rate, but the extent of the increase is difficult to estimate from the regressions, as can be seen by the meaningless values determined for some of the contours.

The conflict between COD data (Figure 8:8) and other values (Figures 8:9 - 8:11) cannot be explained by treatment effect. It probably reflects the instability of the extrapolated model, particularly at its outer limits and in areas with steep gradients.

8:4.3) Solids Accumulation in the Aerobic Tank

A solids analysis relative to each of the 9 aerobic treatments was not feasible as the aerobic tanks did not always require solids removal at the end of a treatment period. A record was kept of

FIGURE 8:8

CONTOUR PLOT TO PREDICT COD OUT

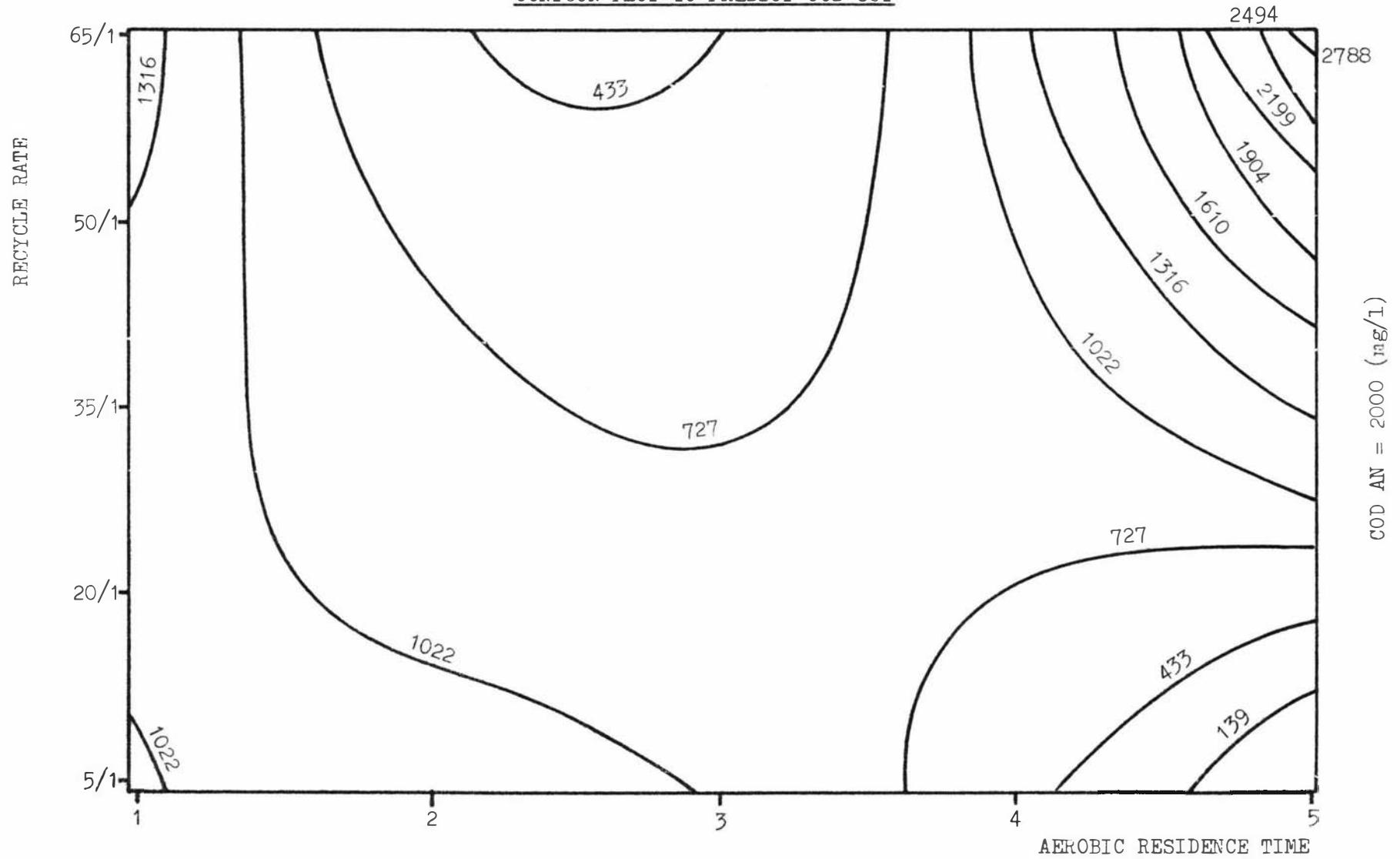
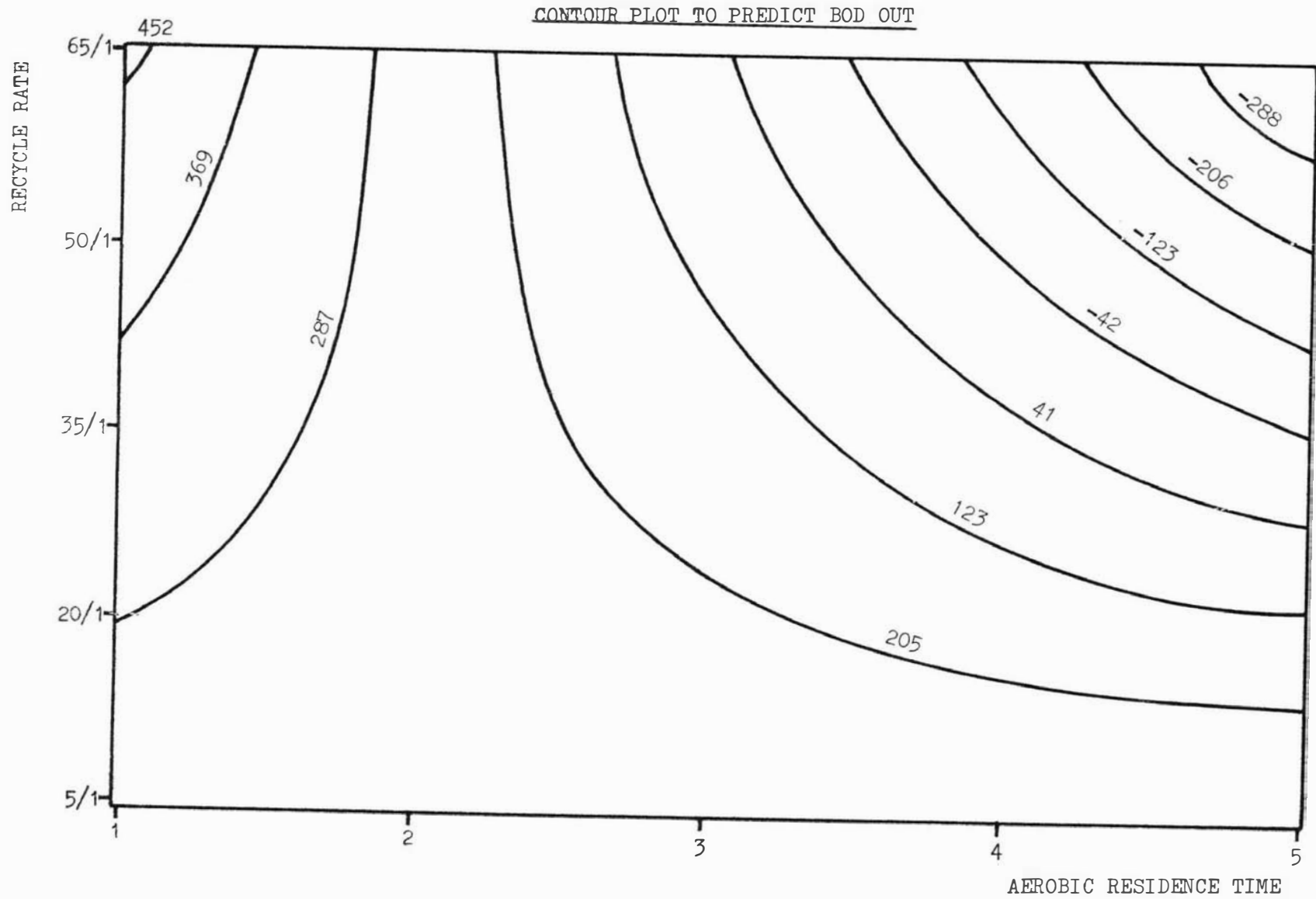


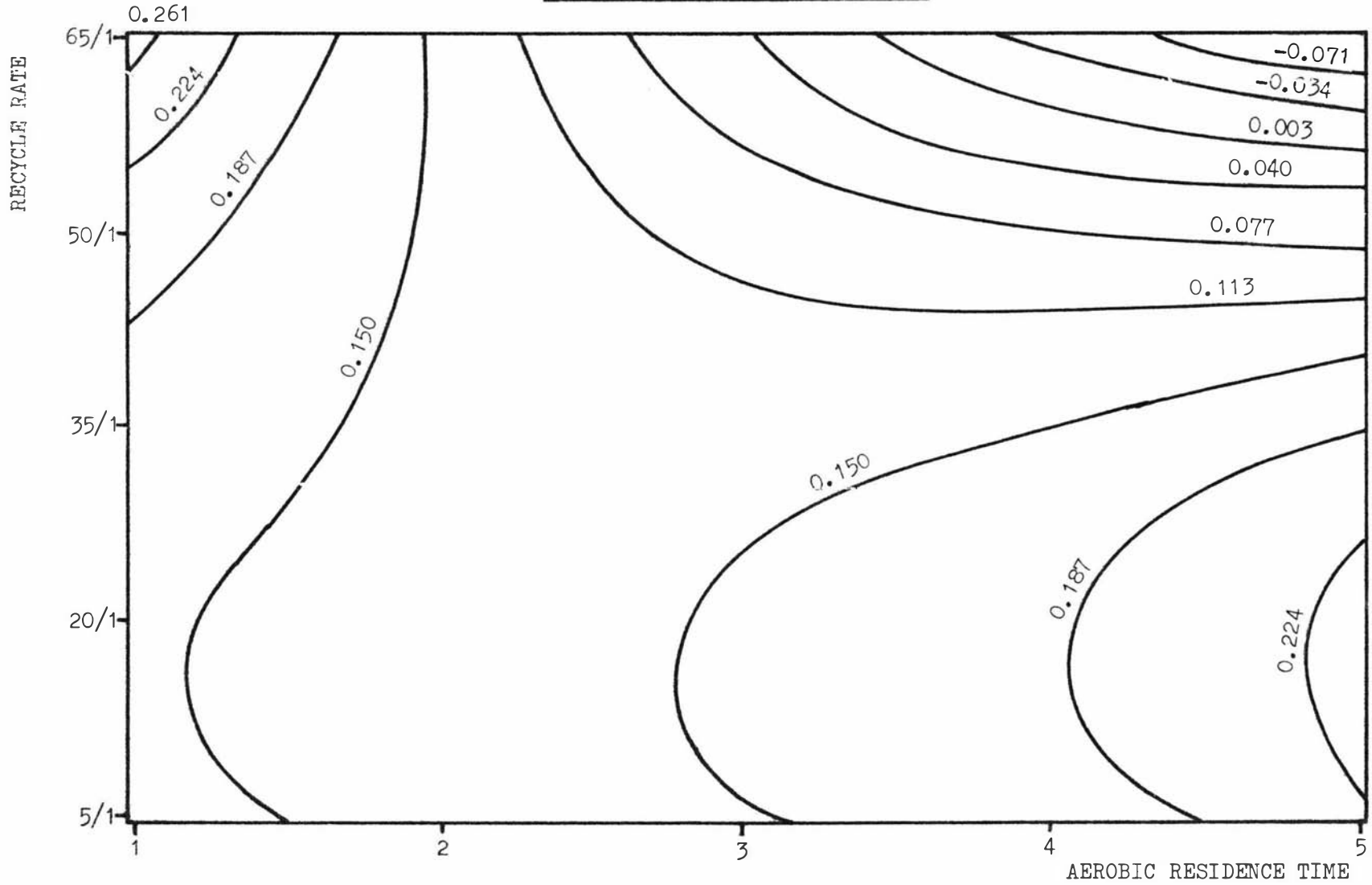
FIGURE 8:9



BOD AN = 600 (mg/l)

FIGURE 8:10

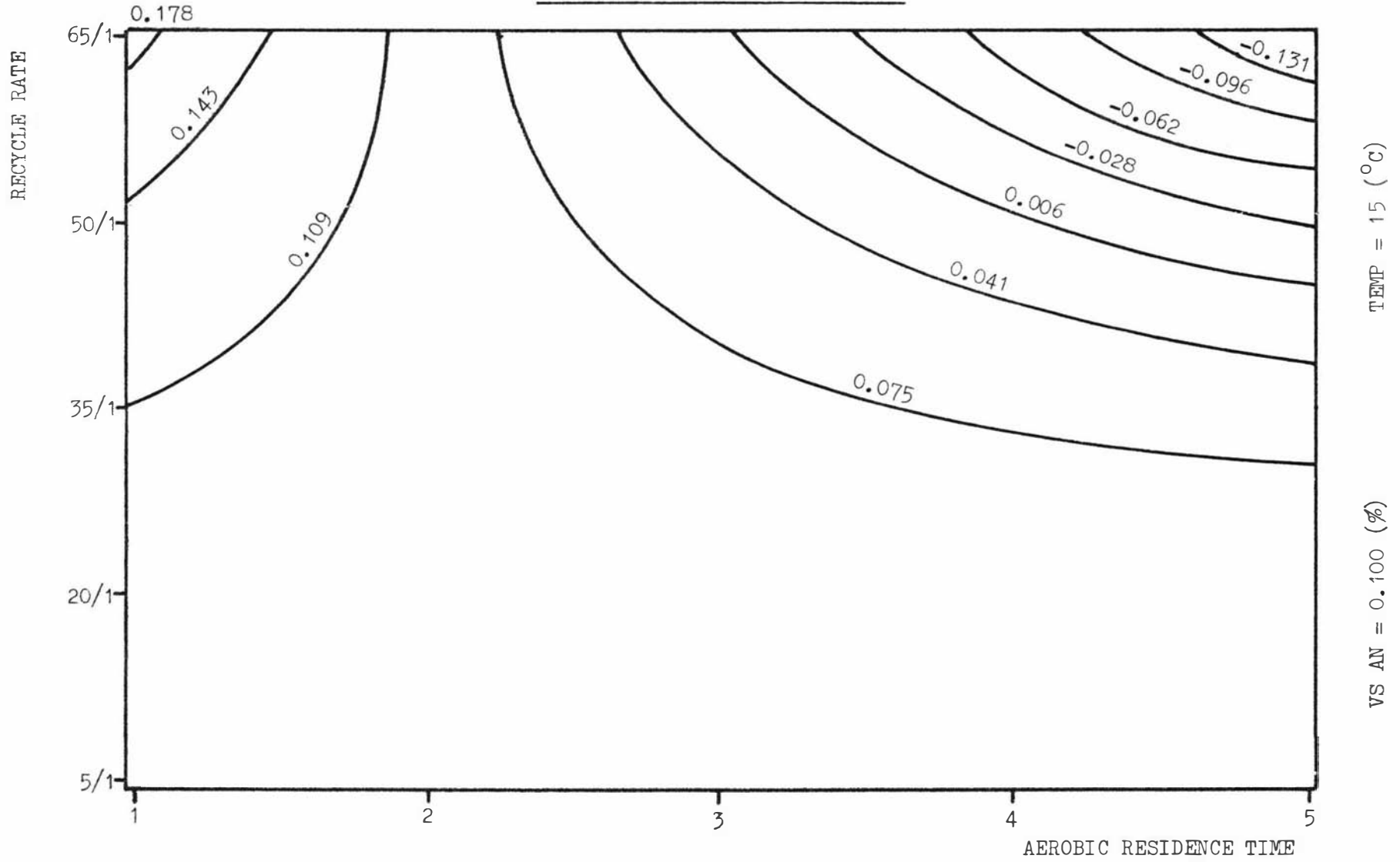
CONTOUR PLOT TO PREDICT TS OUT



TS AN = 0.150 (%)

FIGURE 8: 11

CONTOUR PLOT TO PREDICT VS OUT



solids removed from the laboratory plant aerobic tanks when aerobic residence times were being altered for new settings. At the middle and end of the experimental period the tanks were cleaned out completely, enabling two estimates of solids accumulation (Table 8:16).

The mean TS accumulation rate of 12.6% TS IN provided a 56% TS accumulation/unit BOD removed. This value is high, indicating a low soluble BOD fraction (265), and the need to transfer the secondary sludges back to the anaerobic tank. The settled sludge was removed as a 1.0% TS slurry with a VS level of 69% TS.

Some gassing occurred in the settled solids but this did not prevent the sludge from settling (Figure 8:12). The rapid settling, lack of odour and absence of fibrous material, made the aerobic sludges easier to handle than the anaerobic solids. No problems are envisaged with their disposal in full scale operation.

8:4.4) Treatment Plant Comparisons

Table 8:17 provides the average loading rates to the field plant trickling filter. They are similar to those of the laboratory plants (Table 8:9).

Table 8:18 gives a comparison between similar treatments on laboratory plants, and laboratory and field plants, based on COD and TS output concentrations. Other data reveal similar trends.

The laboratory plants were similar, with the greatest discrepancy occurring at a 3 day aerobic residence time and a 20/1 recycle setting. This variation was only 5.5% and was not considered significant, therefore, similarly designed and operated plants may be expected to provide similar treatment levels.

A comparison of the laboratory and field plant data shows acceptable agreement between values, except at low residence times and high recycle rates. The 30% improvement of discharge concentration in the field plant was significant. Since operation at low residence times and high recycle rates was generally unstable, the greater treatment efficiencies in the field plant could be expected. The greater distances between the filter outlet and final discharge would give

TABLE 8:16

SOLIDS ACCUMULATION IN THE LABORATORY PLANT AEROBIC TANKS

TS AN (kg)	TS OUT (kg)	TS REM (kg)	TS DEST.	% TS IN ACCUM. ⁽¹⁾
6.050	4.540	0.715	0.795	11.8
6.670	5.500	0.888	0.282	13.3
(1.784) ⁽²⁾	(1.173)	(0.627)	-(0.016)	(35.0)

$$\text{NOTE: (1) \% TS IN ACCUM.} = \frac{\text{TS ACCUM}}{\text{TS IN}} \times 100$$

$$\text{TS ACCUM.} = (\text{TS AN} - \text{TS OUT}) - \text{TS DEST.}$$

(2) Values in brackets are corresponding VS analyses.

FIGURE 8:12

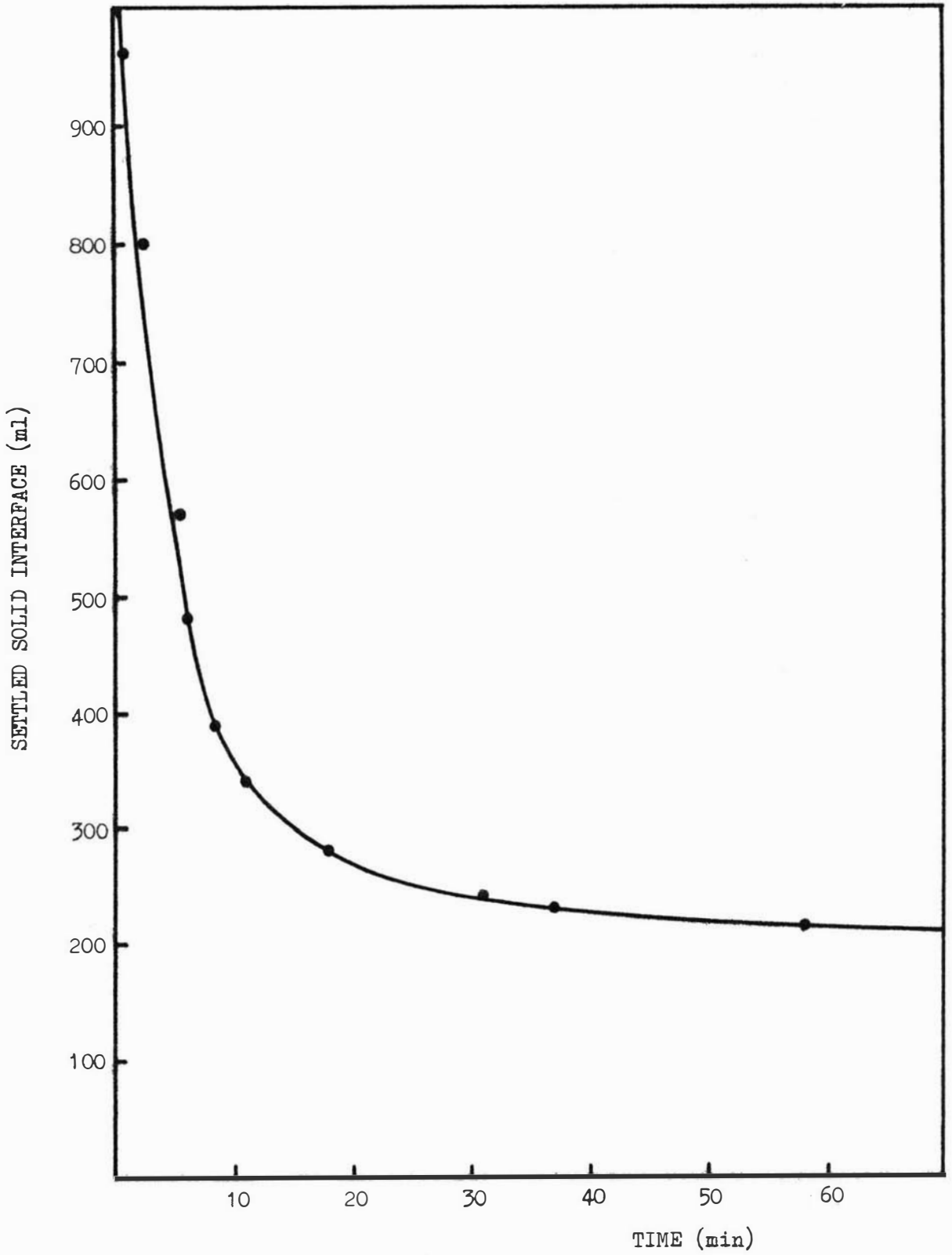
SETTLING CURVE FOR AEROBIC SLUDGE REMOVED FROM LABORATORY PLANTS

TABLE 8:17

FIELD PLANT - DAILY AEROBIC LOADING RATES

VARIABLE	BLOCK I	BLOCK II	BLOCK III	MEAN
COD (kg/m ³ -day) (1)	0.656	0.522	0.520	0.566
BOD (kg/m ³ -day)	-	-	-	-
TS (kg/m ³ -day)	0.528	0.494	0.558	0.527
VS (kg/m ³ -day)	-	0.287	0.301	0.294
Flow 5/1 (m ³ /m ² -day)	2.52 (1.56) ⁽²⁾	2.42 (1.50)	2.26 (1.40)	2.41
20/1 (m ³ /m ² -day)	9.20 (5.71)	10.42 (6.47)	10.85 (6.74)	10.16
35/1 (m ³ /m ² -day)	18.04 (11.20)	18.04 (11.20)	16.61 (10.31)	17.60

NOTES: (1) Loadings are based on the trickling filter volume of 1.635 m³.

(2) Figures in brackets give the flow in litre/min onto the filter.

TABLE 8:18

PLANT COMPARISONS FOR AEROBIC TREATMENT

RECYCLE RATE	PLANT	AEROBIC RESIDENCE TIME					
		1 DAY		2 DAY		3 DAY	
		COD OUT (mg/l)	TS OUT (%)	COD OUT (mg/l)	TS OUT (%)	COD OUT (mg/l)	TS OUT (%)
5/1	L _A ⁽¹⁾	541	0.127	715	0.108	633	0.113
	L _B			714	0.104		
	F ⁽²⁾	547	0.155	614	0.101	641	0.107
20/1	L _A	1618	0.173	1650	0.232	885	0.155
	L _B					938	0.161
	F	1138	0.144	985	0.209	939	0.152
35/1	L _A	1381	0.187	536	0.093	484	0.190
	L _B	1312	0.194				
	F	849	0.150	554	0.102	603	0.161

NOTES: (1) L_A and L_B are the two laboratory plants
 (2) F is the field plant

improved settling, and the size of the field plant would make it less susceptible to the effect of small changes.

Apart from operating at low aerobic residence times and high recycle rates, the laboratory and field plants may be considered to achieve similar efficiencies.

8:5) CORRELATION OF BOD AND COD

Regression equations to estimate BOD based on COD data did not yield high coefficients of determination.

Comparison of the anaerobic outlet data gave the equation;

$$\text{BODAN (mg/l)} = 43.448 + 0.280\text{CODAN (mg/l)}$$

Although significant at 1%, the coefficient of determination was only 0.60, making it of limited value.

Taking aerobic discharge values and using a step-wise regression, the first correlation was;

$$\text{BODOUT (mg/l)} = -24.61 + 0.305\text{CODOUT (mg/l)} \quad (\text{CD} = 0.66^{**})$$

However, inclusion of treatment effects gave;

$$\text{BODOUT (mg/l)} = 3.940 + 0.266\text{CODOUT} + 49.404\text{B}^2\text{C} - 57.019\text{BC}^2 \\ (\text{CMD} = 0.77^{**})$$

The significant interaction of treatment effect on the BOD/COD correlation reduces the practical value of the regression.

CHAPTER 9

GENERAL DISCUSSION

9:1) TOTAL PLANT TREATMENT EFFICIENCIES

The treatment efficiencies over both the anaerobic and aerobic phases were estimated for a 3 day aerobic residence time and a 35/1 recycle rate (Table 9:1). The selection of an anaerobic residence time is not critical due to its limited effect on whole plant treatment efficiencies. However, anaerobic preconditioning by solids removal and waste liquifaction was important in that it enabled satisfactory aerobic treatment in only 1-3 days.

If values obtained at the bottom of the filter (Tables 8:13 and 8:14) are used instead of the final discharge values, i.e., a COD of 550 mg/l and a BOD of 90 mg/l, total treatment efficiencies are 92% and 94% respectively.

Under the worst conditions of low aerobic residence times and high recycle rates, treatment efficiencies of 77-84% removal were achieved with BOD, COD, TS and VS. These values are on the lower limit of the plant selection criteria (Chapter 3:1), indicating that the whole system could maintain a reasonable treatment efficiency under varying operating conditions.

There was some evidence to suggest a "spring flush" of solids from the trickling filter. Data collected for the October settings gave high COD, BOD and TS values through the aerobic treatment, particularly at the bottom of the filter. This phenomenon is characteristic of many trickling filters (246, 248, 268) but causes few operational difficulties.

A visual appraisal of treatment through the plant (Plate 9:1) supports the earlier conclusion that the liquor at the bottom of the filter was of a higher standard than the final discharge. The samples were agitated prior to photographing to show the presence of suspended solids. The quality would be further improved if the floc was settled. The colour, due to chlorophyll pigments, could not be completely removed. The absorbance, at 680 nm, of the final discharge was decreased by only 20% after passing through No.1 Whatman filter paper. High speed centrifugation was required for any further decrease in absorbance.

TABLE 9:1ANAEROBIC/AEROBIC TREATMENT EFFICIENCIES

PARAMETER	UNIT	RAW WASTE INPUT	FINAL DISCHARGE	% REMOVAL
COD	mg/l	6,599	700	89
BOD	mg/l	1,505	160	89
TS	%	0.717	0.104	85
VS	%	0.490	0.055	89

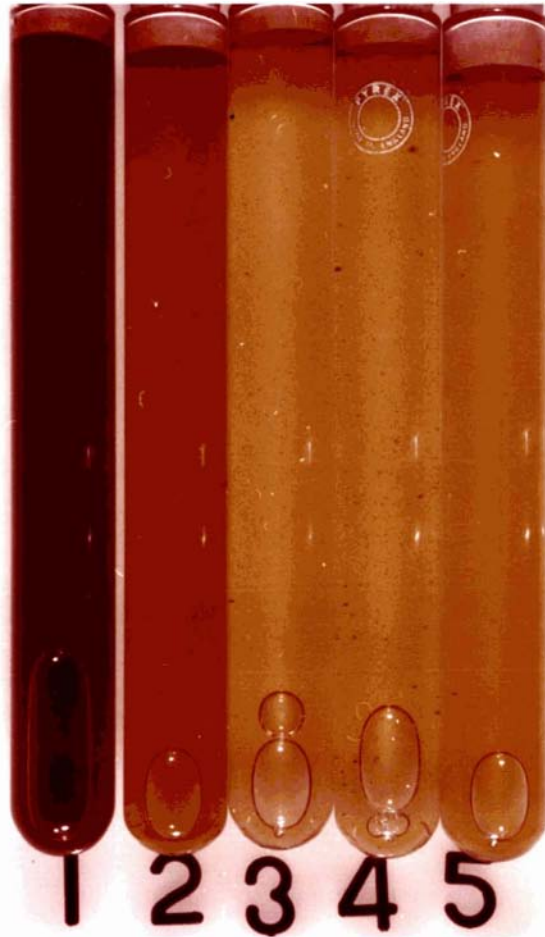


PLATE 9:1 Visual appraisal of dairy shed effluent during treatment. (Numbers correspond to those given in Figure 6:1)

9:2) NITROGEN ANALYSIS

9:2.1) Nitrate Nitrogen

Inspection of data in Table App. V:2 shows no anaerobic block effect on $\text{NO}_3\text{-N}$. Pooling blocks, and attributing any treatment effect to the aerobic phase, Table 9:2 summarizes the $\text{NO}_3\text{-N}$ data. The trends reflect those obtained by other workers (Chapter 2:5.4,5) in that nitrification increased with increasing BOD removal. The effect of increasing recycle in increasing nitrification is not typical, as the greater competition of heterotrophs washed deeper into the filter with the higher flows generally decreases autotrophic activity (79, 254). The high DO levels and the moderate hydraulic load (despite the high recycle rates) probably offset this trend and, in fact, improved conditions for nitrification within the filter. Aeration period had little effect on nitrification.

The $\text{NO}_3\text{-N}$ discharge concentrations of 16-60 mg/l showed a 7-23 fold increase over the raw effluent. While an increase was expected from theoretical considerations, this level of $\text{NO}_3\text{-N}$ may make the final discharge unacceptable for natural waters.* However, high removals of other factors (Table 9:1) suggest that the effluent would be suitable for recycling in the dairy shed to clean holding yards. This would enable periodic discharge to land of a low solid, high nutrient liquid. The limited volumes involved would minimize runoff and infiltration (Chapter 2:3.3), labour requirements and maintenance.

9:2.2) Ammoniacal Nitrogen

No clear trends are evident in the $\text{NH}_4\text{-N}$ data. The interaction between the anaerobic and aerobic phases does not allow the final discharge concentration to be attributed to any particular treatment. The $\text{NH}_4\text{-N}$ concentration ranged from 5-50 mg/l, providing anything from a 50% increase to a 70% decrease by comparison with the raw waste.

* There are no regulations controlling the discharge of N or P at present. However, their introduction in the near future seems inevitable.

TABLE 9:2

NO₃-N DISCHARGE CONCENTRATIONS RELATIVE TO AEROBIC TREATMENT FOR LABORATORY PLANTS

Recycle	Aerobic Residence Time					
	1 Day		2 Day		3 Day	
	Discharge (mg/l)	% Increase	Discharge (mg/l)	% Increase	Discharge (mg/l)	% Increase
5/1	23.16	1430	16.13	629	15.72	670
20/1	64.86	1621	37.15	899	49.25	1121
35/1	45.38	1199	24.43	865	61.72	2237

9:2.3) Kjeldahl Nitrogen

Table 9:3 shows an increase in TKN removal with increasing anaerobic residence time. This may be a treatment effect but is more likely to reflect variations between blocks, as there is no indication that discharge concentrations of TKN show a similar trend. Increasing recycle rates gave a slight increase in TKN removal which would be partly due to the increase in NO_3^- -N. Average TKN discharge concentrations ranged from 60-70 mg/l with 65-70% overall removal.

DKN, like NH_4^- -N, shows no clear trends with variation in treatment. Discharge values of 30-50 mg/l gave 50-70% removal.

9:2.4) Total Nitrogen

The removal of TN and TDN was not as great as the TKN and DKN values suggest, due to the increase in NO_3^- -N. Taking the average raw effluent values (Table 8:1) and mean discharge figures, the treatment efficiencies for all N fractions can be estimated (Table 9:4).

The high TPN removal would probably have been achieved with solids settling in the anaerobic tank. The 36% TDN removal may have resulted from a combination of gaseous losses in the anaerobic tank and microbial growth (secondary sludge) removal in the aerobic phase.

Comparison of the mean and optimum conditions in Table 9:4 indicates the change in N fractions at high aerobic residence times and recycle rates. The effect of treatment on all N forms, except NO_3^- -N, is small, suggesting that NO_3^- -N is the main N fraction requiring further monitoring.

9:3) PHOSPHORUS ANALYSIS

Investigation of the effect of treatment on phosphorus removal revealed no significant trends. DIP concentrations of 15-25 mg/l in the discharge gave a 2-7 fold increase by comparison with the raw waste. TDP followed a similar trend but showed a lower, 0.8 to 5.0 fold, increase during treatment. Discharge TP ranged from 18-30 mg/l, a 20-45% decrease.

Table 9:5 provides mean values of input and output data. The large decrease in TPP corresponds with the TPN data and probably reflects solids sedimentation. Large increases in DIP and TDP parallel the

TABLE 9:3

TN REMOVAL FOR LABORATORY PLANTS

Recycle	Block	Aerobic Residence Time					
		1 Day		2 Day		3 Day	
		Discharge (mg/l)	% Decrease	Discharge (mg/l)	% Decrease	Discharge (mg/l)	% Decrease
5/1	I	56.6	-42.7	74.2	-24.9	82.5	1.2
	II	67.0	-66.0	52.6	-66.5	83.8	-59.5
	III	67.9	-72.2	60.6	-70.9	65.4	-68.6
20/1	I	64.0	-70.0	34.0	-63.1	231.2	-35.8
	II	70.0	-72.7	86.0	-58.5	34.0	-75.4
	III	68.0	-73.1	97.0	-69.1	48.4	-84.1
35/1	I	83.2	-61.0	21.0	-77.2	64.8	-20.1
	II	82.0	-68.0	30.4	-78.0	46.0	-76.7
	III	85.3	-65.9	36.4	-85.1	38.0	-84.9

TABLE 9:4

ANAEROBIC/AEROBIC TREATMENT EFFECT ON NITROGEN CONCENTRATIONS
IN LABORATORY PLANTS

	Raw Waste (mg/l)	Mean Conditions		Optimum Conditions ⁽¹⁾	
		Discharge (mg/l)	Difference (%)	Discharge (mg/l)	Difference (%)
NO ₃ -N	2.9	35	1107 (12 fold)	45	1452 (15 fold)
NH ₄ -N	26.4	20	-24	16	-39
TKN	205	65	-68	60	-71
DKN	115	40	-65	36	-69
TDN	118	75	-36	81	-31
TN	208	100	-52	105	-49
TPN	90	25	-72	24	-73

NOTE: (1) Optimum conditions are high aerobic residence times and high recycle rate.

TABLE 9:5

ANAEROBIC/AEROBIC TREATMENT EFFECT ON PHOSPHORUS
CONCENTRATIONS IN LABORATORY PLANTS

	Raw Effluent (mg/l)	Discharge (mg/l)	Difference (%)
DIP	4.51	18.60	312 (4 fold)
TDP	6.49	20.94	213 (3 fold)
TP	35.20	24.06	-32
DOP	1.98	1.74	-12
TPP	28.71	3.72	-87

$\text{NO}_3\text{-N}$ trends and would be of concern if the effluent was discharged into a water course.

9:4) POLLUTION LOADS ON NATURAL WATERS

Applying the total plant treatment efficiencies (Tables 9:1, 9:4, 9:5) to the daily pollution loads from the dairy shed (Table 8:2), the loadings into a natural water course may be calculated (Table 9:6).

The BOD and VS loadings are minimal and could be reduced to 0.005 kg BOD/cow-day and 0.024 kg VS/cow-day if the liquor at the bottom of the filter was discharged. The increased concentration of dissolved N and P could cause eutrophication despite the low total loads. Periodic land application, in association with hydraulic recycle, would alleviate the problem.

9:5) PLANT OPERATION

9:5.1) Loading and Daily Maintenance

Manual loading of the field and laboratory plants required approximately 1 hour per day. Gravity-feed in a commercial installation would remove this labour requirement. Daily maintenance was minimal and comprised cleaning an occasional blocked anaerobic tank outlet and fixing pump breakdowns.

9:5.2) Pump Performance Problems

The Mono CP 25 had little difficulty in pumping 5% TS slurries removed during anaerobic tank cleaning. The pump had a high wear rate and although it was only used twice daily for loading, and once every 1-2 months for anaerobic tank cleaning, 6 stators and one rotor were replaced during the 15 month experiment. This maintenance would have been greater if a 50% decrease in flow had not been tolerated prior to replacement. The high rotor speed (1,400 rpm) was the primary reason for the wear. Decreasing the pump speed to 300-500 rpm, while increasing the pump size required, would significantly reduce maintenance. On three occasions operation problems (failure of probe switches and a frozen delivery line) would have contributed to the wear rate.

TABLE 9:6

POLLUTION LOADS ON RECEIVING WATERS
AFTER TREATMENT⁽¹⁾

Parameter	Load (g/cow-day)
COD	36.0
BOD	8.0
TS	54.0
VS	27.0
NO ₃ -N	2.266
NH ₄ -N	0.911
DKN	1.783
TKN	2.973
TDN	4.068
TPN	1.215
TN	5.302
DIP	0.904
TDP	0.975
DOP	0.087
TPP	0.187
TP	1.197

NOTE: (1) Aerobic treatment levels of 3 day residence and high recycle rate (mean of 20/1 and 35/1 settings) were selected.

The two rubber impeller pumps used for the trickling filter recycle in the field plant were replaced after 5 months. The continuous duty caused the rubber impellers to either take a permanent "set" or completely disintegrate. Some impellers lasted less than 4 weeks.

The 140mm double ended diaphragm pump driven through a reduction box was reliable. The only maintenance required was an oil change in both units after 5 months of operation.

The variable speed DC motor gave few problems. Four sets of motor brushes and one controller diode were replaced during 15 months continuous duty.

The Hughes variable stroke piston pump was almost maintenance free. The chevron packing, which provided the piston seal, was tightened on two occasions. However, the Cole-Palmer piston pump on the second laboratory plant was not so reliable. The teflon sealed piston was replaced by a leather cup washer and the main driving gear was replaced twice.

9:5.3) Line Blockages through the Treatment Plants

The main problem occurred at the anaerobic outlet. The floating fibrous mat bound around the discharge pipe, reducing flow rates. Baffles were placed in the laboratory plants which reduced, but did not eliminate, the problem. The field plant was less susceptible to blockage at the anaerobic discharge as a result of the larger pipe size.

To reduce the solids load on the filter, and the possibility of recycle line blockages, inlets to the recycle pump were screened through a 2mm mesh. The screen was also required in the field plant to stop leaves, which were blown into the tank, blocking the inlets. The screens acted as a support for the microflora and required fortnightly cleaning with a water jet to avoid blocking. Cleaning was particularly important at the higher flows. Increasing screen area and mesh size would reduce the maintenance required without affecting plant performance.

The recycle lines in the laboratory plants were flushed every 3-4

weeks. The field plant recycle lines were cleaned on 4 occasions. Little effort was involved.

The rotary tipping bucket required no maintenance and there were no filter blockages.

9:5.4) Solids Cleaning

Anaerobic solids from the laboratory plants were removed mechanically and hydraulically. The surface mat, having a high fibre and TS content, was lifted off the top of the tank with a metal tray. This procedure minimized the volume to be handled. The settled sludge was pumped out using a 0.2 kW Mono MS pump.

The surface solids in the anaerobic tank of the field plant were pumped out (Mono CP 25) after being broken up and diluted. These solids formed a thick fibrous mat with a sealed, sun bleached surface (Plate 9:2). Reconstituting this material for hydraulic removal would be expensive and time consuming on a commercial unit. It is envisaged that its fibrous nature would allow mechanical removal and land disposal. Settled sludges were removed via the 50mm drain pipe.

All aerobic sludges were removed as a pumped slurry.

The complete cleaning procedure for the three plants, including sample collection and measurement, required 7 hours. A full scale unit would require approximately one days labour for solids cleaning. The frequency would depend on design.

The only time any significant odour was detected was during cleaning. A slight odour could be detected adjacent to the aerobic inlet of the field plant. A submerged inlet would eliminate this.

9:5.5) Plant Scale Effects on Operation

The inability to scale particle size and effluent composition produced problems with small scale operation. Although the laboratory plants gave equivalent treatment efficiencies, the small size of pumps, feed lines and filter media required greater attention.



PLATE 9:2 Solid crust on field plant anaerobic tank.

The scale increase from the field plant to a full size unit should further reduce maintenance problems as proportionately larger equipment may be used.

CHAPTER 10

CONCLUSIONS

10:1) DAIRY SHED EFFLUENT

- (a) The daily composition of dairy shed effluent fluctuates widely with standard deviations up to 35% of the mean (Appendix V).
- (b) Seasonal variations in the raw effluent were observed but are considered to be of little consequence (Appendix VII).
- (c) Pollution loads from the dairy shed average 0.075 kg BOD/cow-day and 0.360 kg TS/cow-day (Table 8:2).
- (d) Satisfactory predictions of; COD from TS, BOD from COD, VS from TS and DKN from TKN may be made for dairy shed effluent (Table 8:3).

10:2) ANAEROBIC TREATMENT

- (a) Loading rates of 0.63-1.35 kg COD/m³-day and 0.67-1.36 kg TS/m³-day have little effect on COD and TS removals, giving an average of 71% for both. BOD removals increase from 50% to 77% as the loading rates decrease with the greatest increase occurring at loadings of 0.14 kg BOD/m³-day. i.e., when anaerobic residence times rise to 10 days. The pH and E_h remain stable irrespective of treatment, and average 7.0 and -50mV respectively.
- (b) Sludge accumulation rates range from 0.0050 - 0.0071 m³ kg TS IN. Solids loading and accumulation rates are considered to be the primary design factors for anaerobic tanks receiving dairy shed effluent.
- (c) Sludge cleaning may be delayed until the mean hydraulic residence time has been reduced to 3-5 days. The floating solids form a thick fibrous mat which may be removed mechanically and disposed to land.
- (d) Anaerobic treatment efficiencies are unaffected by variations in scale.

10:3) AEROBIC TREATMENT

- (a) Increasing aerobic residence time from 1-3 days, and increasing hydraulic loads to the trickling filter from 2.8-18.2 $\text{m}^3/\text{m}^2\text{-day}$, improves aerobic treatment. The removals of 43-73% BOD, 42-60% COD and 19-29% TS are satisfactory.
- (b) Alterations to allow final discharge directly from the bottom of the filter, rather than from the aerobic tank, will improve treatment efficiencies giving up to 85% BOD removal.
- (c) Insensitivity of treatment efficiency to minor alterations in operating conditions at approximately 3 days residence time and 15-20 $\text{m}^3/\text{m}^2\text{-day}$ hydraulic load suggests that these settings are suitable for commercial operation.
Unstable operating conditions occur at low aerobic residence times and high hydraulic loadings.
- (d) Solids accumulation up to 13% TS IN, or 55%/unit BOD removal, is high and requires consideration in aerobic tank design.
- (e) There is some evidence to suggest that increasing anaerobic residence time decreases the % COD removal in the aerobic phase.
- (f) Variation in scale has little effect on aerobic treatment efficiency, except under unstable operating conditions where larger scale units give improved performance.
- (g) COD is not a good indicator of BOD for treated liquor because of strong treatment interactions in the relationship.

10:4) TOTAL PLANT OPERATION

- (a) Single tank anaerobic/aerobic treatment is unsatisfactory due to solids accumulation. Anaerobic treatment in a separate tank prior to trickling filter aeration is more suitable. Removals of 85-89% for BOD, COD and TS may be obtained with this twin tank anaerobic/aerobic treatment system. Values up to 94% removal would be expected with minor alterations in

design. The brownish/green colouration of the liquor can not be totally removed.

- (b) Total nitrogens were reduced by approximately 50% with the greatest contribution coming from a large decrease in TPN. In the case of $\text{NO}_3\text{-N}$, concentrations increased 15 fold with treatment, giving a final discharge of approximately 45 mg/l. Discharge DIP concentration of 18.6 mg/l was 4 times that of the raw effluent, though TP had a 32% decrease during treatment.
- (c) Pollution loads after treatment of 0.008 kg BOD/cow-day and 0.054 kg TS/cow-day are acceptable. However, $\text{NO}_3\text{-N}$ of 2.266 g/cow-day and DIP of 0.904 g/cow-day may cause some concern if discharged to a water course. Recycled liquor would be suitable for yard cleaning followed by intermittent land disposal.
- (d) Minimum maintenance and operational requirements, in association with acceptable treatment efficiencies, suggest that this anaerobic/aerobic treatment system would be suitable for dairy shed pollution abatement. Periodic cleaning of the anaerobic tank is the major operational problem.

CHAPTER 11

APPLICATION OF ANAEROBIC TREATMENT AND TRICKLING FILTER

AERATION TO THE N.Z. DAIRY INDUSTRY

11:1) DESIGN OF A FULL SCALE ANAEROBIC/AEROBIC TREATMENT PLANT

The design of an anaerobic/aerobic treatment plant for a 250 cow factory supply dairy shed is presented in Appendix VIII.

Anaerobic tank volumes were selected to provide a 2 year sludge removal frequency. A 4 day aeration period, while higher than that used in this study, allows for some decrease in residence time due to solids accumulation. The trickling filter is 2m high and 4m square and requires a 0.25 kW motor to power the recycle pump.

The complete treatment plant would occupy 1,100m², a large proportion of which is taken up by the embankments (Figure 11:1).

11:2) PERFORMANCE AND OPERATION OF THE TREATMENT PLANT

Total daily and annual pollution loads, after treatment, are presented in Table 11:1. The two factors that could cause concern are the levels of TS and dissolved N and P. The low BOD and the limited effect of filtration on the absorbance of the discharge (Chapter 9:1) suggest that the greatest proportion of the TS would be dissolved. The COD levels are of little consequence when considered in association with BOD.

The annual dissolved N and P fractions of the discharge would provide the fertilizer value of approximately 600 kg urea and 850 kg super-phosphate respectively. The effect of this N and P on a water course would depend on dilution ratios and residence time. To utilize these nutrients and avoid any eutrophication, the aerobic liquor may be applied to the land. Intermittent disposal may be achieved by coupling the recycle pump into a spray disposal system, or by allowing the final discharge to be released over a border dyked area. Therefore, dilutions by the receiving water, or land application, would eliminate any possible problem with N and P.

Colour may be of concern if the effluent is discharged into a water course, but with a volume of only 17.5 m³/day stream dilution would minimize any effect.

Operational requirements are minimal and would include periodic inspection of the recycle pump and distributor. Solids removal

FIGURE 11:1

ANAEROBIC/AEROBIC EFFLUENT TREATMENT PLANT FOR A
250 COW FACTORY SUPPLY DAIRY FARM

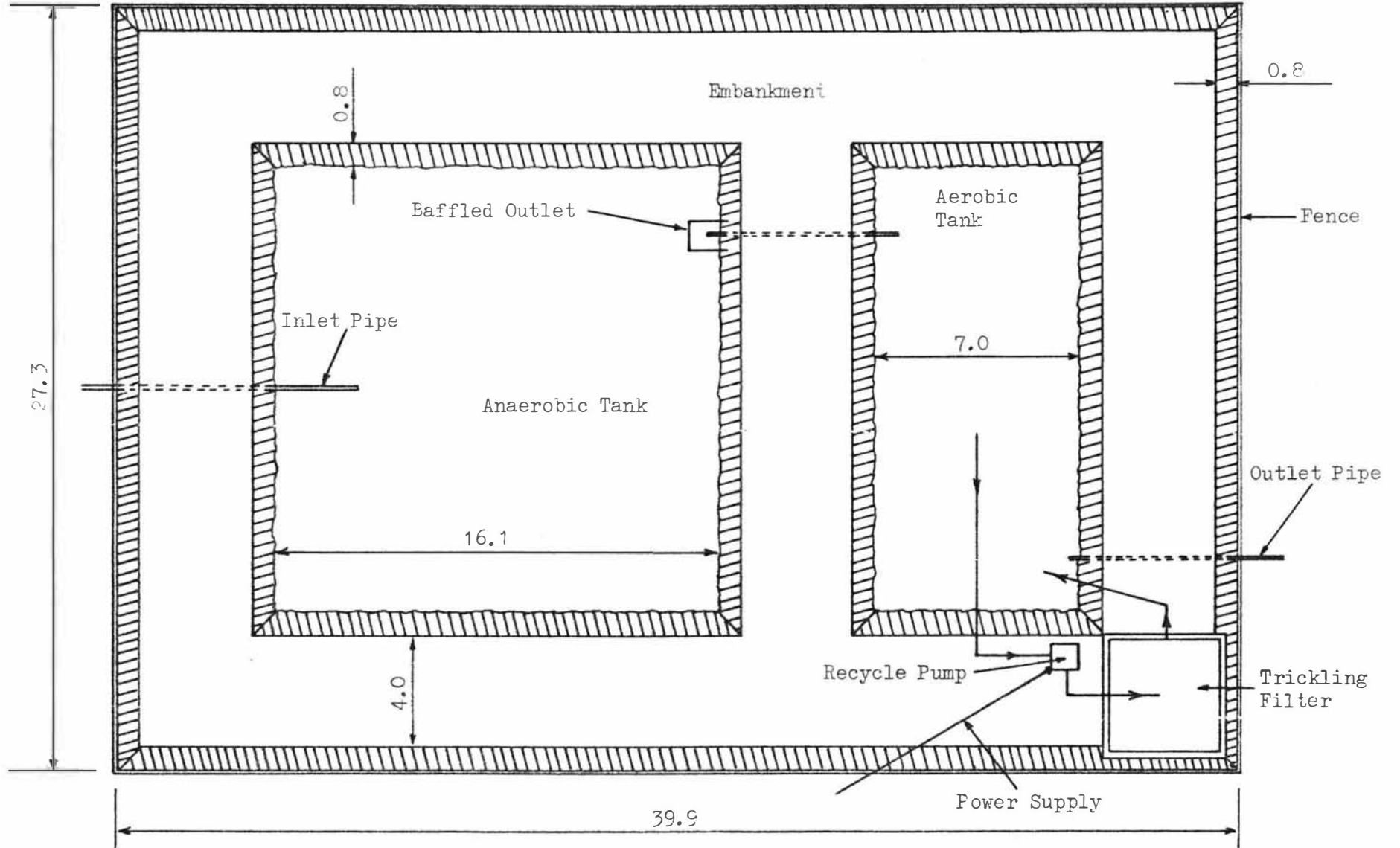


TABLE 11:1

DAILY AND ANNUAL POLLUTION LOADS DISCHARGED FROM AN
ANAEROBIC/AEROBIC TREATMENT PLANT RECEIVING EFFLUENT
FROM A 250 COW FACTORY SUPPLY DAIRY SHED

Parameter	Total Load	
	kg/day	kg/year
COD	9.00	2520
BOD	2.00	560
TS	13.50	280
VS	6.75	1890
NO ₃ ⁻ -N	0.57	159
NH ₄ ⁻ -N	0.23	64
DKN	0.45	125
TKN	0.74	208
TDN	1.02	285
TPN	0.30	85
TN	1.33	371
DIP	0.23	63
TDP	0.24	68
DOP	0.02	6
TPP	0.05	13
TP	0.30	84

every two years would take approximately one day. The total solids removed would be 20.7 tonnes TS which may be disposed onto less than 1 ha of land and preferably ploughed down.

The lack of raw effluent during winter is not considered to be a problem as decomposition of the aerobic sludges would continue to provide a nutrient source. Should the recycle pump be shut off, the filter would dry out but rapid film establishment once normal operating conditions are resumed would minimize any effect on total plant treatment.

Selection of a larger recycle pump would allow the liquor to be recycled to the shed for yard cleaning if desired.

11:3) CAPITAL AND OPERATING COSTS

The capital cost of constructing a full scale treatment plant would be approximately \$3,700 (Appendix VIII).

The inlet/outlet structures, power supply and much of the labour costs would remain unaltered for larger scale operation. This aspect, along with greater savings in land area compared to lagoons, favours the use of trickling filter aeration in larger units or where land is at a premium.

Operating costs of \$600/year are not excessive (Appendix VIII).

This costing, in association with the treatment efficiencies, minimum maintenance and the small land area required, suggests that anaerobic treatment followed by trickling filter aeration is a viable alternative to spray disposal and lagooning.

CHAPTER 12

RECOMMENDATIONS

- I) Monitoring of dairy shed waste should continue to confirm:
- (a) The extent and significance of seasonal fluctuations.
 - (b) The influence of the milking routine and milking machine cleaning procedures on effluent composition.
 - (c) The accuracy of the COD/TS, BOD/COD, VS/TS and DKN/TKN relationships.
- II) Further investigations into solids handling and decomposition should concentrate on:
- (a) The advantages of sedimentation and anaerobic digestion versus other forms of solid/liquid separation and treatment, e.g., composting.
 - (b) Mechanical methods for solids removal from the anaerobic tank surface and subsequent disposal onto the land.
 - (c) The influence of sludge removal frequency on TS destruction in the anaerobic tank.
- III) Trickling filter studies should determine:
- (a) The influence of anaerobic residence time on removal rates in the filter.
 - (b) The ability of the filter to recuperate after periods of minimum loading, e.g., while the herd is not being milked.
 - (c) The advantages or disadvantages of using plastic rather than stone media.
- IV) It is suggested that a full scale anaerobic/aerobic treatment plant using trickling filter aeration be installed to enable these aspects to be studied, and to establish:
- (a) The performance, economics and operational problems of a commercial unit.
 - (b) The feasibility of recycling the aerobic liquid for yard cleaning, with intermittent discharge to land.

APPENDIX I

REPORTED CHARACTERISTICS OF DAIRY SHED EFFLUENT

I:1) EFFLUENT PRODUCTION PER COW

The characteristics of effluent produced per cow per day are dependent on;

- (a) The feed: e.g., the roughage content
- (b) The animal: e.g., its size, breed and physiological state
- (c) The environment: e.g. heat stress or maltreatment.

Sampling and analytical difficulties further affect the values obtained (6, 109).

A selection of data reported in the literature is given in Table App.I:1. The values shown are the range and means from all references cited and as such do not refer to any specific paper. They are mainly based on American work with housed animals, many of which were receiving high energy, low fibre diets.

Tables App. I:2 and App. I:3 are given for comparison and are taken from Bryant's nutritional studies with cows during various stages of lactation under N.Z. conditions (202).

I:2) DAIRY SHED EFFLUENT PRODUCTION

The only effluent causing concern is that produced at the shed during milking and routine stock work. In addition to the animal excreta, there are soil and milking machine washings (113). These pollutants are discharged through a common outlet with large volumes of dilution water.

The pollution load per cow-day from the yard has been estimated to be 2-10% of daily cow effluent production (3, 7). These estimates are based on the quantity of dung and urine deposited on the yard being proportional to yarding time (3, 7, 114). General surveys indicate that volumes range from 15-70 litre/cow-day (7, 111, 116, 117), with case studies giving up to 95 litre/cow-day (10). The resulting dilution ratios range from 4:1 to 45:1.

The volume of effluent is directly influenced by the milking routine, e.g., the water used in udder and cup washing, and the design and operation of yard and plant cleaning systems. High pressure hoses and reverse flow cleaning, while reducing the labour input, have

TABLE APP. 1:1

WASTE PRODUCTION PER COW PER DAY (1)

Parameter	Unit	Range	Mean
Volume	litre/cow-day	23-55	40
Mass	kg/cow-day	23-55	40
	% body weight	7-10	8.5
Total solids (TS)	% wet weight	9-17	12
Volatile solids	% TS	70-80	78
Faeces/urine	%	60/40 - 75/25	65/35
BOD	kg/cow-day	0.5 - 1.2	0.8
COD	kg/cow-day	0.5 - 2.8	2.4
COD/BOD	-	1/1 - 6/1	3/1
Nitrogen	kg/cow-day	0.06 - 0.19	0.13
	% TS	2.7 - 4.0	3.2
Phosphorus	kg/cow-day	0.04 - 0.10	0.06
	% TS	0.5 - 1.1	0.8
Potassium	kg/cow-day	0.07 - 0.16	0.11
	% TS	0.8 - 3.0	2.4
Calcium	kg/cow-day	0.05 - 0.08 ⁽²⁾	0.06
	% TS	1.0 - 1.6	1.15
Magnesium	kg/cow-day	0.03 - 0.04 ⁽²⁾	0.03
	% TS	0.6 - 0.76	0.70
Bacteria	number/g wet faeces	Coliform	4.5×10^5
		Enterococci	8.0×10^7

(1) References used in compiling table:- 2, 3, 7, 43, 44, 58, 60, 88, 94, 95, 103, 116, 117, 119, 201.

(2) Estimated from % TS values.

TABLE APP. I:2

QUANTITIES OF WASTE PRODUCED FROM COWS FEDPASTURE OR SIMILAR RATIONS

Feed	Parameter	Faeces	Urine	Faeces + Urine
Pasture	Wet weight (kg/cow-day)	29	25	54
	Dry weight (kg/cow-day)	3.19	1.18	4.37
	% TS	11	4.7	8.1
Other Rations e.g. Maize Silage	Wet weight (kg/cow-day)	24	16	40
	Dry weight (kg/cow-day)	3.36	0.75	4.11
	% TS	14	4.7	10.3

TABLE APP. I:3

CHARACTERISTICS OF WASTE PRODUCED BY COWS FED PASTURE OR SIMILAR RATIONS

FEED	ELEMENT	FAECES		URINE		FAECES + URINE	
		kg/cow-day	% of TS	kg/cow-day	% of TS	kg/cow-day	% of TS
Pasture	N	0.105	3.30	0.135	11.49	0.240	5.49
	P	0.023	0.73	0.002	0.17	0.025	0.57
	K	0.049	1.55	0.263	22.38	0.312	7.10
	Ca	0.072	2.26	0.002	0.17	0.074	1.69
	Mg	0.021	0.66	0.003	0.25	0.024	0.50
Other	N	0.081	2.40	0.099	13.20	0.180	4.38
Ration e.g.	P	0.016	0.48	0.001	0.13	0.017	0.41
	K	0.033	0.98	0.131	17.47	0.164	3.99
Maize	Ca	0.034	1.01	0.002	0.27	0.036	0.88
Silage	Mg	0.013	0.38	0.003	0.40	0.016	0.39

significantly increased the total volume of water used (113). An average of 60-70 litre/cow-day may be used.

The composition of effluent from the dairy shed can be calculated or measured. A comparison of methods and resulting pollution loads are shown in Table App. I:4.

I:3) HYDRAULIC PROPERTIES OF DAIRY EFFLUENT

Most effluents are handled as a slurry, hence their flow characteristics are important. These are summarized from published work (91-93, 235) in Table App. I:5.

As %TS increases, the efficiency of pumping drops, while with centrifugal pumps the emphasis on open impellers to handle the solids causes a reduction in the total head developed. The wear rate also increases, particularly in positive displacement pumps which reduces the total efficiency. A solids level of 1-3% is regarded as optimal for pumping systems.

TABLE APP. I:4

COMPARISON OF EFFLUENT LOADS DISCHARGED FROM DAIRY SHEDS

PARAMETER	CALCULATED		MEASURED	
	(1)	(2)	(3)	(4)
BOD (kg/cow-day)	0.060	-	0.088	0.059
SS (kg/cow-day)	-	-	0.280	-
TS (kg/cow-day)	0.360	0.320	-	0.450
N (g/cow-day)	10.0	15.7	10.1	13.5
P (g/cow-day)	4.5	1.6	2.9	1.8

- NOTE: (1) Calculated using 7.5% of values given in Table App. I:1. 7.5% is taken to allow for all stock work in the yards.
- (2) Calculated using 7.5% of the values given in Tables App. I:2 and App. I:3. 7.5% is taken to allow for all stock work in the yards.
- (3) Data from Davis (114), assuming the cows are on the yard for 2 hrs/day and milked for 365 days/yr.
- (4) Data from MacGregor et al. (10), assuming an effluent volume of 90 litre/cow-day.

TABLE APP. I:5

SLURRY CHARACTERISTICS AT VARIOUS SOLIDS CONCENTRATIONS

% TS	Headloss Relative to Water	Fluid Behaviour
2%	Equivalent	Newtonian
2-7%	Slightly less	Variable (1)
7%	Greater	Non-Newtonian

NOTE: (1) Non-Newtonian fluids are obtained at approximately 5% TS and above (235).

APPENDIX II

DEVELOPMENT OF AN ANAEROBIC/AEROBIC TREATMENT
PLANT FOR DAIRY SHED EFFLUENT

PAPER PRESENTED AT

The Biotechnology Conference, Massey University, 1975

BY

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INTRODUCTION

Effluent from dairy sheds, particularly the dung and urine hosed from holding yards, presents a major waste disposal problem on a national scale. It is estimated (1) that the farming sector contributes one third of the total BOD loading on water courses and further work (2) indicates that 50% of dairy farms have unsatisfactory disposal methods.

The volume of waste to be handled at each shed varies from 7,000 to 37,000 litre/day. The flow fluctuates with discharges occurring after each milking. The treatment and disposal systems commonly in use are:

- (a) Spray disposal on to adjacent paddocks.
- (b) Anaerobic/aerobic lagoons.

Spray disposal has a number of advantages, namely:

- (a) The ease of solids disposal.
- (b) The irrigation of pasture during the summer months.
- (c) The application of nutrients and the build-up of humus in the soil.

Points (b) and (c) above are limited in value due to the size of the disposal area. The effectiveness of spray disposal in treating the effluent is still being verified by work progressing in the Soil Science Department at Massey University. The system's efficiency depends on its design, the soil type, the pasture cover and, in particular, the management (3). It is the labour intensive aspects of plant maintenance and operation of sprinklers, as well as doubts of the long term effects of spraying on the soil and pasture, which have caused some farmers to favour lagoons.

Lagoon design in New Zealand is based on loadings of 24 kg BOD/1000 m³/day (4). The primary advantage of this system is its low labour input and minimal maintenance. Treatment efficiencies are good with 92.5% and 96% reductions for BOD and solids respectively (5). This is achieved by a combination of microbial treatment and reduction in the volume discharged due to infiltration. The discharge BOD ranges from 50-350 mg/l (5). However, no figures have been published, to the authors' knowledge, regarding nitrogen and phosphorus

concentrations in the discharge from lagoons in New Zealand. The main disadvantage of lagoons is the loss of production from relatively large areas of land in close proximity to the milking shed.

The drawbacks of both these systems, combined with the increased intensification of production, and hence greater volumes of waste discharged from the milking shed, suggested the need for an alternative treatment system. Furthermore, a lack of local knowledge on agricultural wastes and their treatment prompted this investigation of a simple biological treatment process.

A primary settling/anaerobic tank seemed essential to remove the fibrous solids and allow their decomposition. The supernatant would undergo aerobic treatment to allow some breakdown of surfactants as well as allowing an acceptable effluent to be obtained. A trickling filter was selected because of its simplicity of operation and construction, and its limited previous use for dairy shed effluent treatment (6).

2. LABORATORY PLANT DEVELOPMENT

With simplicity being one of the prime objectives, a single tank system was planned with the hope of maintaining anaerobic decomposition of the sludge in the bottom while aerating the surface layer over the trickling filter.

Effluent from a town supply farm permitted experiments to continue all year and allowed the measurement of seasonal changes in the effluent. The only pre-treatment was a 25 mm mesh used to remove large solids.

Two experimental units of the same design as illustrated in Fig. 1 were built but were of different scale.

Plant 1

The plant was loaded each evening with 22 litre to give an 8 day holding time. Various recycle rates were used over a period of 2 months. The results of the COD analyses are shown in Fig. 2 and were obtained using Standard Methods (16). The wide COD variation

in the raw effluent made analysis difficult and the plant was not entirely satisfactory. The increase in solids caused a steady rise in the output COD and the mean reduction over the period was only 68.7%. Furthermore, the build-up of a solid surface crust up to 100 mm thick created problems in surface aeration and solid decomposition.

Plant II

One of the main purposes for the second unit was to determine how readily a bacterial slime would develop on the filter, as a large secondary population was present in Plant I and the bacterial slime was hardly detectable even after altering the hydraulic loadings to the filter. However, this posed no problems in Plant II as a slime was detected in 7-10 days. COD of the final effluent followed the same trend as in Plant I.

Despite the simplicity of a single tank, the system was regarded as impractical and the introduction of separate tanks for the anaerobic/aerobic treatment was then considered. Not only would this solve much of the solids problem, but would simplify the analysis of results by isolating each of the treatment stages.

3. MODIFIED LABORATORY TREATMENT PLANT

(1) Plant Design

The plant characteristics are included in Table I and the arrangement of the plant shown schematically in Fig. 3. Both anaerobic and aerobic tanks had perspex fronts to enable the solids accumulation rate to be observed. To reduce the fluctuations of COD in the raw effluent a simple automatic sample collector was installed as shown in Fig. 4. The size of sample collected could be varied by altering the percentage of channels covered. The unit is still in operation and appears to be very satisfactory.

(2) Loading Rates

(a) BOD Loading

A summary of anaerobic lagoon loading rates reported in the literature is shown in Table II for comparison with those

presented in Table I.

A high loading of $0.275 \text{ kg BOD/m}^3\text{-day}$ to the anaerobic tank was used to determine how the plant would react to high loadings since it had been suggested (7) that operation at higher loadings could be satisfactory.

The trickling filter loading of $0.20 \text{ kg BOD/m}^3\text{-day}$ was approximately the same as that reported in the literature (6).

(b) Total Solids Loading

Only total solids were analysed but if the widely reported volatile solids content of 80% TS (11) is accepted then the anaerobic loading can be given as $1.76 \text{ kg VS/m}^3\text{-day}$. As with the BOD loading this solid loading rate is significantly higher than those of other workers and has proved to be the greatest problem in the system. The TS loading to the trickling filter was approximately half the $1.06 \text{ kg TS/m}^3\text{-day}$ indicated from a study of the literature.

(c) Hydraulic Loadings

The anaerobic holding time of 5 days is significantly less than that reported in most of the literature (9, 10). However, some workers (8) have studied shorter holding times and this work was to be verified.

The hydraulic loading to the trickling filter of $19.2 \text{ m}^3/\text{m}^2\text{-day}$ with a 2 day holding time was at variance with other workers (6). The high recycle rates used were a matter of convenience, while the short holding time was introduced to reduce plant size and study the effects on short term aeration since little information is reported in this area. Ogilvie and Dale (12) investigated the very short term responses while others (13, 14) studied longer holding times.

(3) Results and Operating Efficiencies

(a) Results

Results are shown in Figs 5 and 6 and summarized in Table III.

Only a limited number of samples were analysed for nitrogen and phosphorus. However, the major trend that emerged as expected, was a drop of 20-60% in total nitrogen and phosphorus with a corresponding 2-4 fold increase in the respective dissolved fractions.

(b) Treatment Efficiency

The 50% BOD removal in the anaerobic tank is comparable with the results of Loehr and Ruf (8). The 83% TS removal compares favourably with the data of other workers (9, 10) despite the short holding time.

The 70% BOD removal and final effluent BOD of 200 mg/l is in agreement with other workers (6) while a 51% reduction in TS is a significant improvement on previous results (6).

(c) Solids Accumulation

Despite the adequate BOD and TS reductions the most significant problem is the rate of solid accumulation in the anaerobic tank. The factors contributing to this build-up are:

- (i) The high loading rates.
- (ii) The less degradable nature of the fibrous solids.
- (iii) The initial anaerobic fermentation of this waste in the rumen, thereby removing the more biodegradable fractions.

The rate of accumulation in the tank necessitated the removal of solids after 60 days of operation and this was repeated after a further 43 days.

A summary of results obtained during the solids removal is shown in Table IV.

The lower value of percent solids reduction in the second cleaning could be due to the longer residence time of the solids before cleaning. However, this may be partially off-set by a lag phase during the starting up of the plant.

There is significant variation in the literature on the extent of solid decomposition (8, 10), while other sources (15) indicate

a much slower rate of solids accumulation than would be anticipated from the literature. The figures obtained, although based on TS, are in general agreement with information available. Based on a 9% TS of the sludge and a maximum solids accumulation of 50% of the tank volume, the cleaning frequency would be 40 days.

4. CONCLUSIONS AND RECOMMENDATIONS

- (1) There is a need for further work in the design and operation of simple treatment systems for agricultural wastes.
- (2) A single tank anaerobic/aerobic treatment plant using a trickling filter for aeration was unsatisfactory.
- (3) The short holding time of 5 days in the anaerobic tank and the consequently high loading rates of 0.275 kg BOD/m³-day and 2.2 kg TS/m³-day gave significantly improved discharge showing a 50% and 83% BOD and TS removal respectively. The solids accumulation rate and associated cleaning frequency was not satisfactory. Further work is required to determine the rates of solid accumulation and effective methods of disposal.
- (4) Short term aeration (2 days) using a trickling filter proved very satisfactory giving a 70% BOD removal and a final effluent of 200 ppm BOD. Further work is required on the recycle rate and aerobic holding time in their effect on BOD removal and the transformations of nitrogen and phosphorus in the waste.

5. ACKNOWLEDGMENTS

J.S. Tyler - for the diagrams in this paper.

Agricultural Engineering Staff - for the construction of the pilot plants.

Soil Science Department - for nitrogen and phosphorus analyses.

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TABLE I

LOADING RATES FOR MODIFIED LABORATORY TREATMENT PLANT

Parameter	Anaerobic Treatment	Aerobic Treatment
Hydraulic loading (litres/day)	8	8
Loading Frequency (no/day)	2	2
Mean Hydraulic Residence (days)	5	2
BOD Loading (kg BOD/m ³ d)	0.275	0.199
TS Loading (kg TS/m ³ d)	2.2	0.548
Trickling Filter Recycle Rate	-	37/1

TABLE II

A SUMMARY OF ANAEROBIC LAGOON LOADING RATES

Authors Reference	Hart & Turner (7)	Loehr & Ruf. (8)	Nordstedt et al (9)	Bhagat & Proctor (10)
kg BOD/m ³ d	0.0299 ⁽ⁱ⁾	0.140	0.0576	0.052 ⁽ⁱⁱⁱ⁾ (0.427)
kg VS/m ³ d	0.1664	0.508 ⁽ⁱⁱ⁾	0.112	0.136 (1.12)

- (i) The highest loading figures are quoted.
- (ii) A value of 0.254 kg SS/m³/d was given and converted assuming 60% of the TS were settleable.(10)
- (iii) The values shown are loadings calculated on original volumes, the authors' estimates allowing for loss of holding capacity with operation are shown in brackets.

TABLE III

SUMMARY OF RESULTS FOR COD, BOD, TS, DO, TEMPERATURE AND pH

	COD mg/l (16)	% Removal	BOD mg/l *	% Removal	TS mg/l (16)	% Removal	DO mg/l (16)	Temp. °C	pH (16)
Raw effluent	5975	-	1340	-	11,000	-	7.1	12.8	8.0
Anaerobic Outlet	2350	61	670	50	1,850	83	1.1	15.08	7.6
Final discharge	745	87	200	85	900	92	4.0	16.4	7.2

* Hach BOD apparatus.

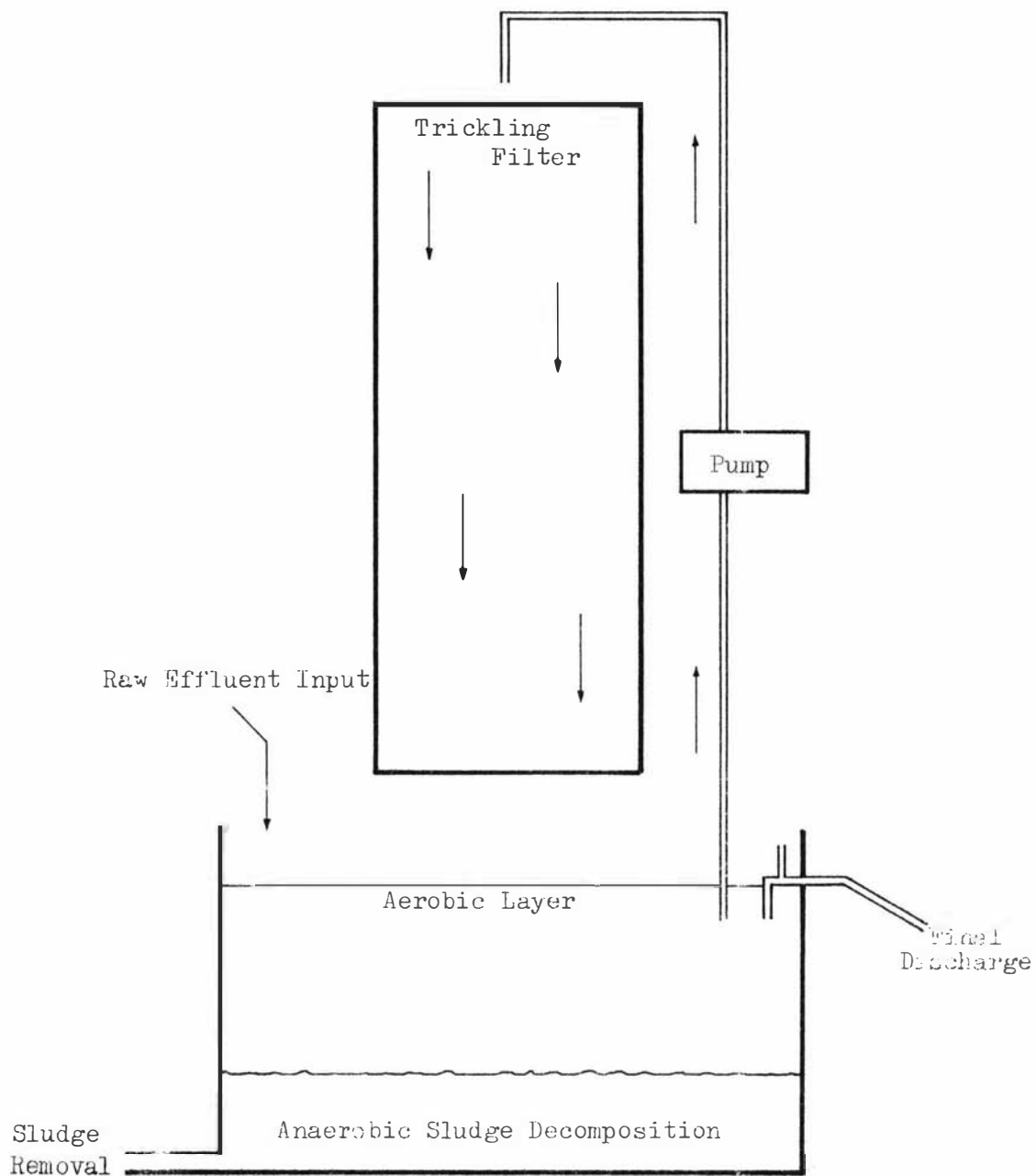
TABLE IV

SOLIDS ANALYSIS IN THE ANAEROBIC TANK

Parameter	First cleaning	Second cleaning	Mean
Total solids input (kg)	5.33	3.44	
Total Solids removed on cleaning (kg)	2.15	2.00	
Solids leaving via the anaerobic discharge (kg)	0.96	0.55	
Approx. mass of solids remaining (kg)	0.3	0.3	
Solid decomposition (kg)	1.92	0.59	
% Solid reduction	36.0	25.9	31
% TS Accumulation	46.0	58.0	52

FIGURE

A SINGLE TANK ANAEROBIC/AEROBIC TREATMENT PLANT



Plant I A 195 litre tank with a 100 mm I.D. x 2.4 m concrete trickling filter and 60 mm stone media.

Plant II. An 8 litre tank with a 75 mm I.D. x 1.8 m Q.V.F. glass column trickling filter and 19 mm stone media. Aluminium covered the glass column.

FIGURE 2.

COD REMOVAL FOR A SINGLE TANK ANAEROBIC/AEROBIC TREATMENT PLANT

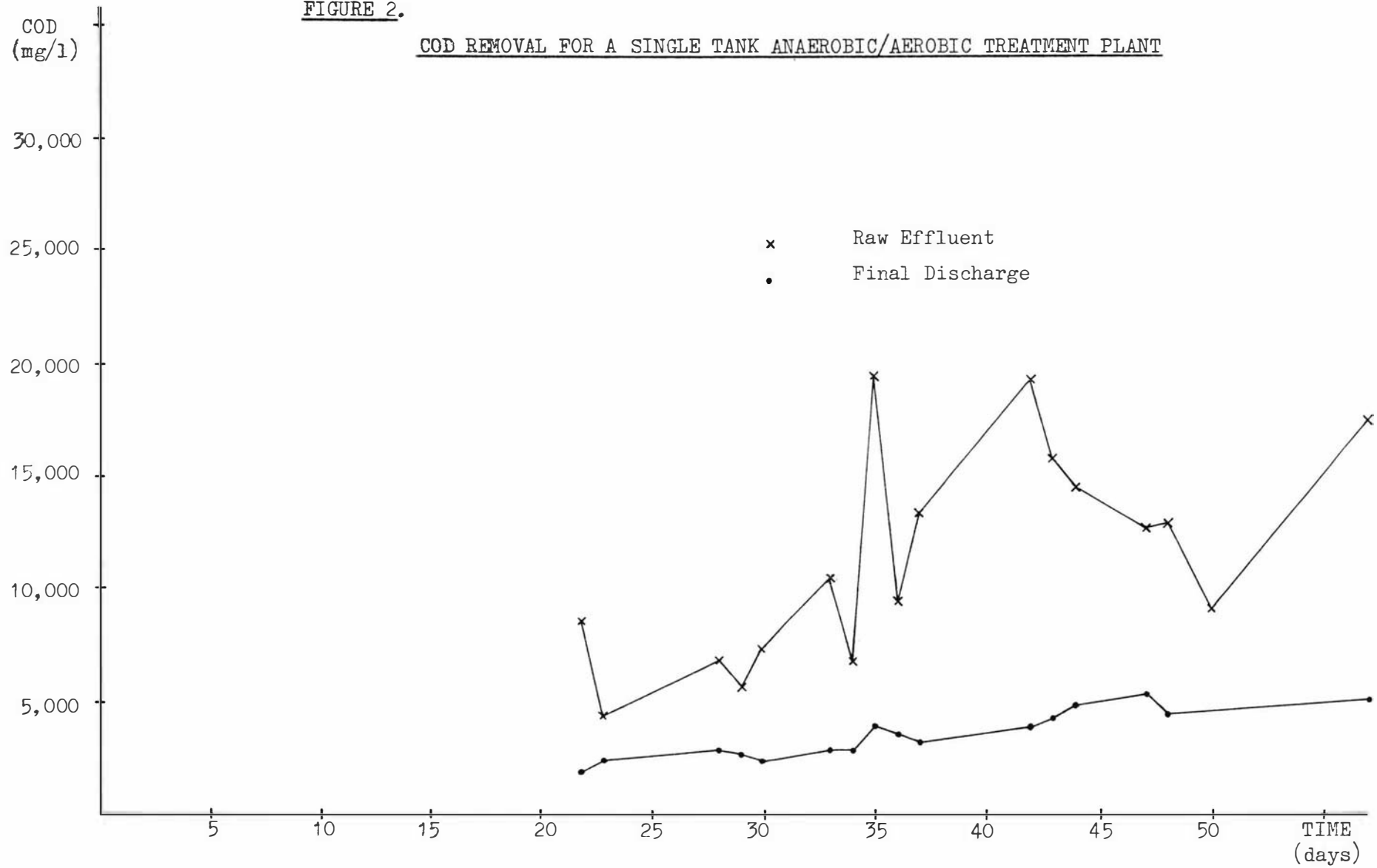
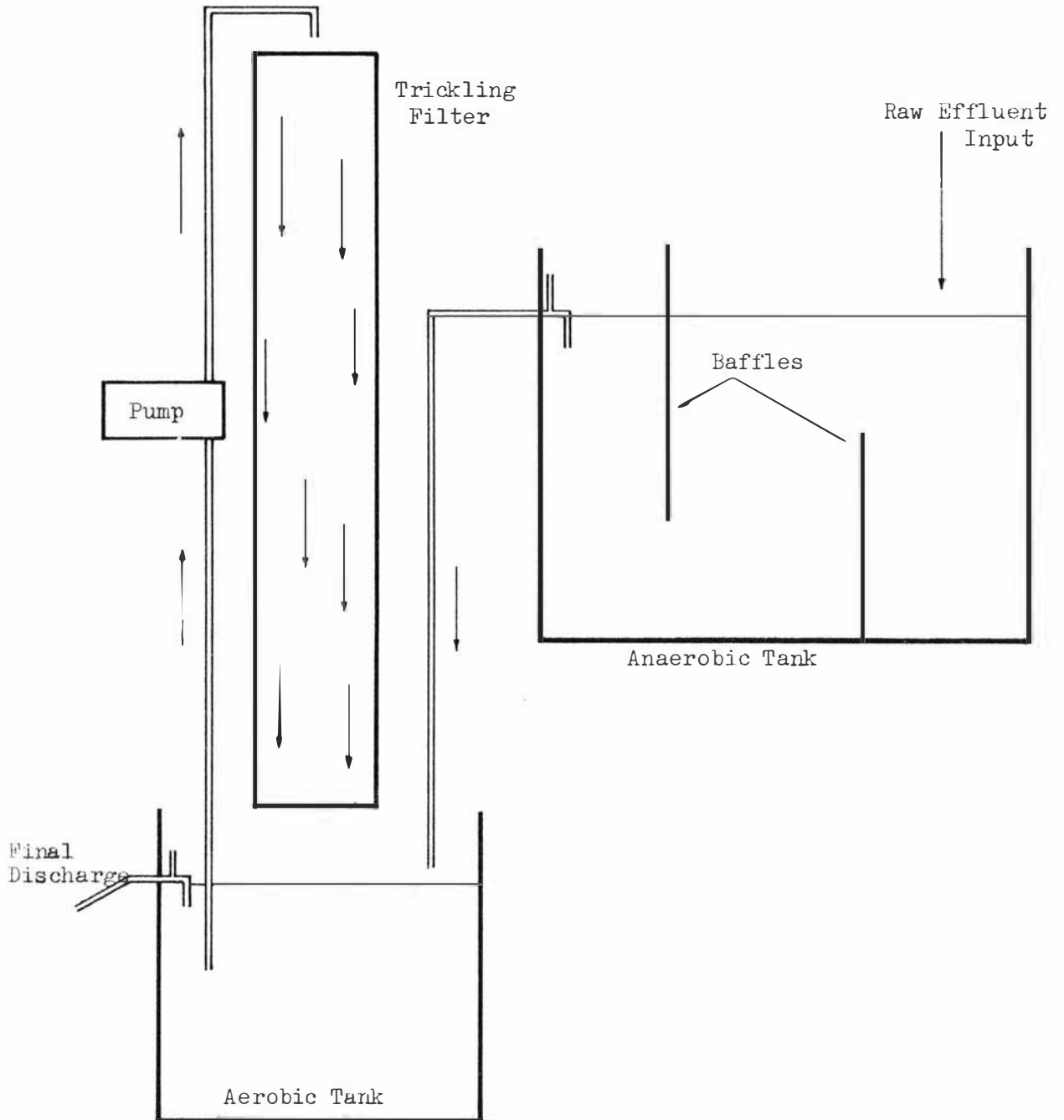


FIGURE 3.

A TWIN TANK ANAEROBIC/AEROBIC TREATMENT PLANT



A 40 litre anaerobic tank coupled to a 16 litre aerobic tank. The trickling filter was 140 mm I.D. x 1.8 m perspex tube with 19 mm stone media.

FIGURE 4.

AUTOMATIC SAMPLER FOR DAIRY SHED EFFLUENT

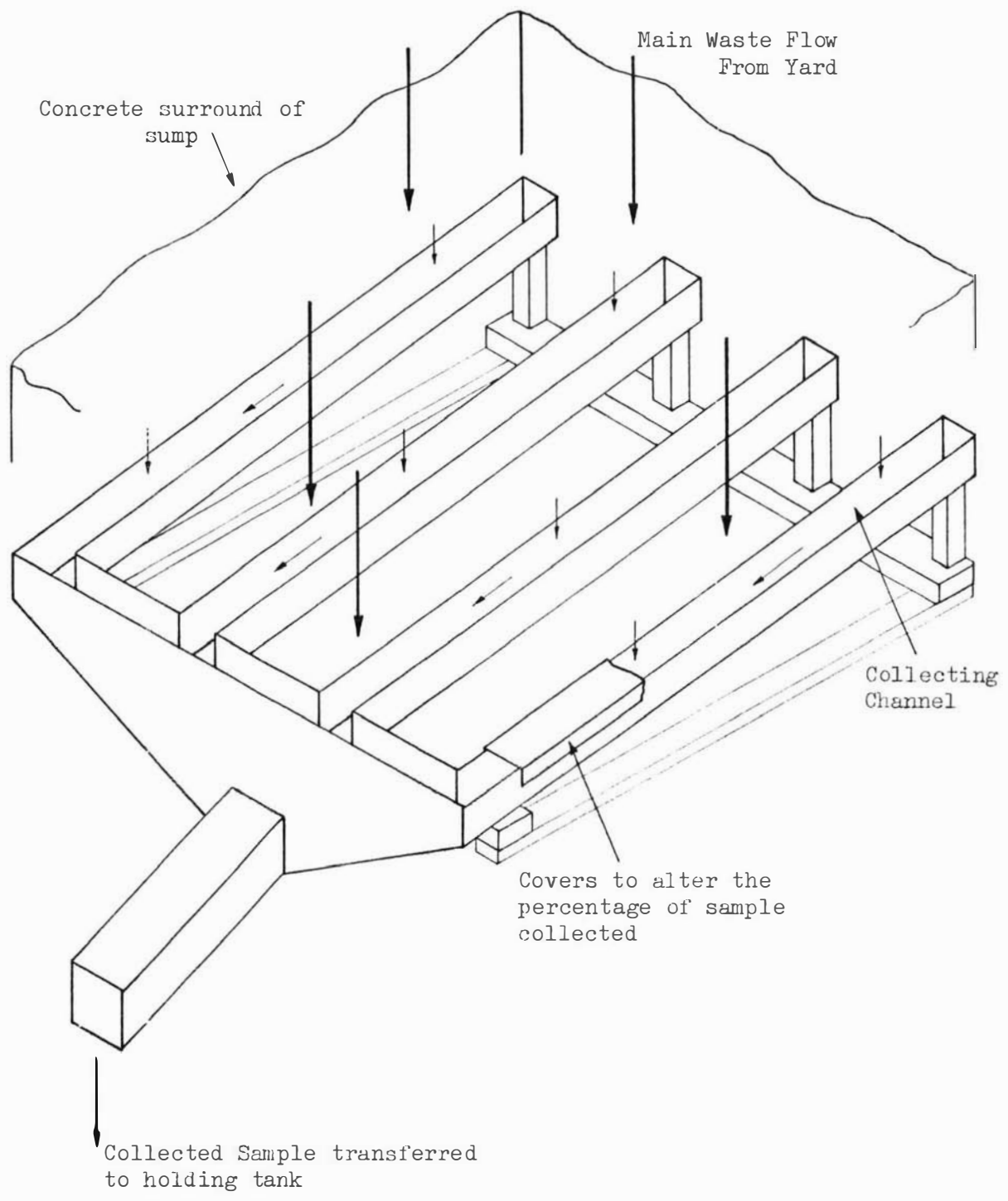


FIGURE 5.

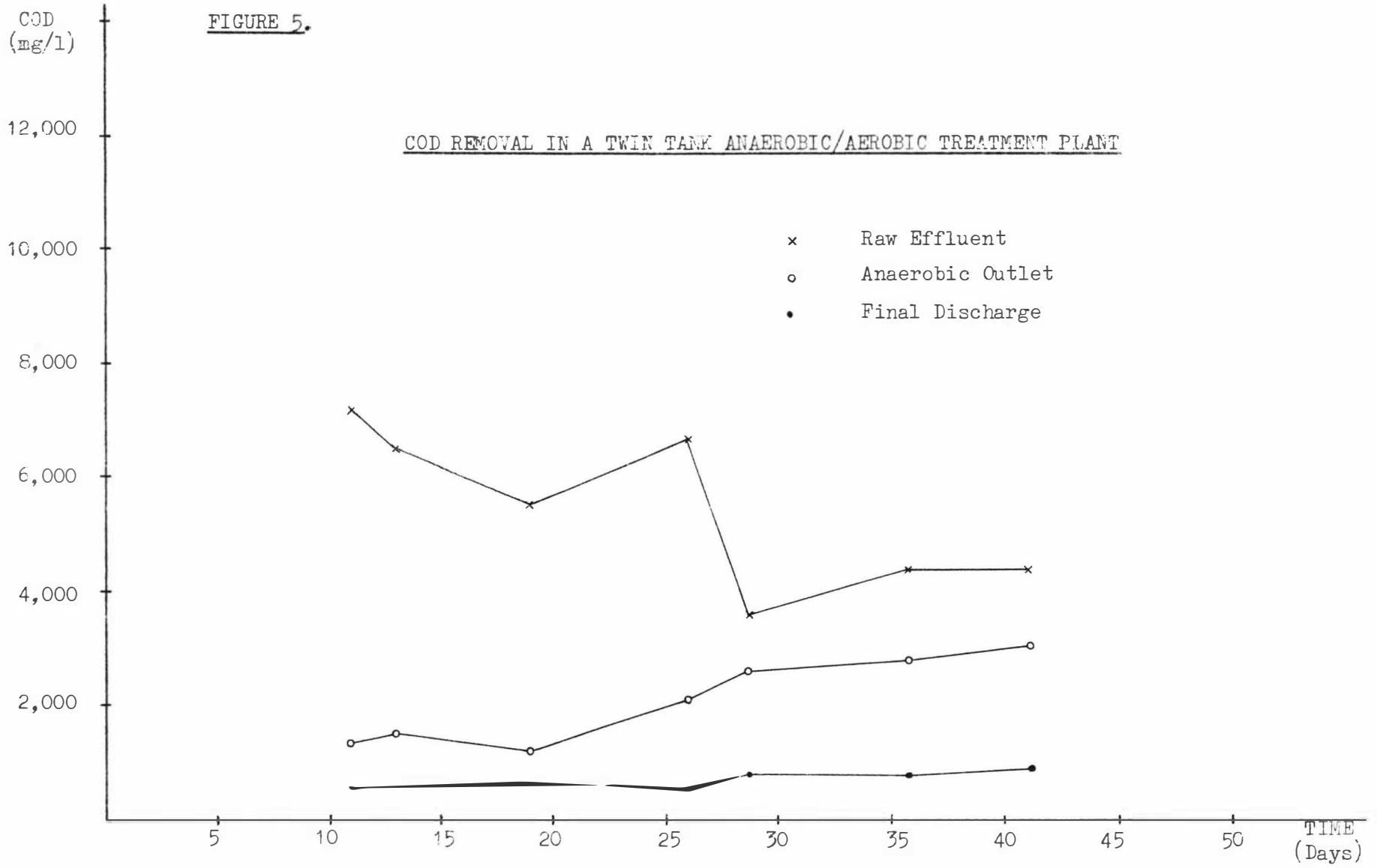
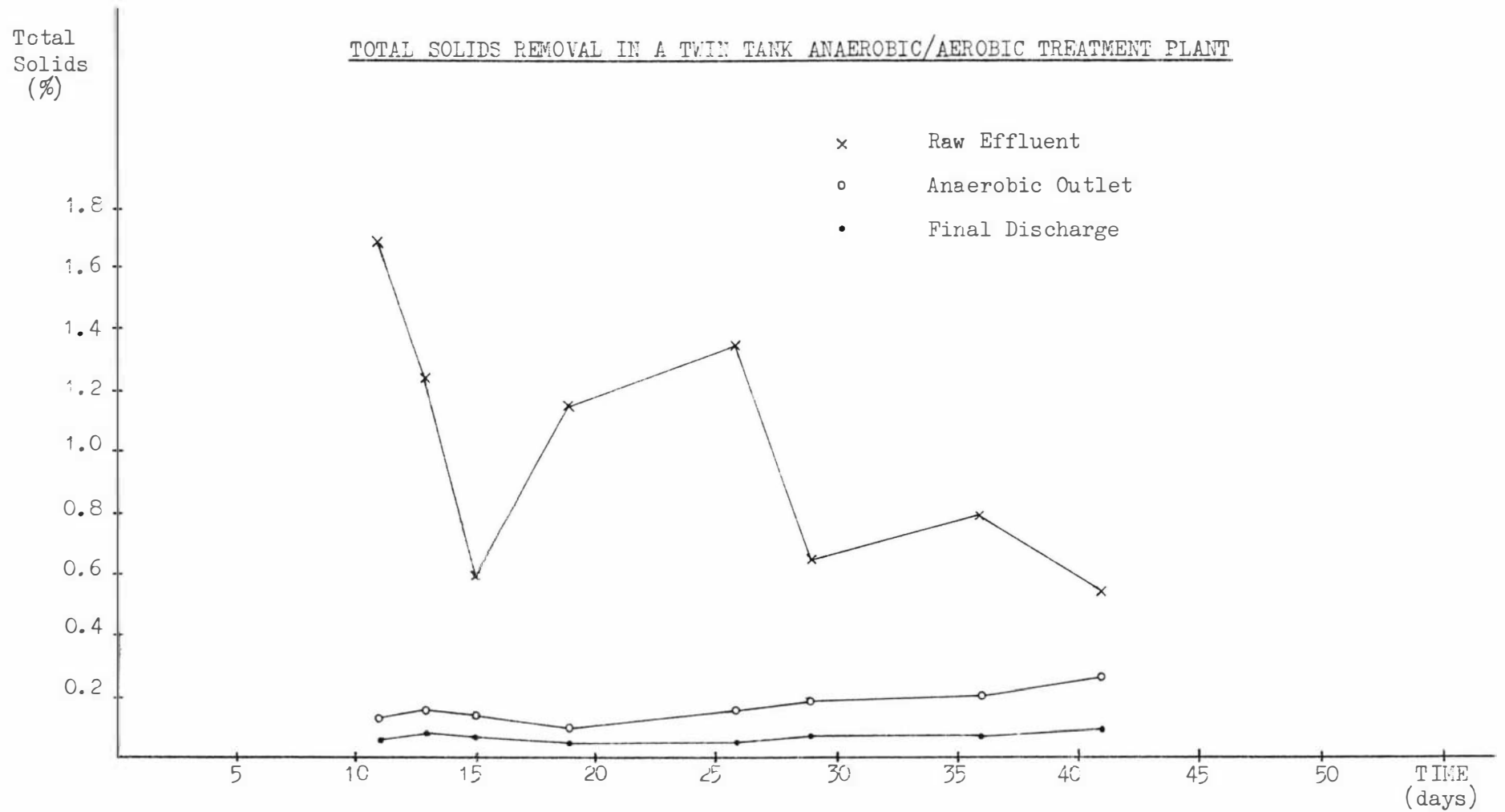


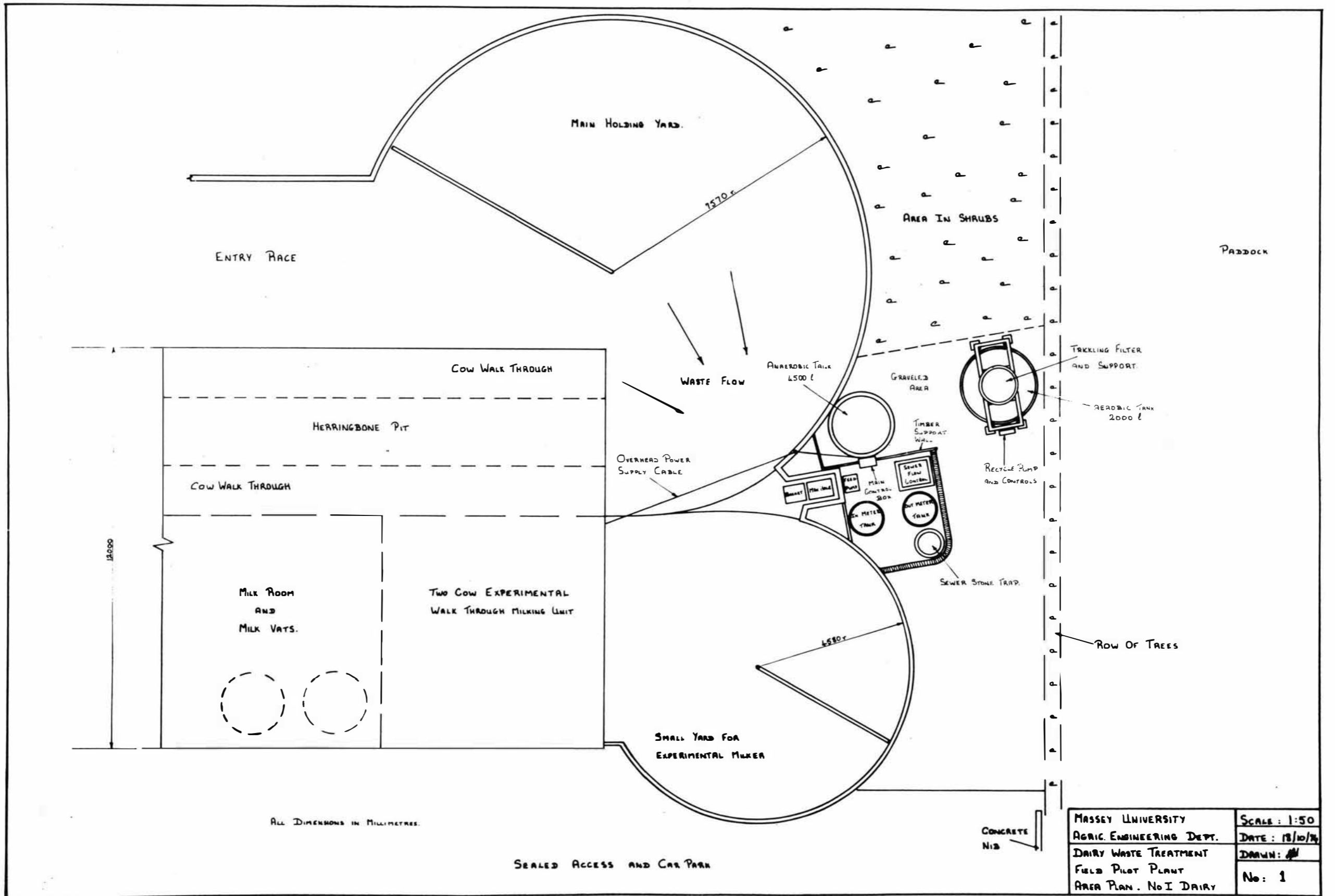
FIGURE 6.



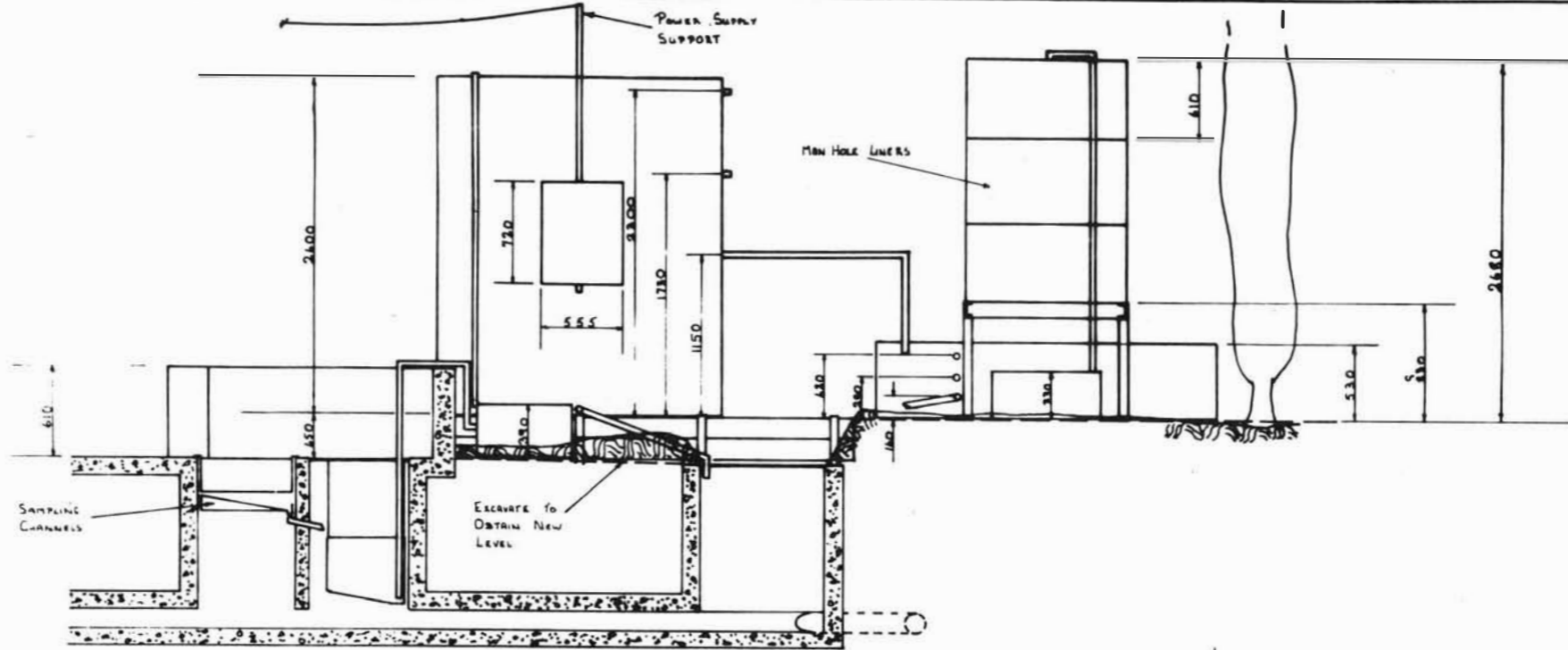
APPENDIX III

WORKING DRAWINGS FOR FIELD SCALE TREATMENT PLANT

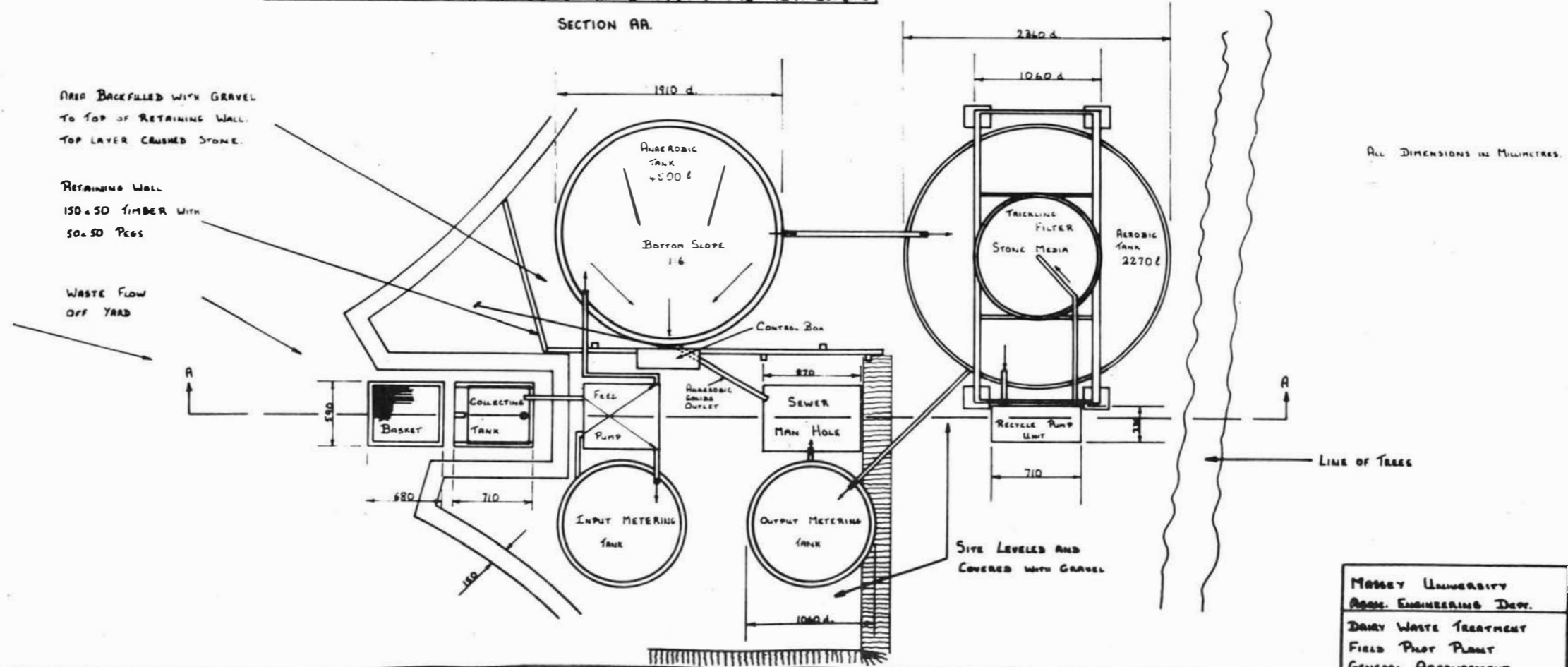
- Drawing 1 - Site Positioning
- Drawing 2 - General Arrangement
- Drawing 3 - Sampling & Loading Details
- Drawing 4 - Trickling Filter Support Details
- Drawing 5 - Electrical Supply Details



MASSEY UNIVERSITY	SCALE: 1:50
AGRIC. ENGINEERING DEPT.	DATE: 18/10/74
DAIRY WASTE TREATMENT	DRAWN: AH
FIELD PILOT PLANT	No: 1
AREA PLAN. No I DAIRY	



SECTION AA.



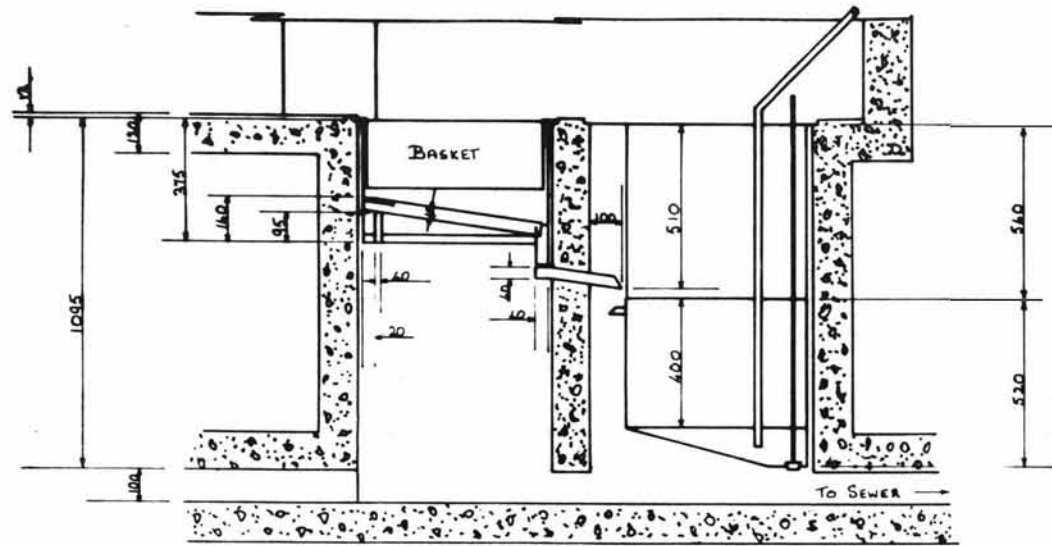
AREA BACKFILLED WITH GRAVEL TO TOP OF RETAINING WALL. TOP LAYER CRUSHED STONE.

RETAINING WALL 150x50 TIMBER WITH 50x50 POSTS

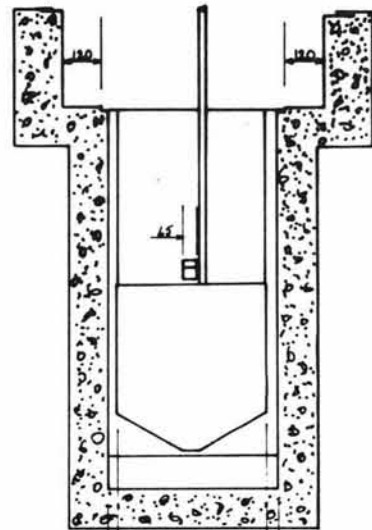
WASTE FLOW OFF YARD

ALL DIMENSIONS IN MILLIMETRES.

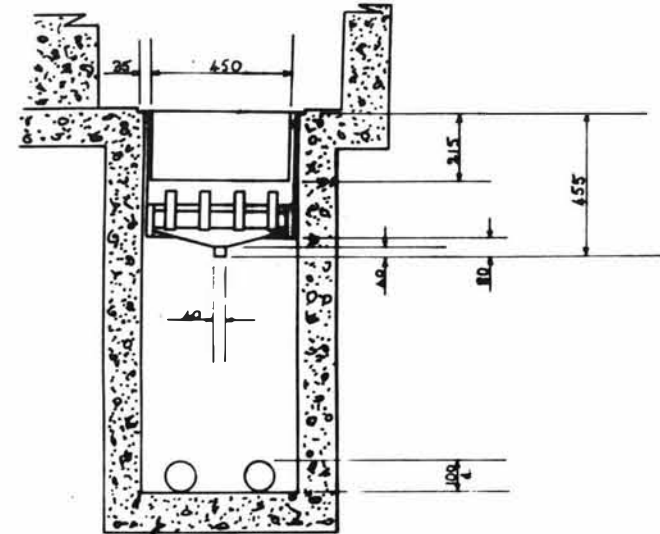
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DAIRY WASTE TREATMENT	DRAWN: [Signature]
FIELD PILOT PLANT	NO: 2
GENERAL ARRANGEMENT.	



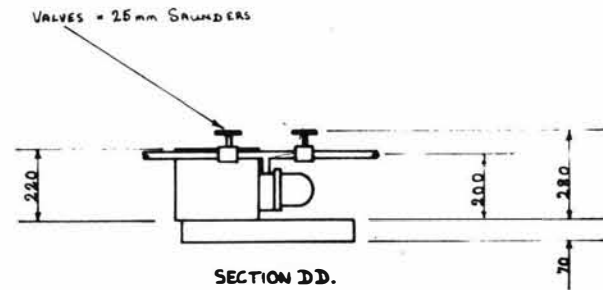
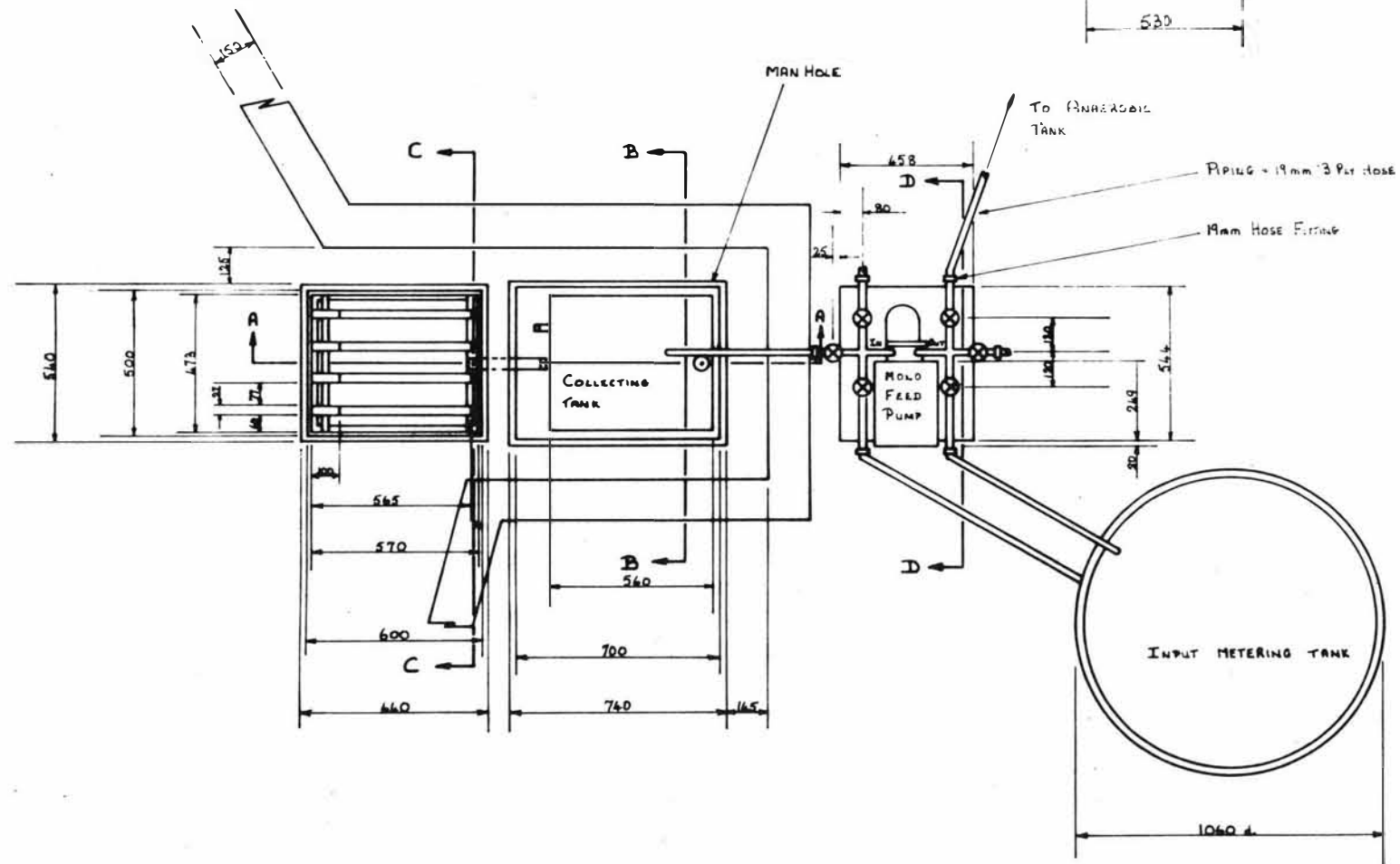
SECTION AA.



SECTION BB.



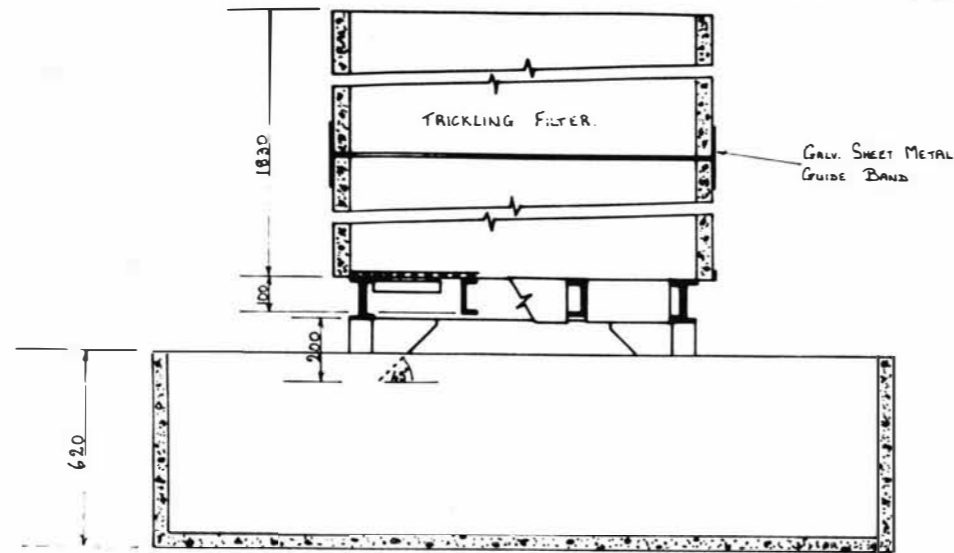
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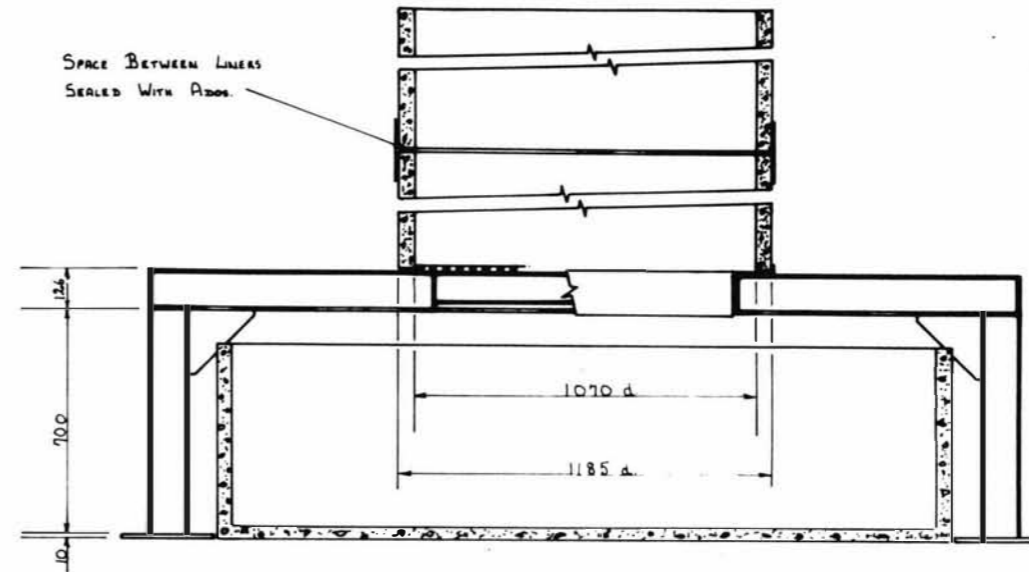
SECTION DD.

ALL DIMENSIONS IN MILLIMETRES.

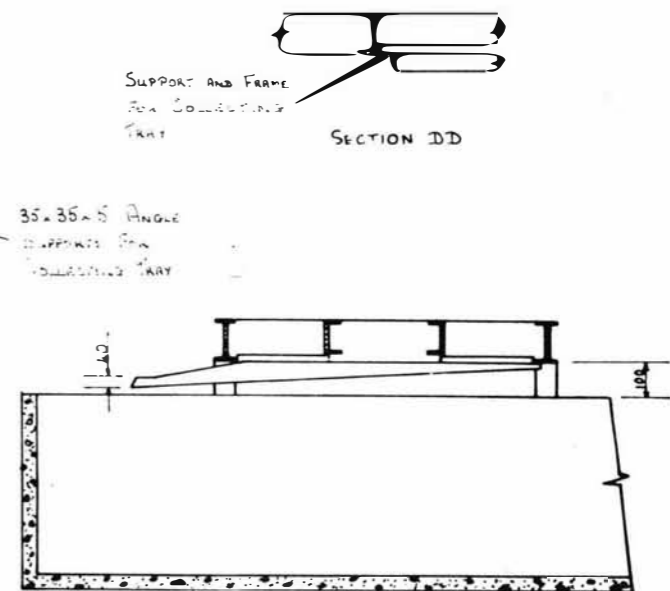
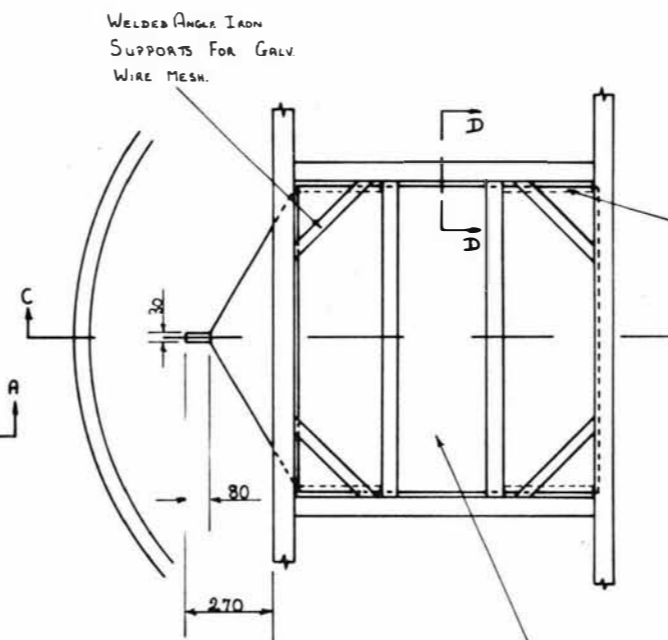
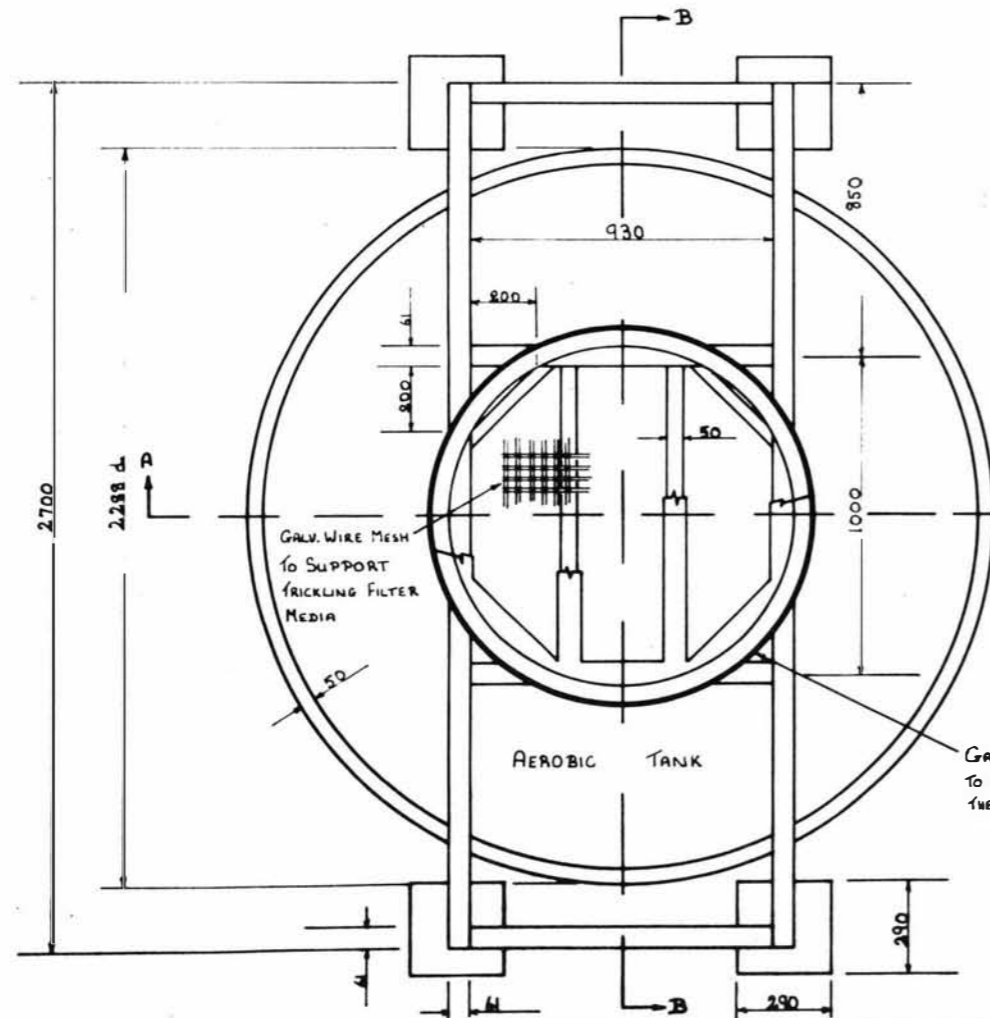
MASSET UNIVERSITY	SCALE: 1:10
AGRIC ENGINEERING DEPT.	DATE: 6/7/78
DAIRY WASTE TREATMENT	DRAWN: [Signature]
FIELD PLOT PLANT	NO: 3
WASTE COLLECTION AND LOADING	



SECTION AA.



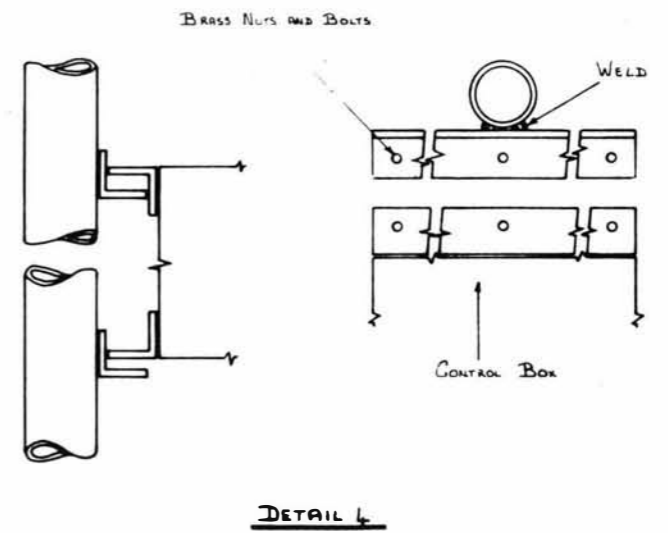
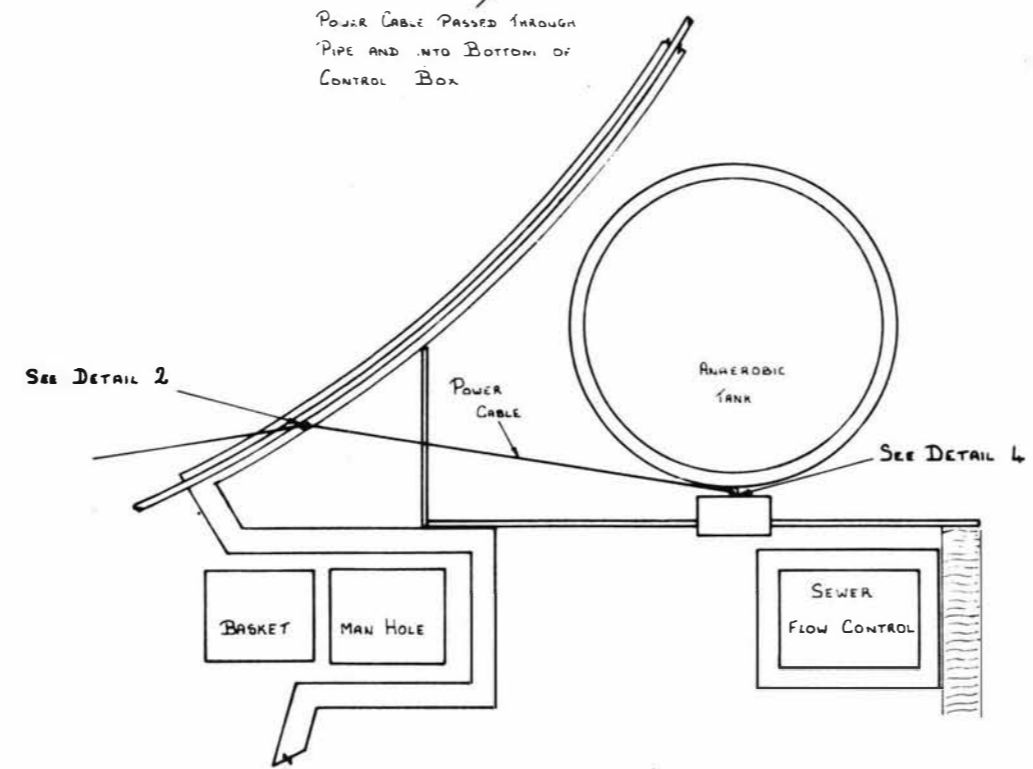
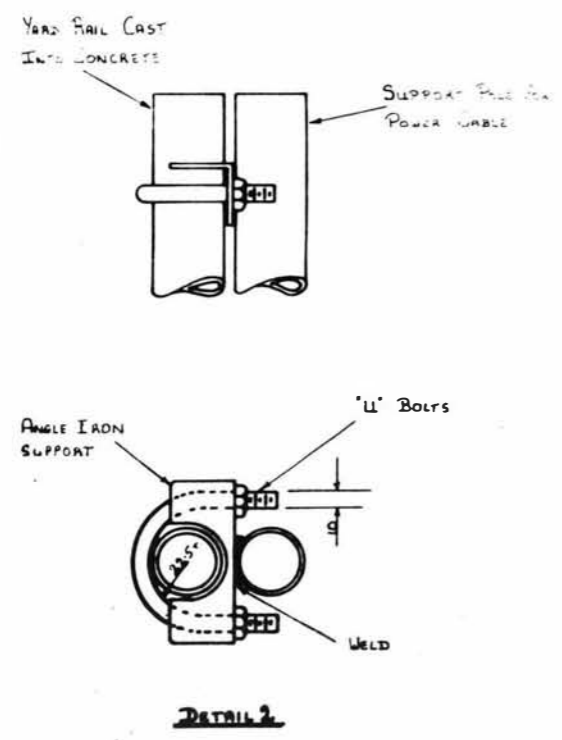
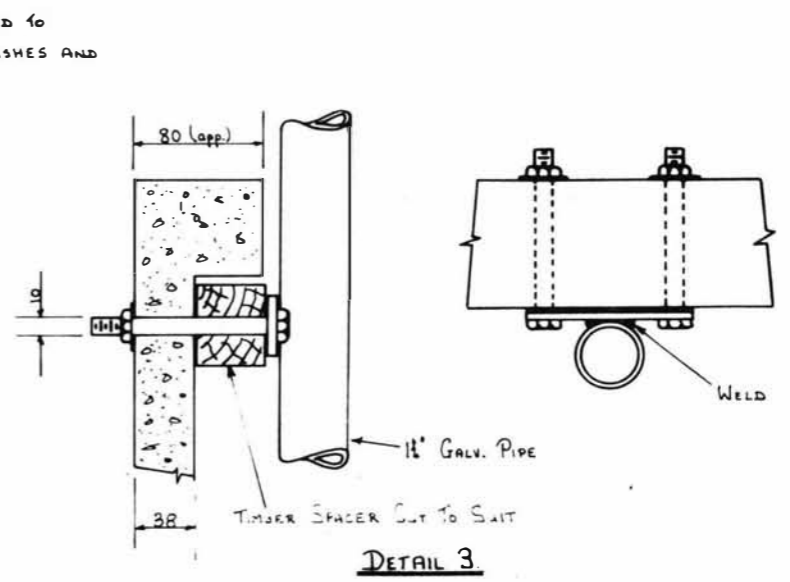
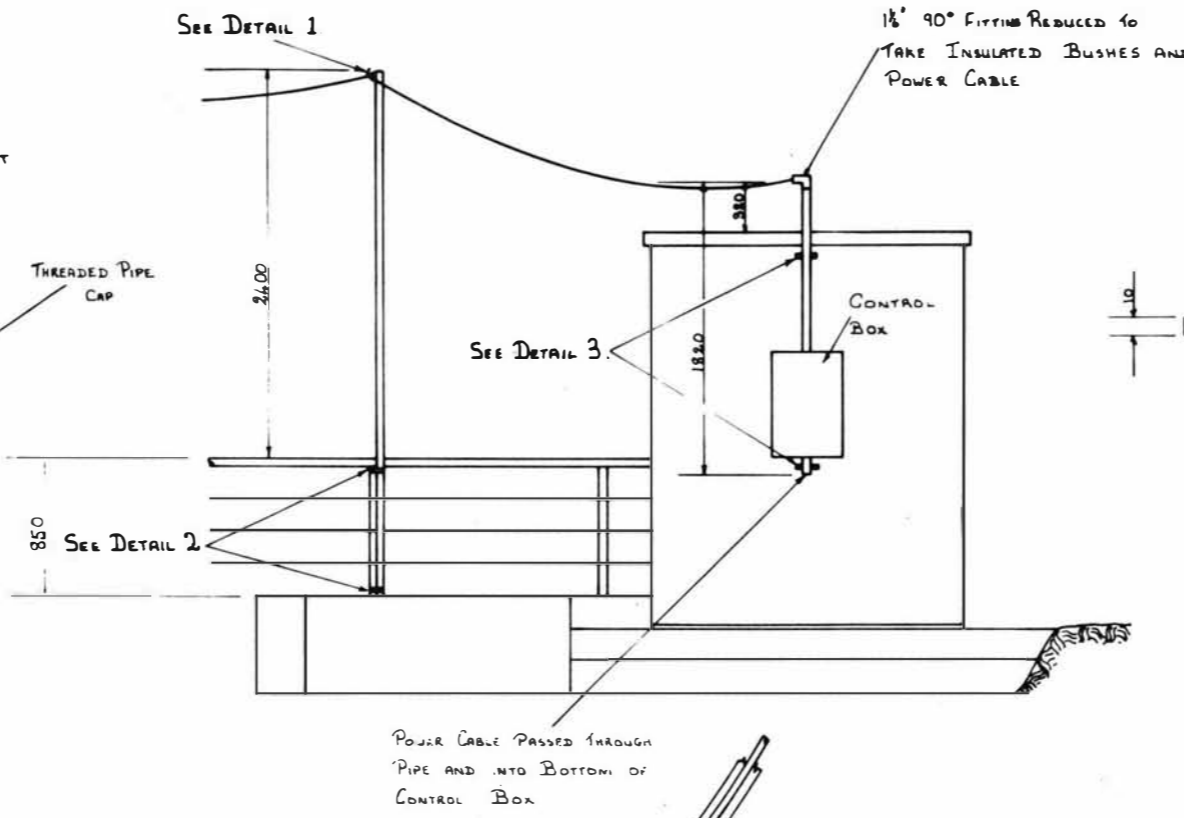
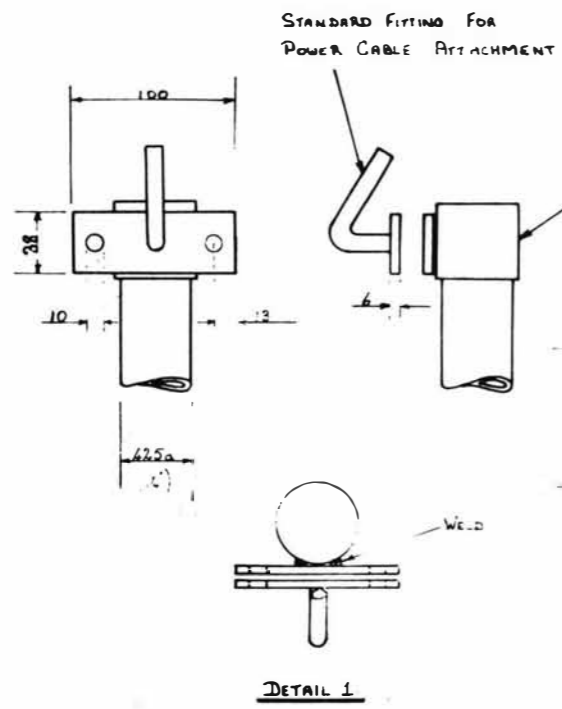
SECTION BB.



SECTION CC.

ALL DIMENSIONS IN MILLIMETRES

MASSEY UNIVERSITY	Scale: 1:10
AGRIC. ENGINEERING DEPT.	DATE: 26/1/70
DAIRY WASTE TREATMENT	DRAWN: [Signature]
FIELD PILOT PLANT	No: 4
TRICKLING FILTER SUPPORT	



ALL DIMENSIONS IN MILLIMETRES.

MASSEY UNIVERSITY	SCALE: 1:2
AGRIC. ENGINEERING DEPT.	DATE: 6/10/76
DAIRY WASTE TREATMENT FIELD PILOT PLANT	DRAWN: [Signature]
ELECTRICAL SUPPLY DETAILS	NO: 5

APPENDIX IV

ROTARY TIPPING BUCKET - DESIGN AND OPERATION

IV:1) INTRODUCTION

A simple distributor was required to apply the recycle flow over the field plant trickling filter. The requirements for the distributor were;

- (a) To give a good distribution over the entire filter surface.
- (b) To provide a periodic "flush" discharge to allow adequate wetting of the filter at low flow rates.
- (c) To require minimum maintenance and be free from blockages.
- (d) To be adjustable for various flushing volumes and frequencies.

Tipping buckets have been used to obtain intermittent discharge in various applications such as flush cleaning of effluent from piggeries. However, the mounting of a tipping bucket on a central pivot, causing it to rotate by the impulse generated from the discharge, has not been reported.*

The principle of operation was to allow half of the bucket to fill with recycled liquor until the movement in its centre of gravity caused it to tip. The discharged volume was directed to one side of the bucket and allowed to strike a deflecting plate. The resulting impulse caused the bucket to rotate. This process was then repeated with the other half of the bucket, allowing continuous operation.

The configuration of the rotary tipping bucket is shown in Figure App. IV:1 and Plates 5:5, App. IV:1 and App. IV:2.

IV:2) DESIGN EQUATIONS FOR THE TIPPING BUCKET

The bucket tips when;

$$\text{Tipper Weight } (W_T) \times \text{Moment Arm } (x) = \text{Liquid Weight } (W_L) \times \text{Moment Arm } (y)$$

(Figure App. IV:2)

* The idea and much of the development of the rotary tipping bucket was the result of work by Mr J.S. Tyler, Agricultural Engineering Department, Massey University.

FIGURE App. IV:1

ROTARY TIPPING BUCKET

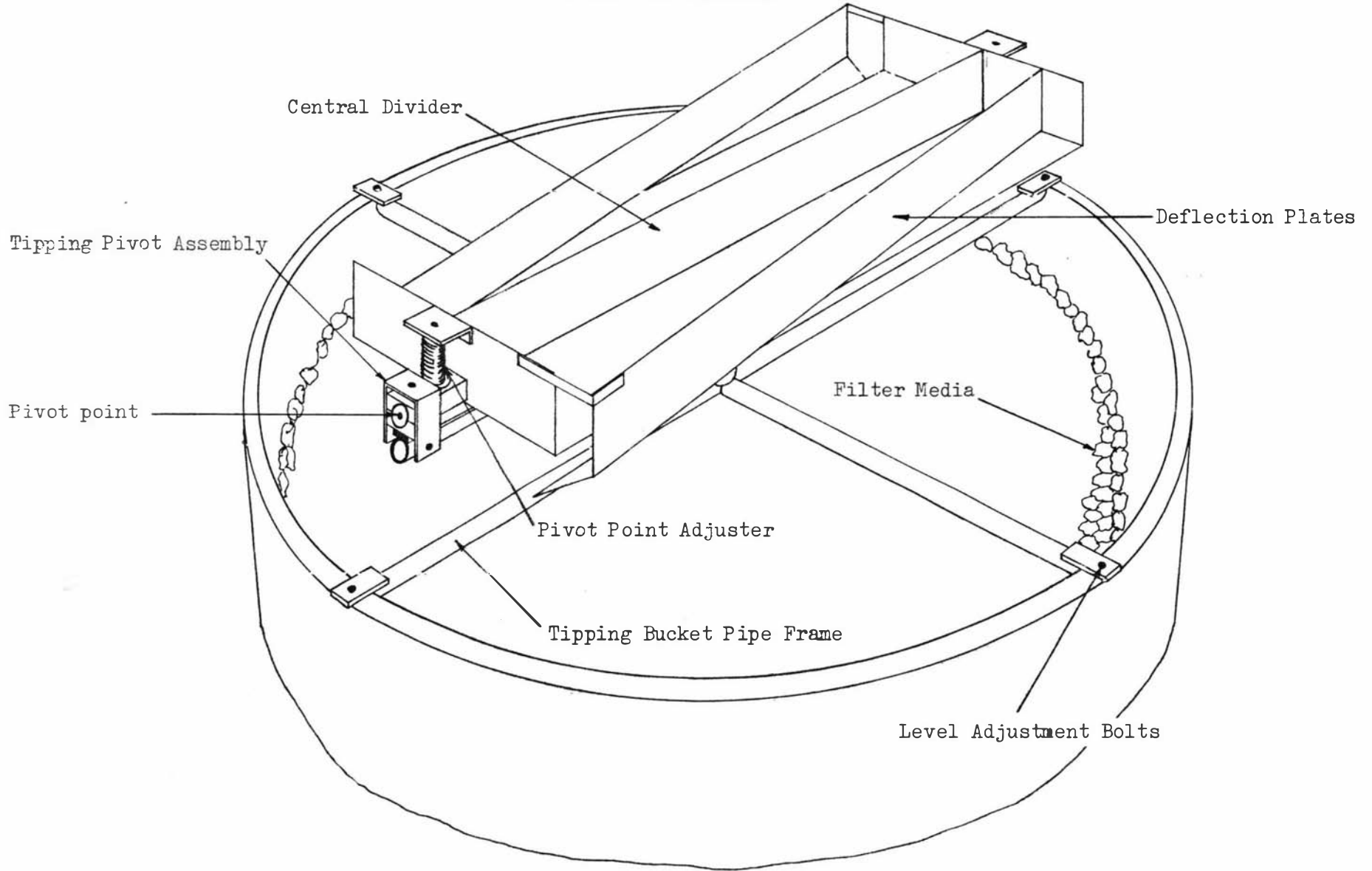




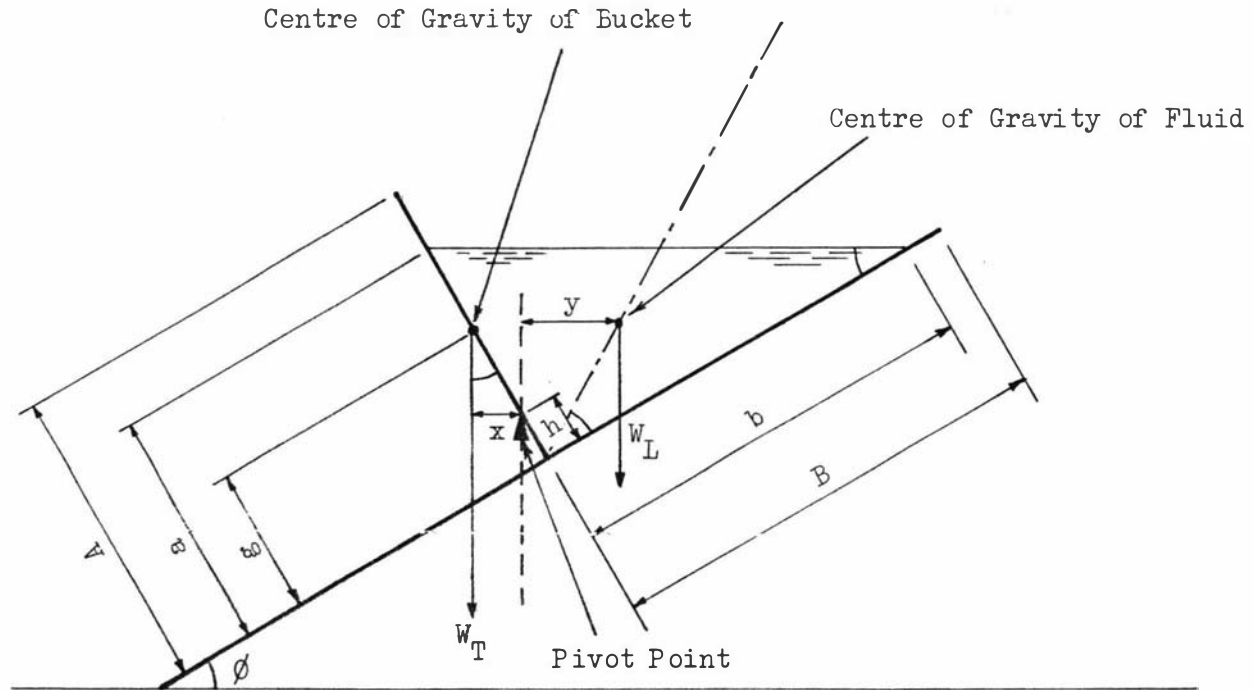
PLATE APP. IV:1 Rotary tipping bucket showing recirculation flow,
central divider and cupped wind vanes.



PLATE APP. IV:2 Rotary tipping bucket showing deflector plate and bucket sub-frame.

FIGURE App. IV:2

ANALYSIS OF FORCES FOR A TIPPING BUCKET



Calculation of these terms, based on the dimensions of the tipping bucket, are presented in the following sections.

IV:2.1) Expression of 'x' in Measurable Dimensions

Using Figure App. IV:2, it may be shown that when $h = h'$

$$x = (g \sin\phi) - (h' \sin\phi) = \sin\phi (g - h') \quad (\text{metres})$$

The distance of the bucket's centre of gravity from the base (g) may be altered by adjusting the relative weight of the base to the super structure.

IV:2.2) Expression of 'y' in Measurable Dimensions

Based on dimensions given in Figures App. IV:2 and App. IV:3, it may be shown that;

$$c = \frac{0.5b}{\cos\phi}$$

$$\text{but } z = \frac{2}{3}c = \frac{2}{3}\left(\frac{b}{2 \cos\phi}\right)$$

Therefore if $h = 0$,

$$y = \left[\sin(90 - 2\phi) \right] \left[\frac{2}{3}\left(\frac{b}{2 \cos\phi}\right) \right]$$

and when $h = h'$,

$$y = \left[\sin(90 - 2\phi) \right] \left[\frac{2}{3}\left(\frac{b}{2 \cos\phi}\right) \right] + h' \sin\phi \quad (\text{metres})$$

The wetted distance out from the central divider (b) may be calculated from the tipping volume (V) since;

$$V = \frac{1}{2}abl \quad (\text{m}^3) \quad (\text{Figures App. IV:2 and App. IV:4})$$

$$\text{but } a = b \tan\phi \quad (\text{metres})$$

$$\text{therefore } V = \frac{1}{2}b^2 l \tan\phi$$

$$\text{therefore } b = \sqrt{\frac{2V}{l \tan\phi}} \quad (\text{metres})$$

FIGURE App. IV:3

DEFINITION OF TERMS FOR DERIVATION OF THE MOMENT ARM (v)

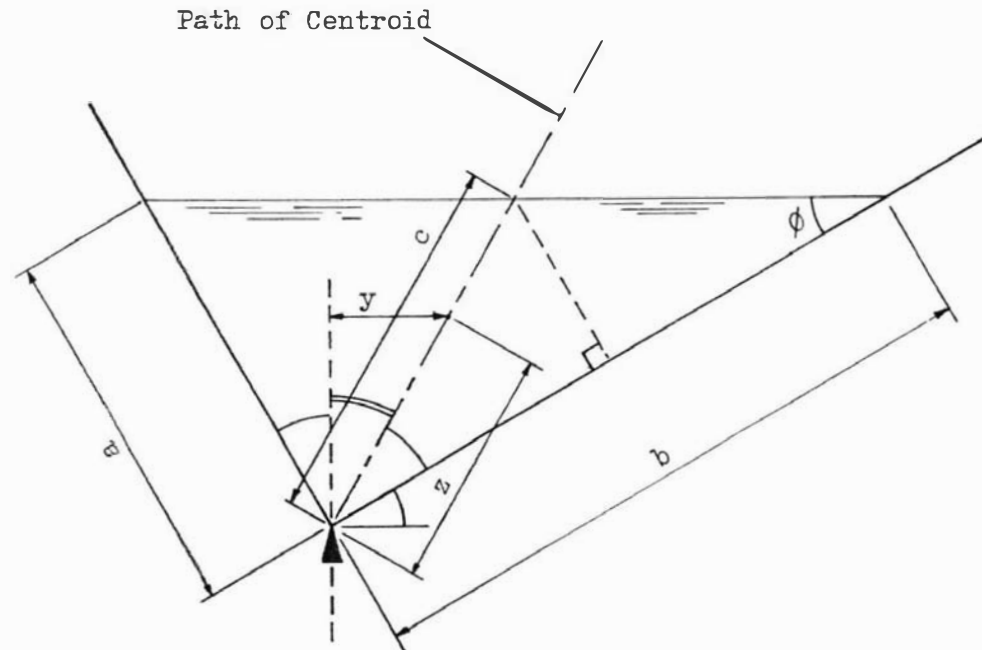
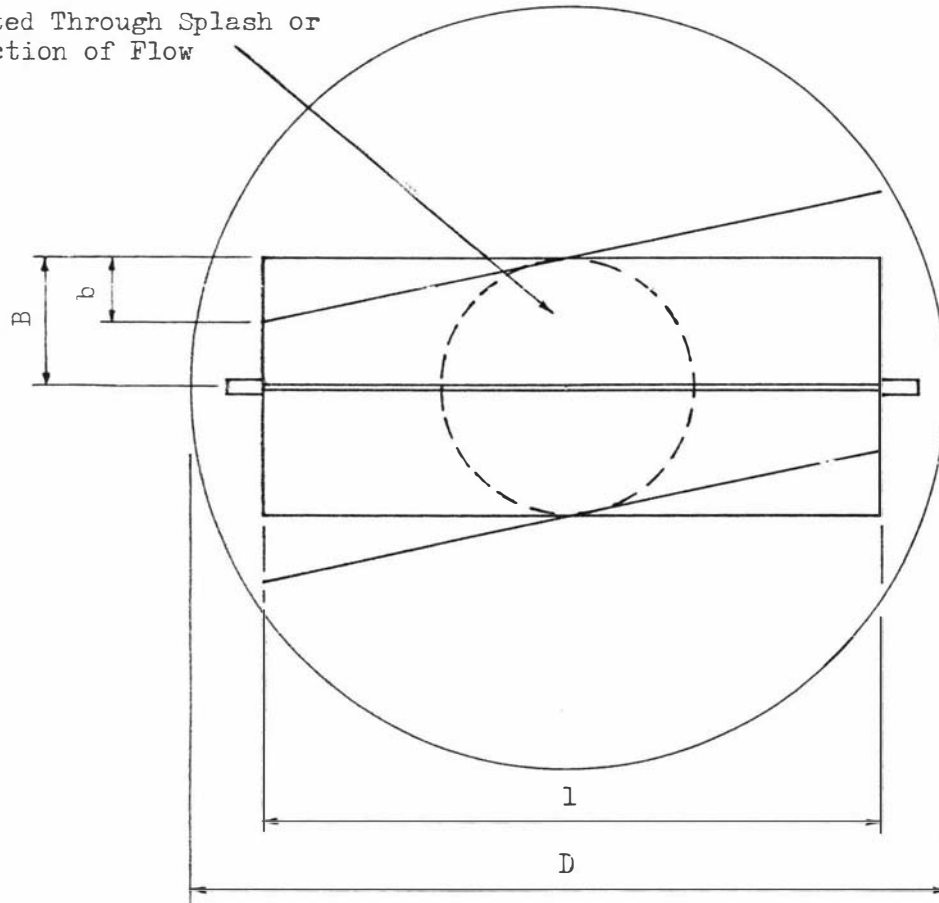


FIGURE App. IV:4

TIPPING BUCKET DIMENSIONS

Area Wetted Through Splash or
by Deflection of Flow



IV:2.3) Calculation of W_T and W_L

$$W_T = \text{Weight of Base } (W_B) + \text{Weight of Super Structure } (W_D)$$

$$= (S_B \times U_B) + (S_D \times U_D) \quad (\text{Newtons})$$

where S = surface area (m^2) and U = unit weight (N/m^2)

$$S_B = 2B \times l \quad (m^2)$$

$$\text{where } B = 2b \text{ (m)} \quad \text{and } l = D - 0.2 \text{ (m)}$$

$$\text{and } S_D = (2 \times \text{side area}) + (3 \times \text{central divide area}^*)$$

$$= (2 \times A \times 2B) + (3 \times A \times l) \quad (m^2)$$

$$\text{where } A = 2a \text{ (m)}$$

The height of the central divider (A) is set to avoid splashing, while the base width ($2B$) is set to accommodate the end deflectors. The reduction in bucket length (l) is to allow clearance for the pivot bearings (Figure App. IV:4).

$$W_L = \text{Tipping Volume} \times \text{Specific Weight}$$

$$= V \times 9810 \quad (N)$$

IV:2.4) Moment Equation for Tipping Bucket

$$W_T \left[\sin\phi (g - h) \right] \leq W_L \left[(\sin(90 - 2\phi)) \left(\frac{2}{3} \left(\frac{b}{2 \cos\phi} \right) \right) + h \sin\phi \right]$$

Solving for h , the final adjustment on the pivot point,

$$h = \frac{\left[W_T \sin\phi g \right] - \left[W_L (\sin(90 - 2\phi)) \left(\frac{2}{3} \left(\frac{b}{2 \cos\phi} \right) \right) \right]}{\sin\phi (W_T + W_L)} \quad (m)$$

IV:3) DESIGN PROCEDURE FOR THE TIPPING BUCKET

The filter diameter, D (m), and the hydraulic load, Q (m^3/m^2 -day), should be known from the filter design. The tipping frequency,

* This includes an approximation for the area of the end deflectors.

f (min^{-1}), and the tipping angle, ϕ° , must be selected.

The tipping bucket can be designed using the following procedure;

- (a) Calculate the tipping volume, V (m^3), by

$$V = \frac{Q D^2}{1833 f} \quad (\text{m}^3)$$

- (b) Calculate bucket dimensions from estimates of 'a' and 'b' (Appendix IV:2.2 and IV:2.3).

- (c) Select a suitable construction material and calculate W_T and g (Appendix IV:2.3). Note that g , the height of the centre of gravity of the empty bucket from the base, is given by;

$$g = \frac{A}{4} \times \frac{W_D}{W_B} \quad (\text{m})$$

- (d) Calculate W_L and substitute into the final equation (Appendix IV:2.4) to determine the height of the pivot point relative to the base, h (m).

Although 'h' may be easily adjusted (Appendix IV:4) it must be less than 'g' for the bucket to operate.

IV:4) EXAMPLE CALCULATION

$$\text{Assume } D = 1.8\text{m}$$

$$Q = 15 \text{ m}^3/\text{m}^2\text{-day}$$

$$f = 6$$

$$\phi = 30^\circ$$

$$(1) \quad V = \frac{15 \times 1.8^2}{1833.5 \times 6} = 0.0044 \text{ m}^3$$

$$(2) \quad b = \frac{2V}{1 \tan \phi} = 0.098\text{m} \quad (1 = 1.8 - 0.2 = 1.6\text{m})$$

$$a = b \tan 30 = 0.057\text{m}$$

$$\text{therefore } B = 0.196\text{m}$$

$$A = 0.114\text{m}$$

(3) Using 18 gauge galvanised plate,

$$\text{Mass} = 10 \text{ kg/m}^2$$

$$\text{Weight} = 100 \text{ N/m}^2$$

$$\text{Base Area (S}_B) = 2 \times 0.196 \times 1.6 = 0.627 \text{ m}^2$$

$$\text{Side Area} = 2 \times (2 \times 0.114 \times 0.196) = 0.089 \text{ m}^2$$

$$\text{Divider and Deflectors} = 3 \times (0.114 \times 1.6) = 0.548 \text{ m}^2$$

$$S_D = 0.089 + 0.548 = 0.637 \text{ m}^2$$

$$\text{Therefore } W_{\Gamma} = (0.627 + 0.637) \times 100 = 126.4 \text{ N}$$

$$\text{Weight Ratio} = \frac{S_D}{S_B} = \frac{0.637}{0.627} = 1.02$$

$$\text{Therefore } g = \frac{A}{4} \times 1.02 = 0.029\text{m}$$

$$(4) \quad W_L = 0.0044 \times 9810$$

$$= 43.16 \text{ N}$$

$$h = \frac{1.833 - 0.816}{84.78}$$

$$= 0.012\text{m}$$

Therefore the pivot point is 12mm above the base of the tipping bucket. It is less than 50% of 'g', allowing stable operation.

IV:5) CONSTRUCTION DETAILS FOR THE TIPPING BUCKET

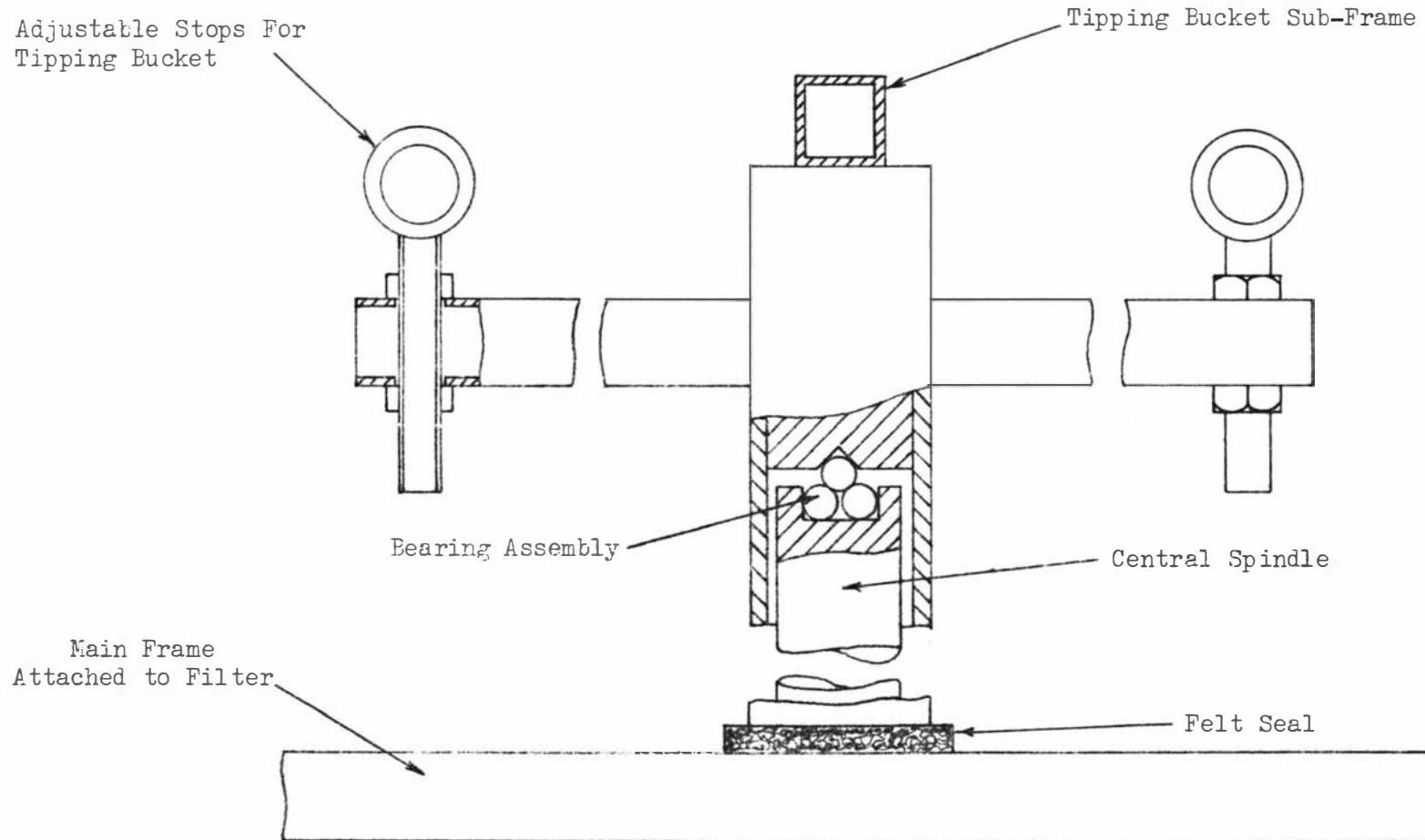
The bucket was constructed from galvanised sheet steel. All joints were pop riveted and soldered.

The tipping angle could be altered by adjusting the height of the bucket stops (Figure App. IV:5).

The central bearing, which allowed the bucket to rotate, was constructed using three ball bearings recessed into the end of the central spindle. A fourth ball bearing supported the rotating frame

FIGURE App. IV:5

CENTRAL PIVOT FOR ROTARY TIPPING BUCKET



which was located over the central spindle. The unit was packed with grease and sealed with a felt seal (Figure App. IV:5).

The pivot for the tipping bucket was mounted in Ferobestos, eliminating the need for lubrication. The height of the pivot point relative to the tipper base (h) could be adjusted by altering the position of the pivot on the screwed brass column. The bearing assembly could be dismantled by undoing two wing nuts, allowing removal of the tipping bucket for cleaning or maintenance (Figure App. IV:6).

The complete unit was mounted on a pipe frame and fixed to the top of the filter. The frame was levelled on foot screws prior to operation (Figure App. IV:1).

IV:6) PERFORMANCE OF THE TIPPING BUCKET

The rotary tipping bucket required no structural maintenance. It was cleaned once to remove excessive microbial growth.

The rotational force was sufficient to move the bucket through 50-100 degrees/tip. Some control of the rotational force could be obtained by adjusting the deflector plates (Figure App. IV:1).

The main operational problem was wind. The longitudinal axis of the bucket would lie into the wind and the hydraulic reaction was often insufficient to overcome the wind effect. Wind also sprayed effluent from the tipping bucket. To combat these problems, a wind shield was installed (compare Plates 5:5 and App. IV:1) and cupped wind vanes were mounted on each end of the bucket (Plates App. IV:1 and App. IV:2). These modifications satisfactorily solved both problems. The speed of rotation increased with wind speed but was not excessive.

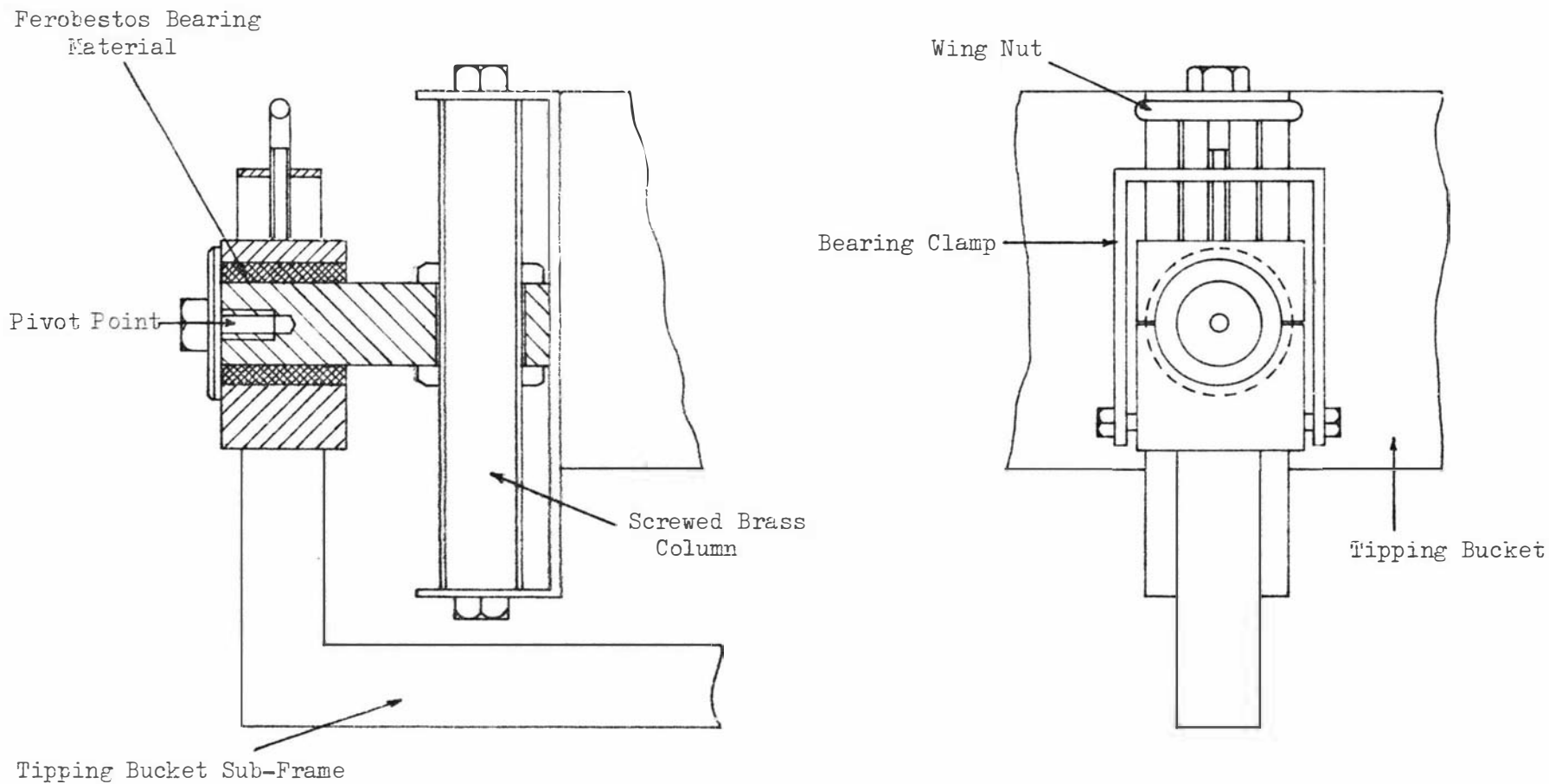
With regular cleaning to maintain a fixed tipping volume, the distributor could be used as a flow meter. A mechanical counter would provide the simplest recorder.

IV:7) CONCLUSION

The good performance, simple construction, low maintenance and high

FIGURE App. IV:6

PIVOT BEARINGS FOR TIPPING BUCKET



flexibility of the rotating tipping bucket suggests that is a suitable device for distributing flow over a packed bed. With careful design and regular cleaning, the unit could also be used as a flow meter.

APPENDIX V

COLLECTED DATA

TABLE APP. V: 1

SAMPLE OF DATA FROM ONE TREATMENT RUN

DATE	PLANT	SETTING	NUMBER	COD mg/l	BOD mg/l	TS %	VS %TS	pH	E _h mV	DO mg/l	TEMP °C	NO ₃ -N mg/l	NH ₄ -N mg/l	TKN mg/l	DKN mg/l	DIP mg/l	TDP mg/l	TP mg/l	FILTER FLOW l/min	
18/8/75	LAB PLANT (A)	7.5/3/20:1	1	4934	920	0.446	62.7	8.18	-5	6.80	12.2	3.8	12.5	121	57.2	4.4	5.4	21.3	0.111 (1)	
			2	1646	495	0.166	62.8	6.73	-285	1.00	14.0									
			3	660	130	0.127	52.1	7.00	-155	2.90	15.0									
			4	657	125	0.128	49.8	7.40	-85	8.20	15.0									
			5	696	160	0.131	51.3	7.05	-90	3.00	14.8	50.5	2.0	28	24.9	15.9	16.3	16.8		
	LAB PLANT (B)	7.5/2/35:1	1	3363	880	0.422	62.2													0.196
			2	1493	575	0.158	61.5	6.60	-270	1.70	14.2									
			3	635	70	0.122	50.0	7.20	-90	7.10	15.1									
			4	643	87	0.126	51.8	7.47	-55	8.20	15.2									
			5	768	180	0.123	50.0	7.00	-70	3.30	14.9	46.6	7.8	34	31.6	13.8	15.6	16.8		
	FIELD PLANT (F)	7.5/3/20:1	2	1555		0.152	59.6	7.45	-310	0.90	11.0									6.2
			3	665		0.115	57.1	6.95	-155	7.80	11.0									
			4	602		0.115	58.4	7.00	-80	9.70	11.0									
			5	602		0.175	38.3	7.00	-80	7.20	11.0	54.7	4.2	23	19.9	10.9	11.6	12.5		

DATE	PLANT	SETTING	NUMBER	COD mg/l	BOD mg/l	TS %	VS %TS	pH	E _h mV	DO mg/l	TEMP °C	NO ₃ -N mg/l	NH ₄ -N mg/l	TKN mg/l	DKN mg/l	DIP mg/l	TDP mg/l	TP mg/l	FILTER FLOW l/min		
19/8/75	LAB PLANT (A)	7.5/3/20:1	1	3511		0.376	66.4	8.25	-5	7.10	13.0	0.6	18.3	150	83.9	3.5	4.4	18.8	0.110		
			2	1410		0.165	61.7	6.65	-270	0.80	15.0										
			3	521		0.124	50.7	7.05	-175	2.80	16.0										
			4	529		0.128	52.8	7.40	-90	8.10	15.9										
			5	524		0.123	50.6	7.10	-85	3.80	15.4	56.6	2.4	30	26.6	14.8	16.0	17.4			
	LAB PLANT (B)	7.5/2/35:1	1	2827		0.367	66.0													0.198	
			2	1222		0.149	60.7	6.68	-260	1.50	15.2										
			3	513		0.121	49.5	7.30	-135	6.70	16.0										
			4	510		0.121	50.5	7.40	-80	8.10	16.0										
			5	602		0.120	47.8	7.10	-95	3.40	15.8	43.4	11.2	37	34.9	14.2	16.2	16.5			
	FIELD PLANT (F)	7.5/3/20:1	2	1410		0.245	36.6	7.60	-300	1.20	12.0									6.1	
			3	457		0.109	53.1	6.97	-150	6.90	12.5										
			4	418		0.114	56.3	7.00	-85	9.10	12.7										
			5	471		0.112	55.7	7.04	-85	6.00	12.2	62.6	2.9	23	18.3	10.9	15.6	12.6			

DATE	PLANT	SETTING	NUMBER	COD mg/l	ROD mg/l	TS %	VS %TS	pH	E _h mV	DO mg/l	TEMP °C	NO ₃ -N mg/l	NH ₄ -N mg/l	TKN mg/l	DKN mg/l	DIP mg/l	TDP mg/l	TP mg/l	FILTER FLOW l/min	
20/8/75	LAB PLANT (A)	7.5/3/20:1	1	8097		0.980	60.2	8.25	-190	6.50	12.3	2.8	21.8	148	98.2	3.1	3.4	41.3	0.108	
			2	1362		0.147	58.0	6.60	-270	0.80	15.2									
			3	483		0.116	46.5	6.98	-180	3.10	15.6									
			4	477		0.121	52.0	7.48	-90	8.60	15.2									
			5	576		0.119	49.5	6.95	-90	3.20	15.0	56.6	1.8	38	31.6	7.3	7.6	16.9		
	LAB PLANT (B)	7.5/2/35:1	1	7037		0.935	59.3													0.194
			2	1304		0.136	58.0	6.70	-250	2.60	14.8									
			3	486		0.111	50.0	7.25	-130	7.10	15.2									
			4	512		0.118	52.5	7.40	-75	8.70	15.3									
			5	570		0.113	48.0	7.10	-85	4.50	15.1	47.5	3.1	33	16.6	6.9	7.1	16.2		
	FIELD PLANT (F)	7.5/3/20:1	2	1500		0.145	63.0	7.52	-305	0.60	11.3									6.6
			3	492		0.114	58.7	6.65	-150	6.80	11.5									
			4	468		0.116	58.1	6.60	-80	9.60	11.5									
			5	489		0.115	53.9	6.95	-90	5.10	11.5	63.7	5.8	27	18.3	5.8	6.3	13.7		

DATE	PLANT	SETTING	NUMBER	COD mg/l	BOD mg/l	TS %	VS %TS	pH	E _h mV	DO mg/l	TEMP °C	NO ₃ -N mg/l	NH ₄ -N mg/l	TKN mg/l	DKN mg/l	DIP mg/l	TDP mg/l	TP mg/l	FILTER FLOW l/min			
22/8/75	LAB PLANT (A)	7.5/3/20:1	1	5296		0.611	61.6	7.95	-230	4.90	10.0	-(2)	-	133	98.4	5.3	6.2	27.3				
			2	1653		0.192	60.9	6.60	-240	1.50	14.2											
			3	527		0.128	45.0	7.00	-160	3.10	15.0											
			4	530		0.108	49.8	7.50	-90	8.30	15.0											0.109
			5	696		0.137	46.3	7.02	-90	3.30	14.3			-	-	36	34.6	14.3	15.4	15.9		
	LAB PLANT (B)	7.5/2/35:1	1	5622		0.487	61.1															
			2	1532		0.158	59.3	6.60	-245	1.10	13.2											
			3	545		0.112	45.3	7.40	-130	7.30	15.0											
			4	675		0.153	50.0	7.65	-80	8.80	15.0											0.195
			5	575		0.113	46.0	7.30	-55	6.10	14.9			-	-	23	14.9	13.6	14.7	15.4		
	FIELD PLANT (F)	7.5/3/20:1	2	1668		0.166	59.5	7.55	-290	0.90	9.3											
			3	596		0.132	55.2	6.55	-150	7.70	8.4											
			4	551		0.132	56.1	6.52	-75	10.10	8.4											6.3
			5	593		0.132	52.4	6.80	-80	6.80	8.2			-	-	35	18.3	11.7	12.5	13.9		

Footnotes to Table App. V:1

- (1) Flow rates over the trickling filter were measured daily during the 4 weeks of each treatment, not just during the final monitoring week.
- (2) - denotes a missed sample.

TABLE APP. V:2

DATA MEANS OF ALL TREATMENTS

PLANT	SETTING	NUMBER	COD mg/l	BOD mg/l	TS %	VS %TS	pH	E _h mV	DO mg/l	TEMP °C	NO ₃ -N mg/l	NH ₄ -N mg/l	TKN mg/l	DKN mg/l	DIP mg/l	TDP mg/l	TP mg/l	FILTER FLOW l/min	
A	5/3/20:1	1	8343	1423	0.771		8.51	-130	2.67	21.9	2.49	45.60	360.00	228.50	3.74	4.10	39.02		
		2	2363	701	0.211		7.56	-320	0.50	22.2									
		3	1074	199	0.161		7.70	-261	0.42	22.5									
		4	841	121	0.150		7.77	-99	5.22	22.3									0.119
		5	885	252	0.155		7.80	-123	0.54	22.1	3.17	51.59	102.40	64.20	14.84	16.50	22.52		
A	5/1/35:1	1	6326	1079	0.646		8.40	-141	4.23	18.0	1.94	31.70	213.50	90.25	4.10	6.68	30.28		
		2	2335	692	0.194		7.25	-313	0.72	19.5									
		3	890	164	0.128		7.57	-188	3.66	19.8									
		4	418	60	0.105		7.68	-102	7.00	19.4									0.194
		5	1517	433	0.163		7.41	-243	2.82	19.4	13.43	53.56	83.20	66.00	17.04	20.48	25.02		
A	5/2/5:1	1	5545	946	0.596		8.21	-181	5.48	15.5	1.14	22.28	98.80	58.62	7.02	9.22	35.13		
		2	1625	482	0.147		7.08	-296	0.92	17.0									
		3	892	165	0.105		7.65	-185	1.41	17.9									
		4	801	115	0.101		7.69	-132	6.60	16.5									0.032
		5	1043	298	0.115		7.59	-170	1.26	16.2	5.74	35.46	74.20	54.80	17.42	18.42	22.24		

PLANT	SETTING	NUMBER	COD mg/l	BOD mg/l	TS %	VS %TS	pH	E _h mV	DO mg/l	TEMP °C	NO ₃ -N mg/l	NH ₄ -N mg/l	TKN mg/l	DN mg/l	DIP mg/l	TDP mg/l	TP mg/l	FILTER FLOW l/min	
A	5/2/35:1	1	6282	1072	0.619		8.00	10	6.86	12.7	2.26	14.80	92.25	64.80	4.42	12.90	21.05		
		2	1461	433	0.132		6.89	-270	1.65	15.4									
		3	518	95	0.094		7.26	-161	3.99	15.5									
		4	359	52	0.082		7.35	-112	7.36	15.4									0.197
		5	536	153	0.093		7.29	-195	5.44	15.2	11.04	1.63	21.00	18.20	18.28	19.15	19.86		
A	5/3/5:1	1	7096	1210	0.762		8.15	-58	6.80	10.5	1.60	14.40	81.00	49.00	5.25	12.30	27.80		
		2	1478	438	0.147		6.99	-273	1.22	12.9									
		3	591	109	0.104		7.46	-214	2.28	13.8									
		4	538	77	0.102		7.60	-156	7.28	13.0									0.028
		5	633	180	0.107		7.51	-153	3.50	12.1	5.30	23.85	82.50	51.75	15.83	17.05	19.58		
B	5/3/20:1	1	8243	1366	0.773														
		2	2816	866	0.269		7.29	-322	0.40	22.0									
		3	1022	187	0.168		7.55	-231	0.39	22.5									
		4	809	109	0.164		7.69	-97	5.09	22.4									0.090
		5	938	167	0.161		7.63	-120	0.66	22.0	31.64	13.83	360.0	38.43	13.20	14.32	19.06		

PLANT	SETTING	NUMBER	COD mg/l	BOD mg/l	TS %	VS %TS	pH	E _h mV	DO mg/l	TEMP °C	NO ₃ -N mg/l	NH ₄ -N mg/l	TKN mg/l	DKN mg/l	DIP mg/l	TDP mg/l	TP mg/l	FILTER FLOW l/min		
A	5/2/35:1	1	6282	1072	0.619		8.00	10	6.86	12.7	2.26	14.80	92.25	64.80	4.42	12.90	21.05	0.197		
		2	1461	433	0.132		6.89	-270	1.65	15.4										
		3	518	95	0.094		7.26	-161	3.99	15.5										
		4	359	52	0.082		7.35	-112	7.36	15.4										
		5	536	153	0.093		7.29	-195	5.44	15.2	11.04	1.63	21.00	18.20	18.28	19.15	19.86			
A	5/3/5:1	1	7096	1210	0.762		8.15	-58	6.80	10.5	1.60	14.40	81.00	49.00	5.25	12.30	27.80	0.028		
		2	1478	438	0.147		6.99	-273	1.22	12.9										
		3	591	109	0.104		7.46	-214	2.28	13.8										
		4	538	77	0.102		7.60	-156	7.28	13.0										
		5	633	180	0.107		7.51	-153	3.50	12.1	5.30	23.85	82.50	51.75	15.83	17.05	19.58			
B	5/3/20:1	1	8243	1366	0.773													0.090		
		2	2816	866	0.269		7.29	-322	0.40	22.0										
		3	1022	187	0.168		7.55	-231	0.39	22.5										
		4	809	109	0.164		7.69	-97	5.09	22.4										
		5	938	167	0.161		7.63	-120	0.66	22.0	31.64	13.83	360.0	38.43	13.20	14.32	19.06			

PLANT	SETTING	NUMBER	COD mg/l	BOD mg/l	TS %	VS %TS	pH	E _h mV	DO mg/l	TEMP °C	NO ₃ -N mg/l	NH ₄ -N mg/l	TKN mg/l	DKN mg/l	DIP mg/l	TDP mg/l	TP mg/l	FILTER FLOW l/min			
B	5/1/20:1	1	6068	1006	0.627																
		2	2689	827	0.220		7.23	-310	0.71	19.3											
		3	1142	209	0.155		7.55	-158	3.76	19.3											
		4	821	111	0.141		7.67	-70	7.30	19.3										0.113	
		5	1618	288	0.173		7.49	-173	3.75	18.9	45.96	29.53	64.00	49.40	17.24	21.40	28.36				
B	5/1/5:1	1	6155	1020	0.605																
		2	1689	519	0.148		7.42	-289	1.30	16.9											
		3	789	144	0.108		7.57	-164	4.32	16.8											
		4	792	107	0.113		7.94	-131	8.50	16.5										0.031	
		5	1046	186	0.121		7.51	-230	3.56	16.3	28.02	17.70	56.60	37.60	16.16	17.02	21.08				
B	5/2/20:1	1	6626	1098	0.596																
		2	1497	460	0.145		6.79	-262	1.69	15.0											
		3	539	98	0.096		7.30	-151	5.16	15.2											
		4	524	71	0.100		7.43	-112	8.24	15.4										0.111	
		5	631	112	0.101		7.22	-195	4.74	15.1	22.52	7.00	34.00	29.00	17.88	18.18	18.92				

PLANT	SETTING	NUMBER	COD mg/l	BOD mg/l	TS %	VS %TS	pH	E _h mV	DO mg/l	TEMP °C	NO ₃ -N mg/l	NH ₄ -N mg/l	TKN mg/l	DKN mg/l	DIP mg/l	TDP mg/l	TP mg/l	FILTER FLOW l/min	
F	5/2/35:1	2	1529		0.138		7.37	-279	1.38	11.4									
		3	651		0.112		7.32	-160	7.76	11.4									
		4	489		0.100		7.37	-126	9.36	11.5									11.20
		5	554		0.102		7.39	-135	7.62	11.2	48.16	3.12	33.60	23.40	14.36	15.30	17.06		
F	5/3/5:1	2	1695		0.149		7.53	-284	1.52	7.5									
		3	739		0.113		7.46	-204	3.44	7.4									
		4	589		0.110		7.52	-160	9.94	7.5									1.560
		5	641		0.113		7.52	-150	5.16	7.0	36.03	10.25	39.75	17.00	12.23	13.50	17.18		
A	7.5/2/5:1	1	5283	1251	0.591	66.4	7.97	-95	6.52	9.9	2.10	22.55	174.75	40.00	5.23	6.10	30.20		
		2	1352	479	0.137	54.9	6.74	-248	2.00	13.7									
		3	684	139	0.106	44.0	7.47	-208	1.80	14.3									
		4	595	103	0.103	43.4	7.63	-161	6.24	14.4									0.030
		5	715	207	0.108	45.5	7.37	-173	2.84	13.0	2.13	33.05	60.50	40.00	12.20	13.68	16.53		

PLANT	SETTING	NUMBER	COD mg/l	BOD mg/l	TS %	VS %TS	pH	E _n mV	DO mg/l	TEMP °C	NO ₃ -N mg/l	NH ₄ -N mg/l	TKN mg/l	DKN mg/l	DIP mg/l	TDP mg/l	TP mg/l	FILTER FLOW l/min	
A	7.5/3/20:1	1	5394	1278	0.610	61.7	8.15	-89	6.54	11.9	2.70	20.85	138.00	84.43	4.66	5.46	32.72	0.108	
		2	1505	533	0.165	59.7	6.64	-265	0.98	14.6									
		3	545	110	0.122	48.9	7.01	-160	3.12	15.3									
		4	541	93	0.121	50.7	7.46	-83	8.34	15.2									
		5	611	177	0.125	49.0	7.02	-85	3.30	14.8	54.95	2.53	34.00	29.20	13.22	14.00	19.28		
A	7.5/1/35:1	1	8730	2068	0.920	57.2	8.28	-20	6.06	13.7	4.79	28.45	256.25	146.50	5.78	6.03	54.43	0.192	
		2	2341	830	0.229	56.1	7.12	-306	0.76	14.7									
		3	607	123	0.163	47.4	7.00	-143	6.78	15.4									
		4	593	102	0.167	47.7	7.07	-68	8.62	15.3									
		5	1381	401	0.187	49.4	7.20	-234	4.44	15.0	76.79	28.50	82.00	48.40	26.71	29.18	31.39		
A	7.5/1/5:1	1	5491	1301	0.545	66.5	8.09	-68	5.91	18.1	1.75	27.76	197.00	72.80	7.38	8.68	54.61	0.030	
		2	2607	924	0.240	60.6	6.76	-276	0.94	18.7									
		3	713	144	0.144	40.7	7.44	-184	2.36	19.6									
		4	619	107	0.141	40.9	7.68	-123	7.59	18.4									
		5	1443	419	0.183	51.7	7.03	-235	2.22	18.1	24.05	21.88	67.00	40.80	28.69	32.10	39.43		

PLANT	SETTING	NUMBER	COD mg/l	BOD mg/l	TS %	VS %TS	pH	E _h mV	DO mg/l	TEMP °C	NO ₃ -N mg/l	NH ₄ -N mg/l	TKN mg/l	DKN mg/l	DIP mg/l	TDP mg/l	TP mg/l	FILTER FLOW l/min	
A	7.5/3/5:1	1	11154	2643	1.176	71.9	8.16	-112	4.84	19.0	1.76	21.61	207.00	101.20	5.55	7.10	47.52		
		2	3631	1287	0.320	63.9	6.81	-310	1.17	19.7									
		3	1490	302	0.231	46.7	7.49	-201	0.87	19.8									
		4	1288	223	0.219	45.5	7.60	-141	5.86	18.9									0.030
		5	1677	487	0.263	47.5	7.43	-205	0.38	18.6	11.90	36.69	83.75	55.50	30.49	34.33	41.69		
B	7.5/2/5:1	1	6372	1841	0.603	66.8													
		2	1165	405	0.130	53.6	7.49	-273	1.14	13.3									
		3	609	105	0.100	44.1	7.52	-188	3.80	13.9									
		4	518	91	0.107	47.1	7.76	-142	7.96	14.6									0.030
		5	714	180	0.104	46.4	7.54	-174	2.90	13.4	23.53	15.83	44.75	40.00	9.78	10.98	14.53		
B	7.5/2/35:1	1	4854	1402	0.578	61.3													
		2	1556	542	0.167	59.2	6.66	-254	1.74	14.3									
		3	542	94	0.116	48.0	7.28	-122	7.04	15.2									
		4	585	103	0.127	51.0	7.49	-75	8.46	15.3									0.195
		5	625	158	0.117	48.3	7.12	-75	4.38	15.1	46.85	5.95	30.40	23.92	12.32	13.52	18.44		

PLANT	SETTING	NUMBER	COD mg/l	BOD mg/l	TS %	VS %TS	pH	E _h mV	DO mg/l	TEMP °C	NO ₃ -N mg/l	NH ₄ -N mg/l	TKN mg/l	DKN mg/l	DIP mg/l	TDP mg/l	TP mg/l	FILTER FLOW l/min		
B	7.5/1/20:1	1	8482	2451	0.920	58.3														
		2	2447	852	0.236	56.4	7.20	-306	0.68	14.4										
		3	597	103	0.170	46.1	7.19	-145	6.30	15.2										
		4	640	113	0.166	47.2	7.32	-77	8.12	15.2										0.108
		5	982	248	0.169	46.6	7.30	-206	5.22	15.0	66.26	22.17	70.00	35.60	24.54	26.19	28.87			
B	7.5/3/35:1	1	5548	1603	0.543	67.1														
		2	2553	889	0.226	62.5	6.70	-280	1.16	18.2										
		3	690	119	0.134	43.6	7.45	-161	5.52	18.8										
		4	734	129	0.142	45.3	7.59	-105	7.46	18.9										0.200
		5	857	216	0.147	46.3	7.31	-111	2.04	18.7	35.92	7.04	46.00	26.80	27.09	31.04	34.47			
B	7.5/2/20:1	1	11250	3251	1.134	71.1														
		2	3879	1351	0.325	65.0	6.82	-326	0.68	18.5										
		3	1650	286	0.209	52.1	7.45	-230	0.67	19.1										
		4	1472	260	0.207	51.1	7.51	-135	5.62	19.7										0.110
		5	1981	501	0.228	54.3	7.34	-223	0.26	18.5	18.39	27.63	86.00	43.80	27.96	31.37	39.94			

PLANT	SETTING	NUMBER	COD mg/l	BOD mg/l	TS %	VS %TS	pH	E _h mV	DO mg/l	TEMP °C	NO ₃ -N mg/l	NH ₄ -N mg/l	TKN mg/l	DKN mg/l	DIP mg/l	TDP mg/l	TP mg/l	FILTER FLOW l/min	
F	7.5/2/5:1	2	1458		0.138	59.7	7.44	-269	2.84	7.3									1.500
		3	668		0.103	52.6	7.13	-180	4.12	7.2									
		4	458		0.102	53.6	7.15	-143	10.24	7.3									
		5	614		0.101	51.9	7.18	-167	4.52	7.1	42.25	10.65	35.50	29.50	8.20	9.25	12.38		
F	7.5/3/20:1	2	1554		0.172	55.1	7.52	-300	0.92	10.9									6.466
		3	566		0.117	55.1	6.72	-147	7.18	10.7									
		4	515		0.119	56.2	6.72	-79	9.62	10.7									
		5	535		0.131	50.7	6.91	-83	6.14	10.6	62.30	4.33	29.20	18.62	10.06	11.62	15.38		
F	7.5/1/35:1	2	2676		0.229	59.6	8.10	-329	0.54	12.0									11.200
		3	1177		0.170	53.4	7.13	-145	8.12	12.6									
		4	746		0.158	51.1	7.06	-109	9.04	12.6									
		5	849		0.150	45.6	7.34	-184	7.26	12.5	91.51	11.46	66.00	34.80	21.19	23.03	26.28		

PLANT	SETTING	NUMBER	COD mg/l	BOD mg/l	TS %	VS %TS	pH	E _h mV	DO mg/l	TEMP °C	NO ₃ -N mg/l	NH ₄ -N mg/l	TKN mg/l	DKN mg/l	DIP mg/l	TDP mg/l	TP mg/l	FILTER FLOW l/min	
A	10/1/35:1	1	7803	2302	0.800	72.3	8.31	-108	2.96	23.2	3.15	38.80	249.72	136.72	3.89	4.87	30.96	0.200	
		2	2209	378	0.226	53.7	6.77	-302	1.32	20.9									
		3	605	58	0.160	35.6	7.35	-188	5.52	21.5									
		4	487	63	0.155	35.8	7.45	-128	7.70	21.3									
		5	1783	411	0.207	50.1	7.02	-256	4.28	20.7	45.54	26.55	63.43	52.38	24.48	25.88	30.84		
A	10/3/35:1	1	5103	1505	0.510	70.3	8.31	3	3.58	21.0	5.84	43.48	252.50	162.20	2.82	3.02	34.68	0.200	
		2	1474	252	0.189	48.9	6.90	-301	1.63	20.9									
		3	405	39	0.161	41.1	6.99	-176	4.55	21.1									
		4	364	47	0.167	40.3	7.13	-111	7.88	20.9									
		5	484	112	0.161	41.4	7.07	-170	4.40	20.4	96.27	15.16	38.04	28.20	18.39	19.79	20.88		
A	10/2/20:1	1	8808	2598	0.916	75.8	8.31	-35	3.94	20.3	7.39	37.54	304.20	206.62	3.55	5.12	42.17	0.120	
		2	2877	493	0.293	53.2	7.23	-291	1.42	18.7									
		3	549	53	0.197	40.1	6.84	-157	4.62	19.4									
		4	533	69	0.198	41.4	6.83	-95	7.48	19.0									
		5	1650	380	0.209	39.9	7.26	-191	2.40	18.3	70.53	66.79	97.02	102.80	20.86	22.19	25.77		

PLANT	SETTING	NUMBER	COD mg/l	BOD mg/l	TS %	VS %TS	pH	E _h mV	DO mg/l	TEMP °C	NO ₃ -N mg/l	NH ₄ -N mg/l	TKN mg/l	DKN mg/l	DIP mg/l	TDP mg/l	TP mg/l	FILTER FLOW l/min		
A	10/3/5:1	1	5421	1599	0.524	67.1	8.21	-41	4.10	22.1	2.30	13.88	208.20	96.70	2.83	3.82	35.18	0.030		
		2	1821	312	0.188	54.8	6.88	-269	1.16	20.7										
		3	915	88	0.154	45.0	7.17	-164	2.98	21.5										
		4	850	110	0.161	46.1	7.55	-97	7.16	20.5										
		5	1057	244	0.167	47.3	7.26	-106	3.16	19.9	29.97	21.09	65.44	48.52	21.57	23.09	26.44			
A	10/1/5:1	1	4576	1350	0.590	70.5	8.36	-53	5.13	17.8	2.30	22.56	244.20	188.60	1.44	1.91	12.31	0.030		
		2	1033	177	0.161	54.8	6.71	-261	1.23	18.5										
		3	350	34	0.126	46.5	7.18	-148	4.68	19.6										
		4	336	43	0.144	50.1	7.16	-75	8.16	18.4										
		5	541	125	0.127	50.7	6.97	-155	5.30	17.9	17.37	25.63	67.90	42.87	13.36	13.94	14.56			
B	10/1/35:1	1	8695	2325	0.776	71.9													0.200	
		2	2519	759	0.230	54.5	6.78	-305	0.82	20.7										
		3	929	199	0.175	43.0	7.59	-171	6.08	21.6										
		4	910	220	0.176	44.6	7.76	-123	7.66	21.5										
		5	1312	395	0.194	47.2	7.06	-209	3.94	20.8	45.76	21.82	71.16	53.30	20.81	22.56	27.14			

PLANT	SETTING	NUMBER	COD mg/l	BOD mg/l	TS %	VS %TS	pH	E _h mV	DO mg/l	TEMP °C	NO ₃ -N mg/l	NH ₄ -N mg/l	TKN mg/l	DKN mg/l	DIP mg/l	TDP mg/l	TP mg/l	FILTER FLOW l/min		
B	10/1/20:1	1	4874	1303	0.513	71.1														
		2	1622	489	0.198	48.9	6.93	-309	0.88	20.3										
		3	617	132	0.173	45.0	7.20	-185	5.33	20.5										
		4	579	140	0.184	46.1	7.42	-121	8.23	20.5										0.110
		5	876	264	0.173	44.2	7.13	-249	4.60	20.1	82.37	33.34	67.98	49.44	16.57	17.80	19.65			
B	10/3/20:1	1	7838	2096	0.911	73.8														
		2	2040	614	0.246	49.0	7.19	-310	0.82	18.4										
		3	649	139	0.190	40.1	7.19	-156	4.74	18.6										
		4	648	157	0.194	41.1	7.32	-87	7.78	18.6										0.075
		5	796	240	0.192	39.7	7.22	-143	1.00	18.2	107.23	15.59	48.44	33.30	18.26	19.17	21.59			
B	10/2/5:1	1	5592	1495	0.534	67.6														
		2	1416	427	0.166	53.2	6.63	-287	1.00	20.7										
		3	885	190	0.147	45.8	7.30	-173	3.50	20.9										
		4	804	194	0.155	46.2	7.69	-110	7.42	20.6										0.030
		5	972	293	0.154	46.7	7.16	-130	2.98	20.0	33.10	14.66	60.62	37.82	16.73	17.97	20.11			

PLANT	SETTING	NUMBER	COD mg/l	BOD mg/l	TS %	VS %TS	pH	E _h mV	DO mg/l	TEMP °C	NO ₃ -N mg/l	NH ₄ -N mg/l	TKN mg/l	DKN mg/l	DIP mg/l	TDP mg/l	TP mg/l	FILTER FLOW l/min		
B	10/2/35:1	1	3936	1060	0.590	70.5														
		2	761	229	0.142	51.9	6.83	-275	1.18	18.4										
		3	268	57	0.138	49.8	6.79	-122	7.18	18.9										
		4	247	60	0.144	53.9	6.93	-57	8.56	19.0										0.195
		5	290	87	0.142	50.4	6.87	-112	5.70	18.6	15.41	9.16	36.40	23.80	11.94	12.64	13.74			
F	10/3/35:1	2	2053		0.208	53.3	7.66	-340	0.30	20.2										
		3	679		0.189	48.9	6.93	-171	6.27	20.5										
		4	712		0.206	51.9	6.90	-129	6.66	20.6										10.310
		5	603		0.190	48.9	6.99	-130	2.40	21.7	122.77	2.43	29.16	17.20	16.94	18.21	20.35			
F	10/2/20:1	2	2463		0.255	53.6	7.55	-313	0.32	17.7										
		3	881		0.233	52.5	6.82	-138	5.46	18.5										
		4	852		0.234	51.6	6.63	-86	7.20	18.6										6.733
		5	985		0.232	51.1	6.97	-103	2.08	18.4	139.74	8.80	54.85	26.18	18.40	19.47	22.22			

PLANT	SETTING	NUMBER	COD mg/l	BOD mg/l	TS %	VS %TS	pH	E _h mV	DO mg/l	TEMP °C	NO ₃ -N mg/l	NH ₄ -N mg/l	TKN mg/l	DKN mg/l	DIP mg/l	TDP mg/l	TP mg/l	FILTER FLOW l/min	
F	10/1/5:1	2	1148		0.145	55.1	7.12	-276	1.42	15.9									
		3	527		0.148	56.0	6.97	-151	5.68	16.0									
		4	418		0.148	58.8	6.46	-63	9.06	15.9									
		5	547		0.155	58.1	6.96	-60	6.63	16.4	22.93	5.83	38.53	27.12	12.82	13.34	14.91	1.300	

APPENDIX VI

LABORATORY PLANT DATA FROM ANAEROBIC AND
AEROBIC SOLIDS REMOVAL.

Treatment Setting	Solids Source	Volume Removed (l)	TS (%)	VS (% TS)
5/3/20:1	An. Slurry ⁽¹⁾	20	3.56	-
5/1/35:1	An. Slurry	20	4.16	-
	Ae. Slurry ⁽²⁾	2	1.48	-
5/2/5:1	An. Surface Mat	-	9.03	-
	An. Slurry	20	3.01	-
	Ae. Slurry	2	1.29	-
5/2/35:1	An. Surface Mat	-	10.12	-
	An. Slurry	20	3.78	-
	Ae. Slurry	4	1.24	-
5/3/5:1	An. Surface Mat	-	11.57	-
	An. Slurry	20	4.01	-
	Ae. Slurry	8	0.68	-
5/1/20:1	An. Surface Mat	-	9.04	-
	An. Slurry	20	3.84	-
	Ae. Slurry	2	2.89	-
5/1/5:1	An. Surface Mat	-	7.93	-
	An. Slurry	20	3.25	-
	Ae. Slurry	2	2.18	-
5/2/20:1	An. Surface Mat	-	9.90	-
	An. Slurry	20	3.84	-
	Ae. Slurry	4	0.94	-
5/3/35:1	An. Surface Mat	-	6.25	-
	An. Slurry	20	3.87	-
	Ae. Slurry	8	0.74	-
7.5/2/5:1	Ae. Slurry	1	0.40	70.4
7.5/3/20:1	An. Surface Mat	-	16.86	53.9
	An. Slurry	30	4.68	53.4
	Ae. Slurry	16	0.47	63.3

Treatment Setting	Solids Source	Volume Removed (l)	TS (%)	VS (% TS)
7.5/1/35:1	Ae. Slurry	8	0.87	67.0
7.5/1/5:1	An. Surface Mat	-	13.77	49.1
	An. Slurry	28	5.80	47.3
7.5/3/5:1	Ae. Slurry	16	0.63	63.8
7.5/2/35:1	An. Surface Mat	-	12.46	57.6
	An. Slurry	30	4.28	56.4
	Ae. Slurry	9.5	0.74	69.2
7.5/1/20:1	Ae. Slurry	8	1.07	69.3
7.5/3/35:1	An. Surface Mat	-	12.83	48.3
	An. Slurry	36	4.79	48.6
	Ae. Slurry	16	0.70	70.3
7.5/2/20:1	Ae. Slurry	8	0.75	73.5
10/1/35:1	Ae. Slurry	8	1.03	74.4
10/1/20:1	An. Surface Mat	-	12.23	54.6
	An. Slurry	40	4.37	62.5
10/3/20:1	Ae. Slurry	16	0.50	69.0
10/2/5:1	Ae. Slurry	8	0.49	74.1
10/2/35:1	An. Surface Mat	-	10.21	69.8
	An. Slurry	80	2.42	66.1
	Ae. Slurry	16	0.25	69.7
10/3/35:1	An. Surface Mat	-	13.60	53.8
	An. Slurry	40	4.90	61.7
	Ae. Slurry	16	0.68	69.9
10/2/20:1	Ae. Slurry	8	0.80	70.0
10/3/5:1	Ae. Slurry	16	0.85	72.2

Treatment Setting	Solids Source	Volume Removed (1)	TS (%)	VS (% TS)
10/1/5:1	An. Surface Mat	-	10.68	67.4
	An. Slurry	80	2.31	63.3
	Ae. Slurry	8	0.82	72.0

NOTES: (1) An. = Anaerobic

(2) Ae. = Aerobic

APPENDIX VII

MONTHLY VARIATIONS IN DAIRY SHED EFFLUENT

FIGURE App. VII:1

COD AND BOD IN DAIRY SHED EFFLUENT

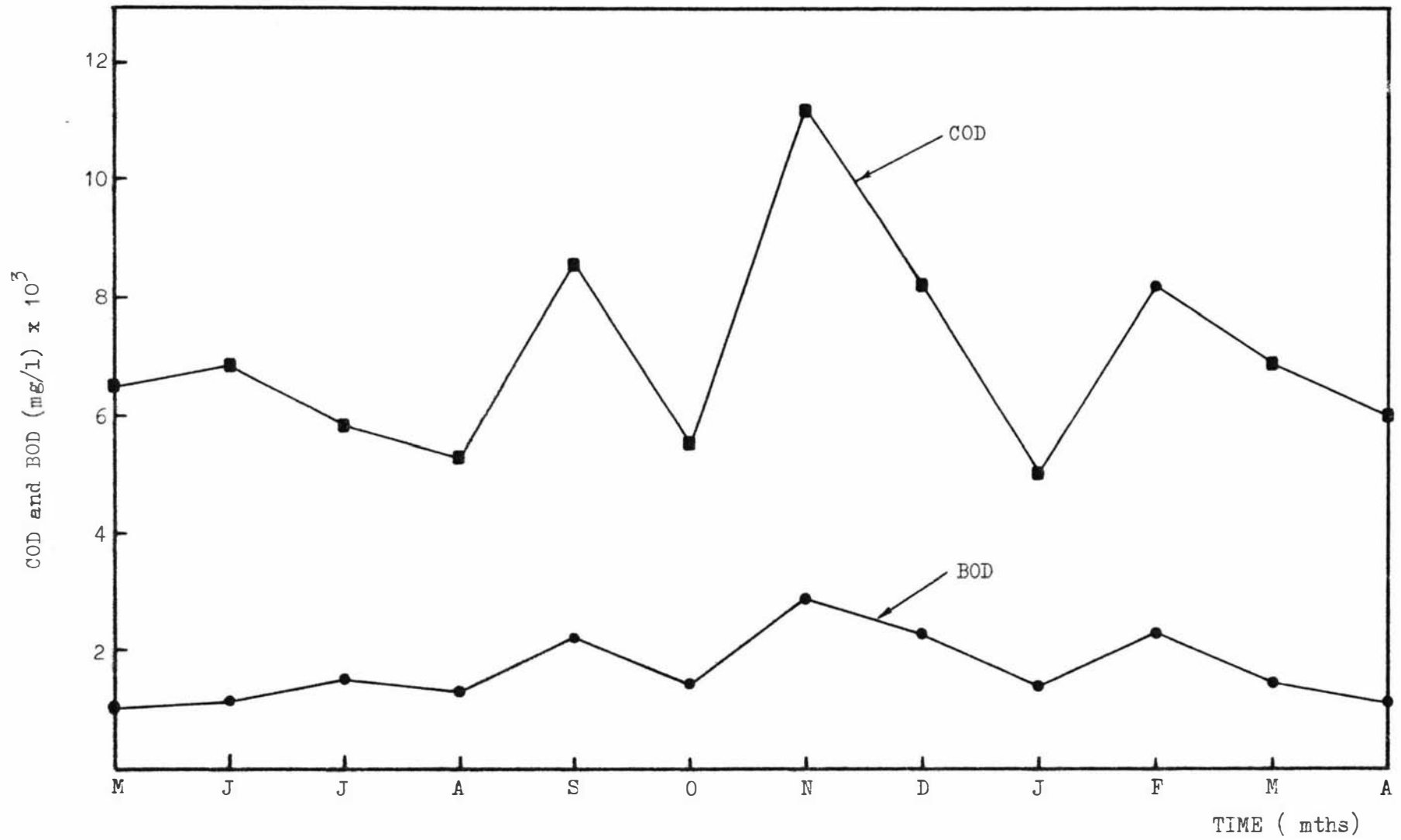


FIGURE App. VII:2

TS AND VS IN DAIRY SHED EFFLUENT

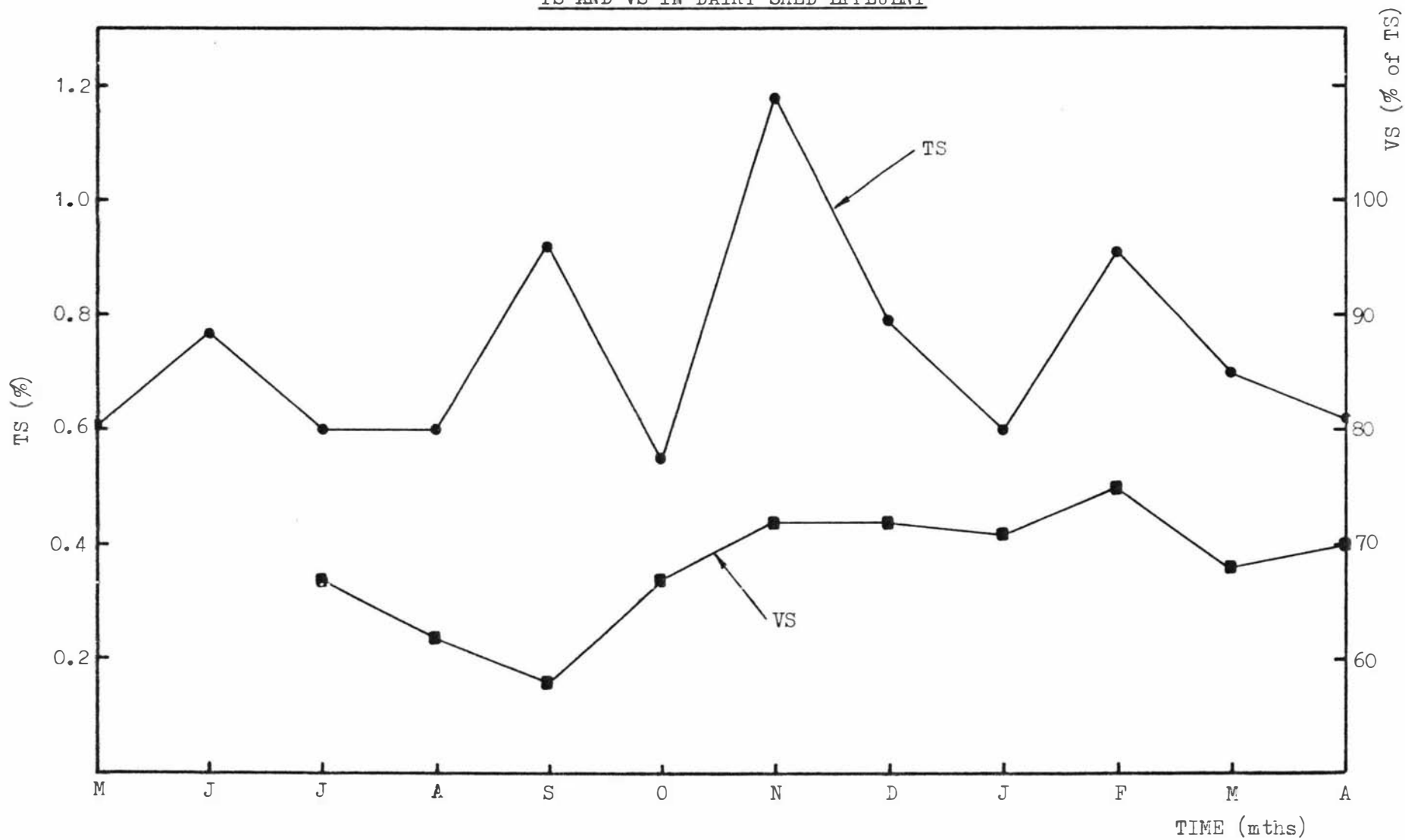


FIGURE App. VII:3

TEMPERATURE AND DO IN DAIRY SHED EFFLUENT

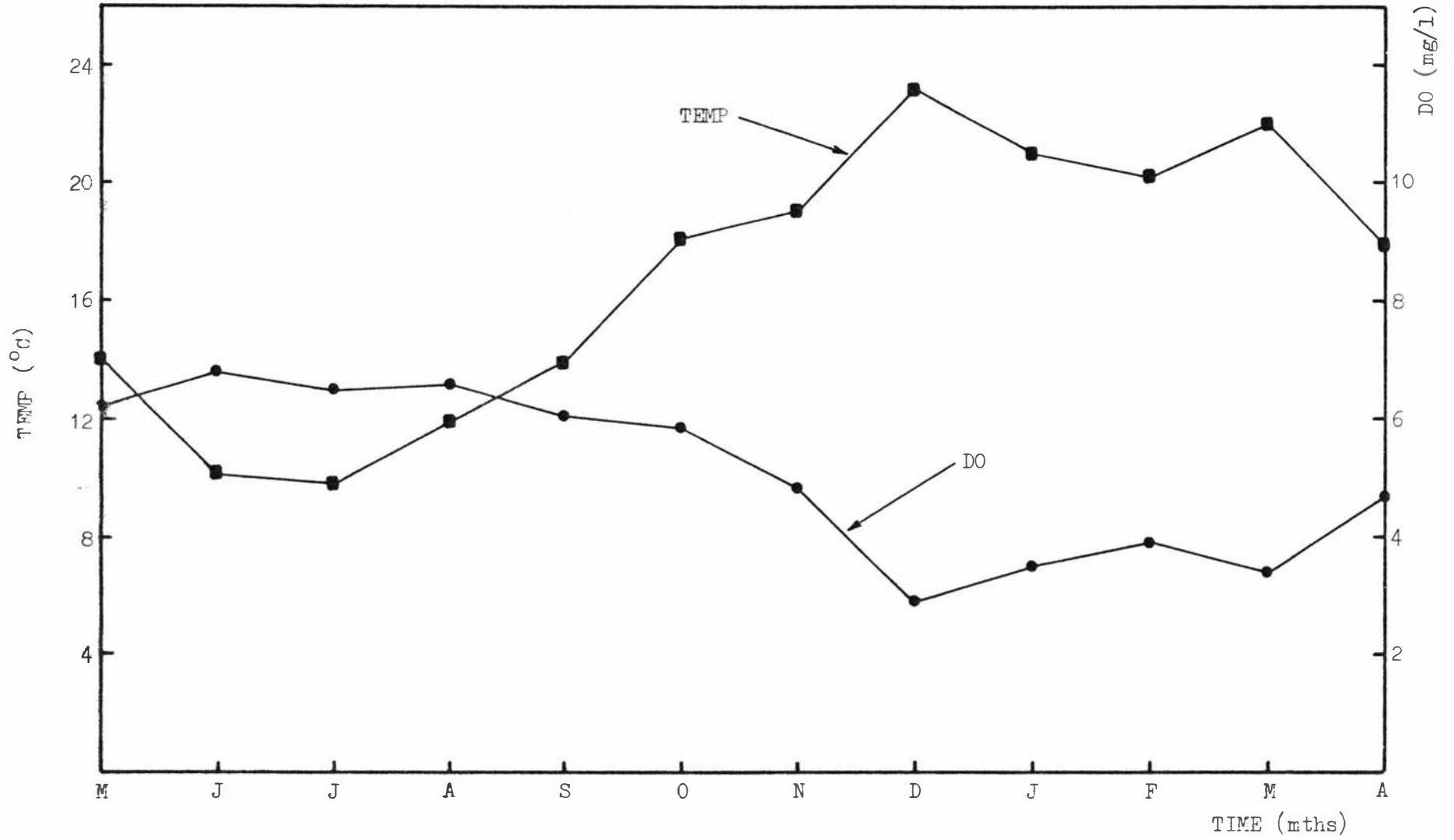


FIGURE App. VII:4

pH AND E_h IN DAIRY SHED EFFLUENT

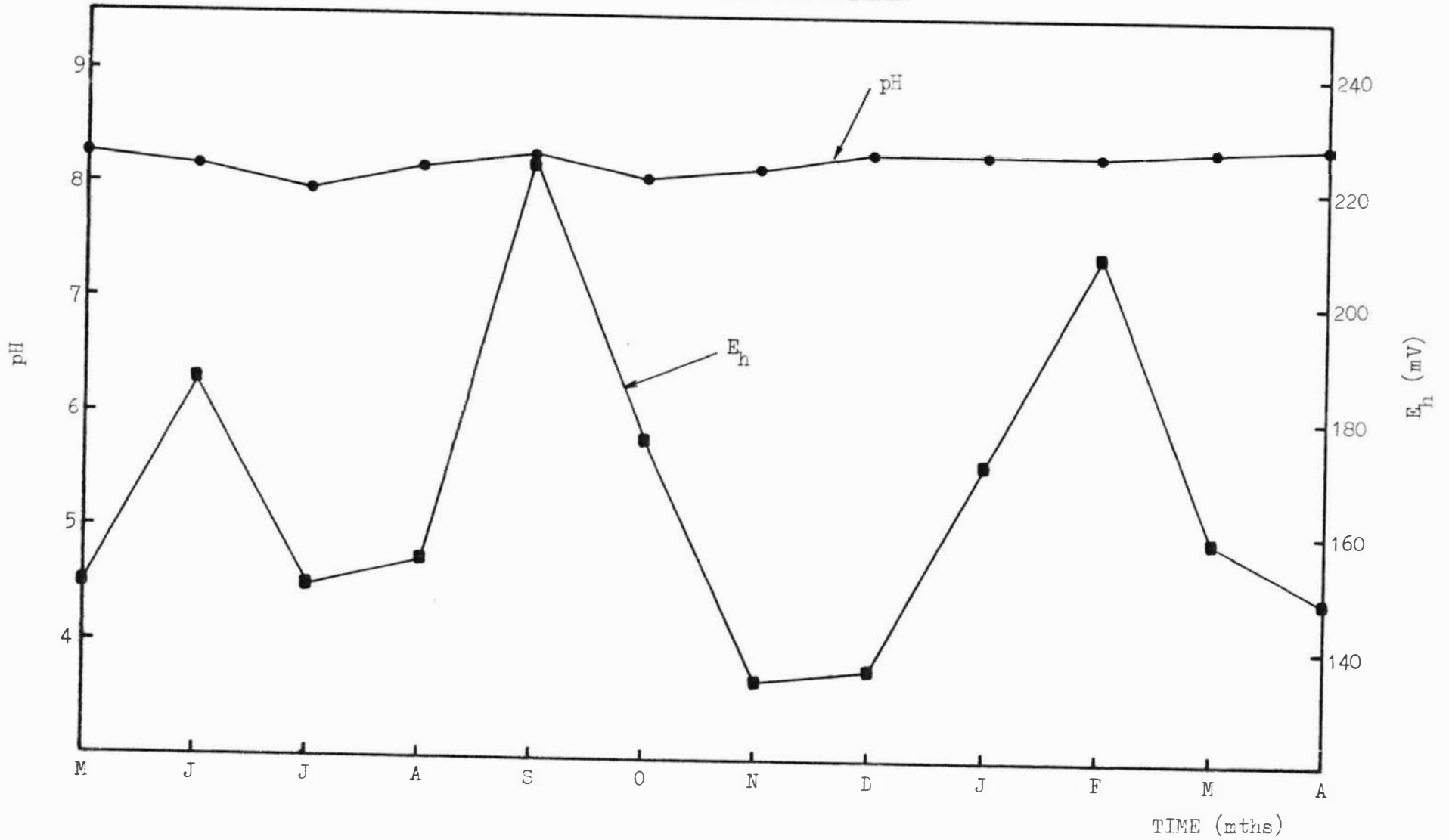


FIGURE App. VII:5

NO₃-N AND NH₄-N IN DAIRY SHED EFFLUENT

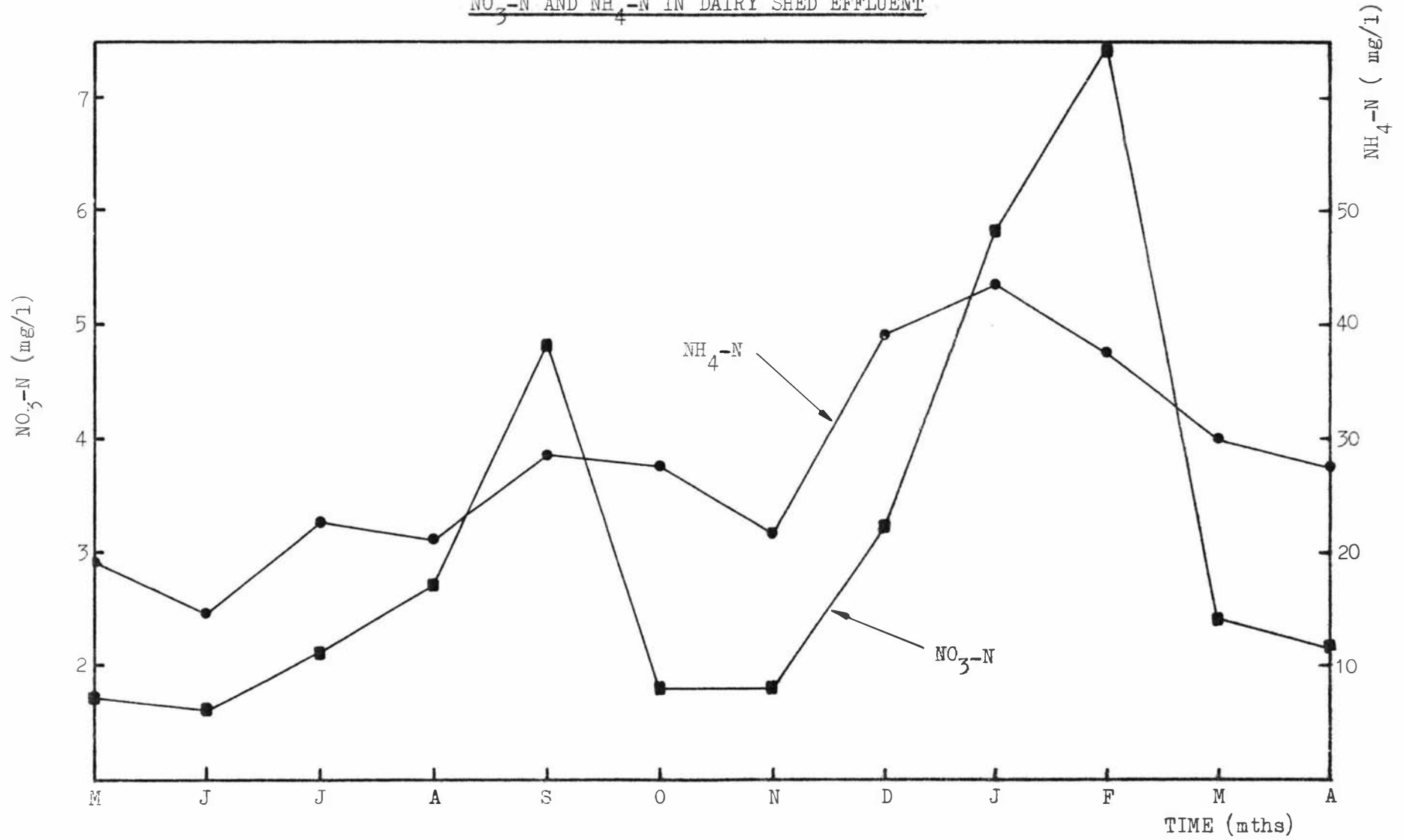


FIGURE App. VII:6

DKN AND TKN IN DAIRY SHED EFFLUENT

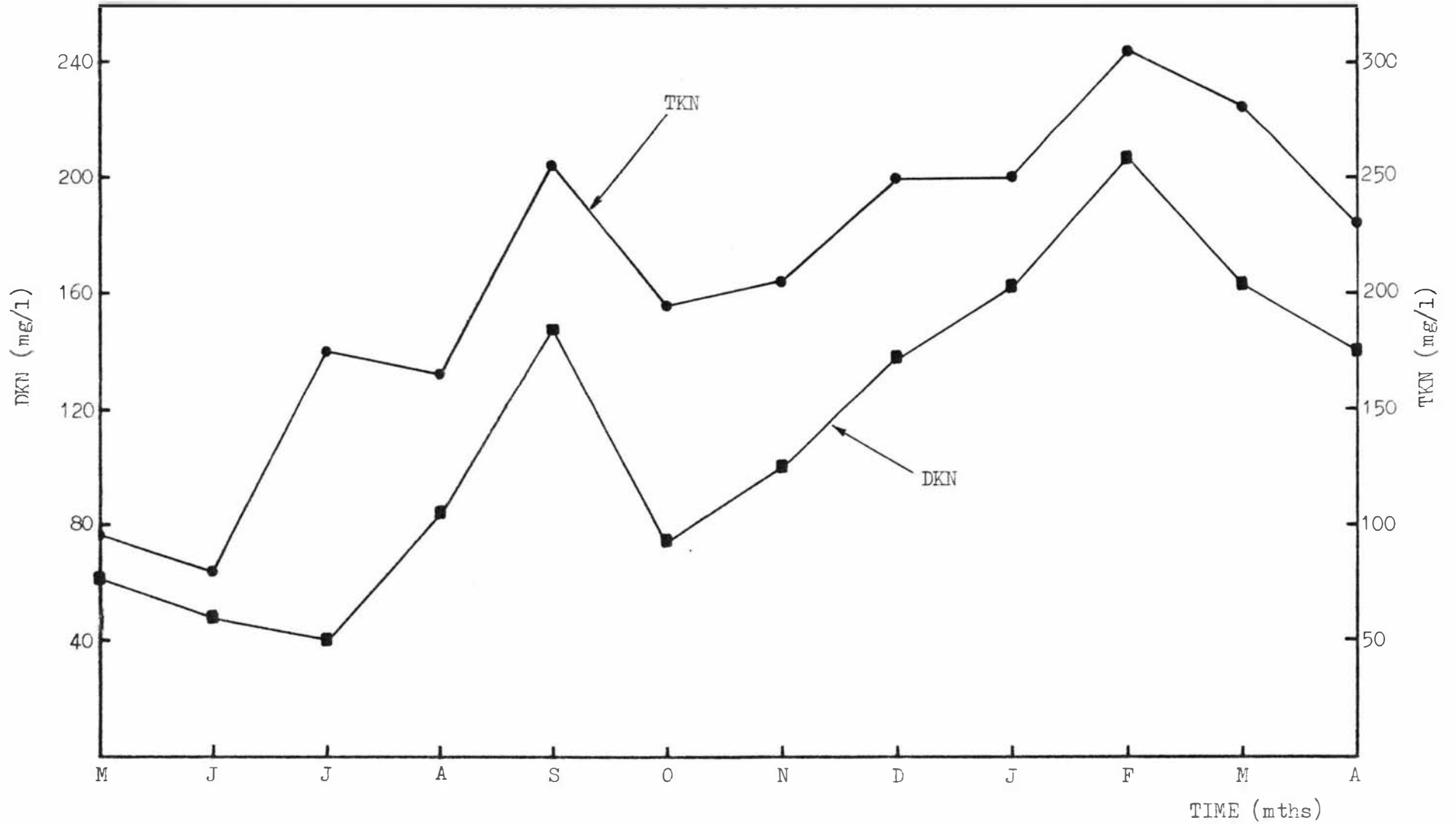
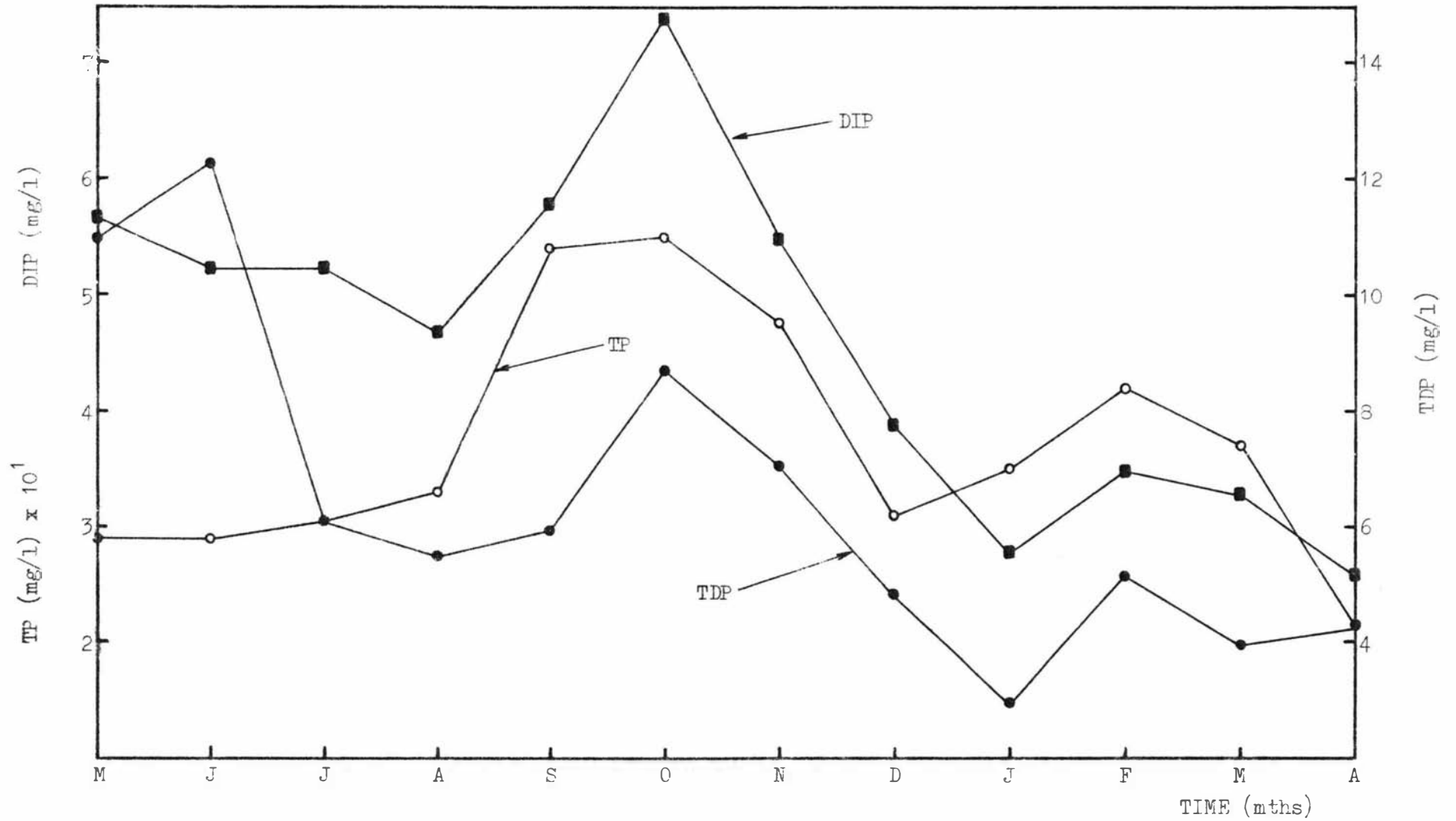


FIGURE App. VII:7

DIP, TDP AND TP IN DAIRY SHED EFFLUENT



APPENDIX VIII

DESIGN OF ANAEROBIC TANK AND TRICKLING FILTER AERATION
SYSTEM FOR A 250 COW FACTORY SUPPLY DAIRY SHED

VIII:1) ASSUMPTIONS FOR PLANT DESIGN

- (a) The total herd of 250 cows is in the shed for 280 days each year. The daily pollution load is presented in Table App. VIII:1.
- (b) Solids are to be removed from the anaerobic tank every two years and the mean hydraulic residence time must remain greater than 3 days.
- (c) All lagoons batters have a 2:1 slope. The top of the embankments are 4m wide.
- (d) The sludge accumulation rate in the anaerobic tank is $0.005 \text{ m}^3/\text{kg TS IN}$.
- (e) The anaerobic tank is square, 3m deep and removes 70% of the BOD, COD and TS.
- (f) The aerobic tank provides a 4 day residence time. It is the same width as the anaerobic tank and has a maximum depth of 3m.
- (g) The trickling filter is 2m high and contains 40mm stone media. It is loaded at $0.175 \text{ kg BOD/m}^3\text{-day}$ with a hydraulic load of $18 \text{ m}^3/\text{m}^2\text{-day}$.
- (h) The centrifugal recycle pump is 50% efficient and the driving motor is 90% efficient.
- (i) Anaerobic sludge has an 8% TS level and is distributed to land at 50 tonne DM/ha.
- (j) Aerobic solids accumulation rate is 60% of the BOD removal rate. 70% BOD removal is achieved in the aerobic phase.
- (k) Aerobic sludge contains 4% TS.

TABLE APP.VIII:1POLLUTION LOAD FROM A 250 COWFACTORY SUPPLY DAIRY SHED

Parameter	Load ⁽¹⁾
COD	82.5 kg/day
BOD	18.8 kg/day
TS	90.0 kg/day
VS	61.3 kg/day
NO ₃ -N	0.037 kg/day
NH ₄ -N	0.330 kg/day
DKN	1.44 kg/day
TKN	2.56 kg/day
TDN	1.47 kg/day
TPN	1.13 kg/day
TN	2.60 kg/day
DIP	0.057 kg/day
TDP	0.081 kg/day
DOP	0.025 kg/day
TPP	0.359 kg/day
TP	0.440 kg/day
Volume	17.5 m ³ /day

NOTE: (1) Based on Table 8:2

VIII:2) ANAEROBIC TANK DESIGN

$$\begin{aligned} \text{Minimum required volume} &= 3 \times 17.5 && \text{(a, b)*} \\ &= 52.5 \text{ m}^3 \end{aligned}$$

$$\begin{aligned} \text{Total sludge volume} &= 0.005 \times 90 \times 560 && \text{(a, b, d)} \\ &= 252 \text{ m}^3 \end{aligned}$$

$$\begin{aligned} \text{Therefore, total tank volume} &= 52.5 + 252 \\ &= 305 \text{ m}^3 \\ &= \text{Excavated volume} \end{aligned}$$

Tank dimensions are 27.3 x 27.3m and are shown in Figure App. VIII:1. (c, e)

$$\begin{aligned} \text{Embankment area} &= 0.4 \times 4.8 \\ &= 1.92 \text{ m}^2 \end{aligned}$$

$$\begin{aligned} \text{Fill for anaerobic embankments} &= 21.7 \times 1.92 \times 4 \\ &= 167 \text{ m}^3 \end{aligned}$$

The anaerobic tank volume will provide an initial residence time of 17 days.

VIII:3) AEROBIC DESIGNVIII:3.1) Aerobic Tank Design

$$\begin{aligned} \text{Tank volume} &= 17.5 \times 4 && \text{(f)} \\ &= 70 \text{ m}^3 \\ &= \text{Excavated volume} \end{aligned}$$

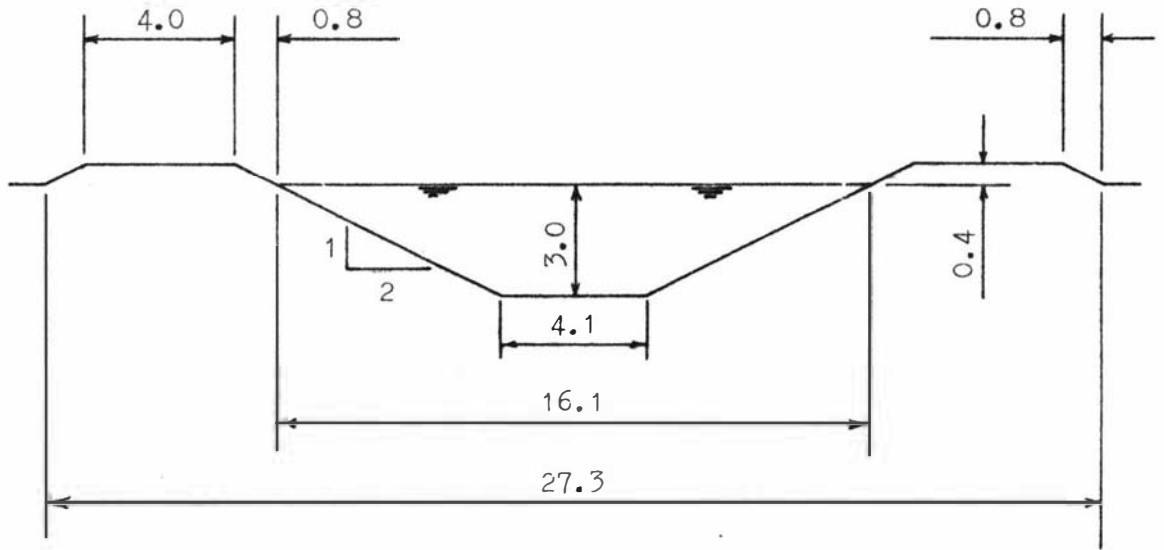
$$\text{Mean tank width} = 10\text{m}$$

$$\begin{aligned} \text{Therefore, cross section} &= 70/10 && \text{(f)} \\ &= 7 \text{ m}^2 \end{aligned}$$

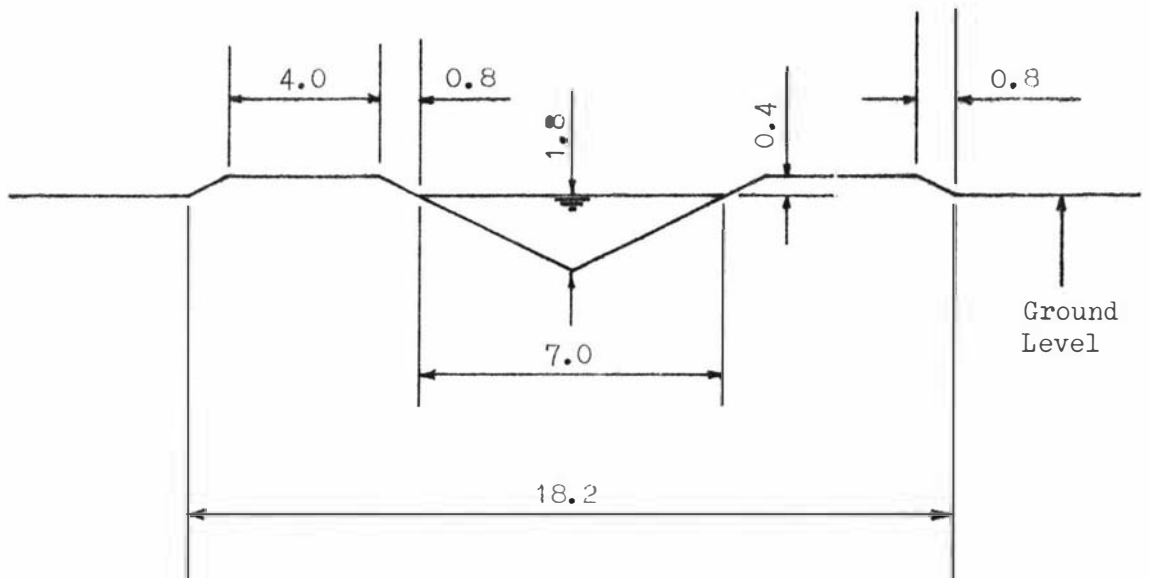
* Letters in parenthesis refer to the assumptions in Appendix VIII:1.

FIGURE App. VIII:1

ANAEROBIC AND AEROBIC TANK DIMENSIONS



Anaerobic Tank



Aerobic Tank

The aerobic tank has a Vee bottom to accommodate the 2:1 batter. Thus the surface length (x) to depth (y) relationship is;

$$x = 4y$$

$$\text{and } y = \sqrt{\frac{\text{Crosssectional Area}}{2}}$$

The aerobic tank dimensions are 27.3 x 18.2m allowing for embankments (Figure App. VIII:1).

$$\begin{aligned} \text{Volume for side embankments} &= 1.92 \times 12.6 \times 2 \\ &= 48.4 \text{ m}^3 \end{aligned}$$

$$\begin{aligned} \text{Volume for end embankment} &= 1.92 \times 21.7 \\ &= 41.6 \text{ m}^3 \end{aligned}$$

$$\text{Fill for aerobic embankments} = 90 \text{ m}^3$$

$$\begin{aligned} \text{Total fill for excavation} &= 305 + 70 \\ &= 375 \text{ m}^3 \end{aligned}$$

$$\begin{aligned} \text{Total fill for embankments} &= 167 + 90 \\ &= 257 \text{ m}^3 \\ &= 300 \text{ m}^3 \text{ allowing for compaction} \end{aligned}$$

VIII:3.2) Trickling Filter Design

$$\begin{aligned} \text{Filter volume} &= 18.8 \times 0.3 / 0.175 && (\text{e, g}) \\ &= 32.23 \text{ m}^3 \end{aligned}$$

$$\begin{aligned} \text{Filter area} &= 32.23/2 && (g) \\ &= 16.11 \text{ m}^2 \end{aligned}$$

$$\text{Filter dimensions} = 4.01\text{m square}$$

$$\begin{aligned} \text{Flow rate to filter} &= (18 \times 16.11 \times 1000)/(24 \times 60) \\ &= 200 \text{ l/min (approx.)} \end{aligned}$$

50mm galvanised pipe provides a head loss of approximately 5.0m/100m at this flow.

Filter construction could be pipe frames (42mm) set in a concrete base, supporting wire mesh netting and polythene. The filter media would be contained within this structure and supported by Web grating over the drainage channels. Flow distribution should be satisfactory with three 32mm galvanised pipes discharging through a series of orifices on to splash plates (Figure App. VIII:2).

$$\begin{aligned} \text{Recycle pump power input} &= (200 \times 9.81 \times 3.1)/60,000 \\ &= 0.101 \text{ kW WP} && (h) \\ &= 0.203 \text{ kW BP} && (h) \\ &= 0.225 \text{ kW power input} \end{aligned}$$

A 0.25 kW motor would be satisfactory, therefore,
 the power consumption = 5.41 units/day
 = 1973 units/year

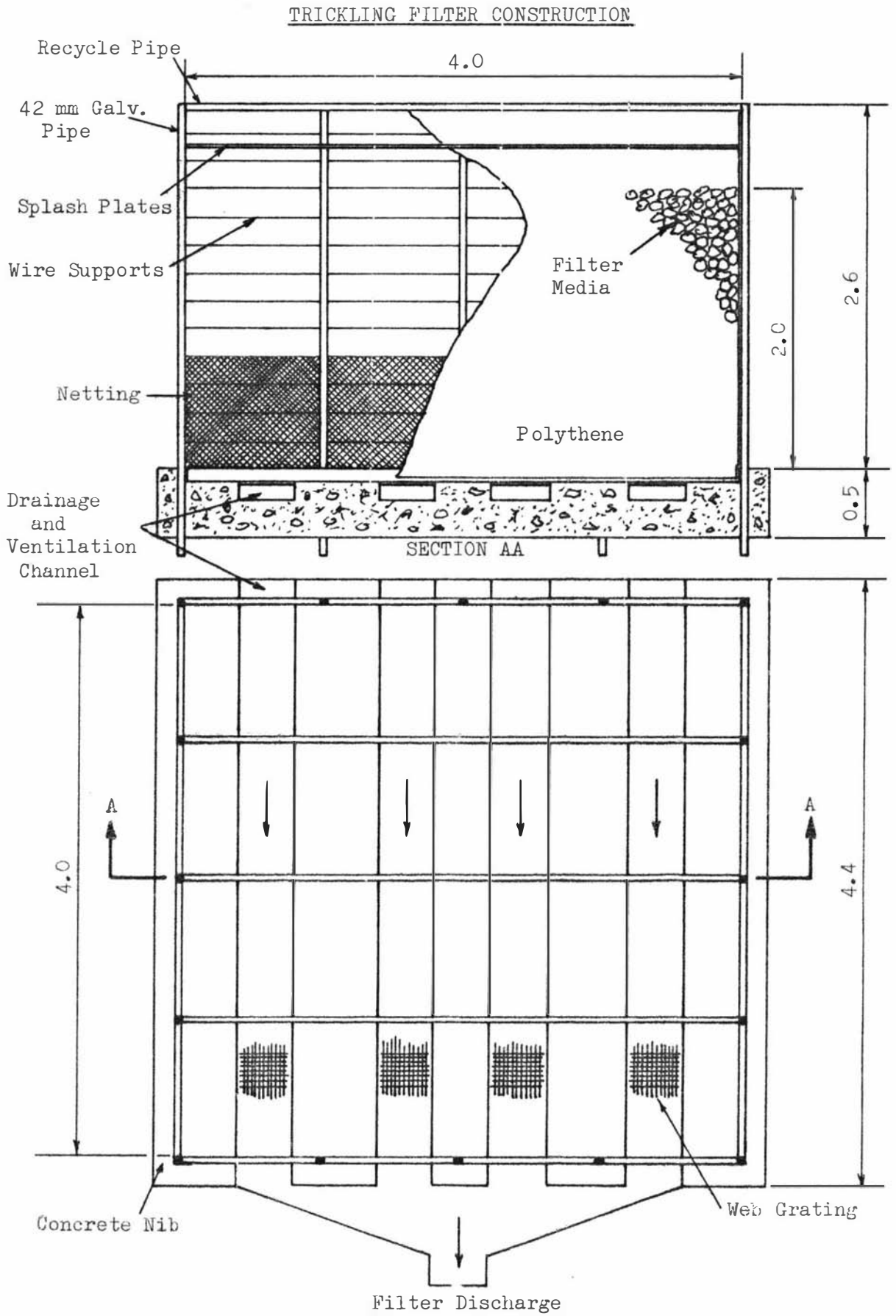
VIII:4) SOLIDS ACCUMULATION AND REMOVAL

$$\text{Anaerobic sludge accumulation} = 252 \text{ m}^3/2 \text{ year}$$

$$\begin{aligned} \text{Anaerobic TS accumulation} &= 252 \times 0.08 \times 1000 && (i) \\ &= 20.16 \text{ tonnes/2 year} \end{aligned}$$

$$\begin{aligned} \text{Aerobic TS accumulation} &= 18.8 \times 0.3 \times 0.3 \times 0.6 \times 560 \text{ (j, e)} \\ &= 569 \text{ kg/2 year} \end{aligned}$$

FIGURE App. VIII:2



$$\begin{aligned} \text{Total solids for removal} &= 20.16 + 0.57 \\ &= 20.73 \text{ tonnes/2 year} \end{aligned}$$

Therefore less than $\frac{1}{2}$ ha of land is required for solids distribution. (i)

$$\begin{aligned} \text{Aerobic sludge volume} &= 569 / (0.04 \times 1000) \\ &= 14 \text{ m}^3 \end{aligned} \quad \text{(k)}$$

This would have little effect on aerobic treatment.

VIII:5) COST OF TREATMENT PLANT

VIII:5.1) Capital Cost

45m of 150mm delivery pipe and laying	\$700
50mm piping plus inlet/outlet structure	\$300
375 m ³ earth works	\$400
8.0 m ³ concrete	\$250
Galvanised pipe and fittings	\$300
Web grating	\$100
Pump and motor	\$250
Power supply	\$150
Splash plates, clamps	\$50
Netting, wire and plastic	\$100
Fencing total area	\$100
Labour	\$300
Filter media	\$250
Miscellaneous and contingencies	\$450
Total	= \$3,700

VIII:5.2) Operating Costs

Power, 2,000 units/year	\$60
Maintenance, labour	\$260
Maintenance, equipment	\$30
	<hr/>
	\$350
250 m ³ sludge removal	\$400 = \$200/year
Miscellaneous	\$50
	<hr/>
	<u>\$600/year</u>

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