CHARACTERIZATION AND TREATABILITY STUDY OF THE EFFLUENT FROM A FISH PROCESSING PLANT

CHARACTERIZATION AND TREATABILITY
STUDY OF THE EFFLUENT
FROM A FISH PROCESSING PLANT

BY

M. J. RIDDLE, A.N.C.A.E., M.Sc.

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE

MASTER OF ENGINEERING

McMASTER UNIVERSITY

JANUARY, 1972.

MASTER OF ENGINEERING
(Chemical Engineering)

McMASTER UNIVERSITY
Hamilton, Ontario

TITLE: Characterization and Treatability Study of the Effluent from a Fish Processing Plant

AUTHOR: M. J. Riddle, Associate National College of Agricultural Engineering, (U.K.), M. Sc., (Guelph).

SUPERVISOR: Dr. K. L. Murphy

NUMBER OF PAGES: xiii,215

SCOPE AND CONTENTS:

The wastewater from a freshwater fish processing plant was characterized. The plant processed perch and smelt, and thus the wastewater characterized was taken from the perch and smelt processing lines and a combined perch and smelt wastewater. The plant also manufactured fish meal from the fish offal. During this process the offal is pressed to obtain stickliquor. Since this stickliquor is a potential waste product it too was characterized.

It was concluded that the wastewater was either of medium strength with large flows or of high strength with low flows.

Batch and continuous reactor studies were undertaken to ascertain the degradability of the combined wastewater. It was determined that a reactor with either a detention in excess of 5 days with no sludge recycle or a short detention time reactor (7.5 hours) with sludge recycle would be necessary to effect maximum removal of total BOD_5.

The effect of physical treatment, flotation, sedimentation and in-plant screening, were also examined in a preliminary manner.

ACKNOWLEDGEMENTS

The author wishes to express his sincere gratitude to:

1. My wife, Margaret, for her patience and understanding throughout the year.

2. Dr. K. L. Murphy for his guidance and support throughout the project.

3. Mr. R. Mills without whose assistance the project would not have been possible.

4. Mr. K. Conn and the technicians at the Canada Centre for Inland Waters, Burlington for their analytical support work.

5. The field technicians for their perseverance during this study.

6. The management of Omstead Fisheries, 1961, Limited for their assistance and cooperation.

7. J. Toutloff, L. Ford and E. Lyons for typing of the manuscript.

8. Finally to my colleagues in the Department of the Environment, especially Mr. P. Higgins whose initial suggestions set the project in motion.

Financial assistance provided by the Environmental Protection Service, Department of the Environment, is appreciated.

TABLE OF CONTENTS

PAGE NUMBER

LIST OF FIGURES

LIST OF TABLES

TABLE NUMBER | | PAGE NUMBER

CHAPTER 1

INTRODUCTION.

Canada's position as a major fish processor can be judged from the 1969 fisheries statistics. During that year approximately 1.5 million metric tons of fish (live weight) were landed in Canada with a landed value of 169.1 million dollars. Canada exported some 394,000 metric tons of processed fish with a value of 227.2 million dollars. This makes Canada the third largest fish exporting country in the World

Table 1.1. below summarizes the landings in volume and value for 1969 for both Atlantic and Pacific Regions, as well as freshwater fish. It should be noted that the freshwater catch represented only 4.5 per cent of the total volume of fish landed.

Table 1.1 Volume and Value of Seawater and Freshwater Fish caught in Canada. (1969-Annual Statistics Review of Canadian Fisheries).

	Landings (pounds x 10^6)	Landed Value ($ x 10^6)	Marketed Value
Atlantic	2437.1	120.5	273.1
Pacific	174.5	47.5	87.9
Sea Fisheries-Total	2611.6	168.0	361.0
Freshwater Fisheries	120.0	14.5	20.0
Canada-Total	2731.6	182.5	381.0

In 1969 the freshwater fish catch in Canada totalled 120 million pounds with a landed value of 14 million dollars and a marketed value of 20 million dollars. Of this quantity 62.5 million pounds with a landed value of 7.3 million dollars was the commercial catch from the lakes and rivers of Ontario. The majority of the freshwater fish commercially landed in Ontario are caught in Lake Erie. Perch and smelt represent over 90 percent of this commercial catch.

Table 1.2 below gives the quantities and values of perch and smelt caught in Lake Erie and landed in the Province of Ontario.

Table 1.2: Volume and Value of Perch and Smelt landed in the Province of Ontario and caught in Lake Erie.

	Lake Erie		Province of Ontario.	
	'000 lbs caught	'000 dollars value	'000 lbs caught	'000 dollars value
Perch	29,802	3,240	30,758	3,339
Smelt	15,076	541	15,226	562
Total fish catch	48,027	4,245	62,500	7,389

It is clear from these figures that the processing of fresh water fish represents a sizeable food industry. In Ontario there are 12 processing plans. The largest plant in Canada, Omstead Fisheries of Wheatley, Ontario, processed some 34 million pounds of perch and smelt in 1969.

The method of processing fish requires the use of considerable quantities of water for : cleaning the fish, transporting the waste material, plant clean up and for use in deodorizers. The discharge of this waste water directly into adjacent lakes and rivers solved the disposal problem of the fish processors for many years. In the last ten years the expansion of the fish processing industry and the improvement of the by-product recovery techniques made it economical to remove the large solid material from the waste water by screening. The screenings were processed and the resulting fish meal was sold as animal feed. Following the screening operations the remaining waste water was discharged to the lakes and rivers.

During the last few years, with the increased awareness of the public, industry and government, on matters concerning pollution, there has been considerable pressure on many industries to treat their waste water. Indeed many provinces have recently passed legislation in an attempt to curb industrial pollution. The fishing industry in anticipation of further legislation and a more vigorous enforcement of existing regulations on the disposal of their effluent, have requested assistance in finding means of treating their wastes in a practical and economic manner.

As will be noted in the literature review some progress has been made in the treatment of wastes from salt water fish processing(seafood). In contrast there is little or no information available on the characteristics or treatment of effluent from fresh water fish processing plants. The objectives of this study were:

1) to characterise the effluent from a freshwater fish processing plant, and
2) to determine its physical and biological treatability.

Information of the type obtained from this study should lead to the rational design of treatment facilities for fresh water fish processing plants.

CHAPTER 2

LITERATURE REVIEW

The fish processing industry is comprised of three sections:

1) Industrial fisheries - the rendering or reduction of whole fish into meal, oil and solubles. Oily fish species such as menhaden, herring and alewives comprise the bulk of the raw material for the industrial fisheries;
2) Seafood processing - such fish are canned, salted, frozen or marketed fresh. Fish processed in this manner include salmon, crab, and numerous bottom fish; and
3) Fresh water fish processing - the majority of fish processed are frozen or marketed fresh. Perch, smelt, pickerel, and trout are species of fish commercially processed.

As stated in the introduction the production of fish meal, oil and solubles is now widely accepted as a method of by product utilization in both seafood and fresh water fish processing. Following separation of the solids from the waste water, the solids are pressed to further reduce moisture content prior to cooking. The liquid effluent from the pressing operation is called stickwater. This stickwater, while small in volume in relation to the total effluent of a fish processing plant, has a high pollutional load. The 5 day BOD of stickwater is in the range of 100,000 mg/l, but 5 day BOD values as high as 1,000,000 mg/l have been recorded. The stickwater can be evaporated and the concentrated solubles obtained added to the fish meal. If such a process is not economically feasible the stickwater is wasted. In the case where the stickwater is added to the effluent, the process of by-product utilization has produced a strong liquid waste from the original solid waste material.

The literature reviewed can be categorized as follows:

1) by-product recovery and stickwater treatment,
2) characterization and treatability studies of the effluent from fish processing plants, and
3) methods of effluent treatment.

2.1. By product recovery and stickwater treatment.

It has long been established that the effluent from fish processing plants contained valuable proteins and oils. The quantity of effluent produced by these plants was often large and the wasting of proteins and oil represented a substantial commercial loss.

Beall (1933) examined the losses of protein and oil in the effluent of pilchard reduction plants in British Columbia. He stated that the effluent from the plant contained approximately 0.57 percent oil, 1.91 percent suspended meal, and 2.96 percent dissolved protein. Beall passed the effluent over a recovery machine, which consisted of two superimposed vibrating wire screens set at a slight slope. He found that 48 percent of the suspended meal was retained by the screen. On the basis of an effluent volume of 960,000 gallons per season, this represented a saving of some 50 tons of meal, valued at approximately $1,500. Beall was unable to effect any reduction in the oil and dissolved protein concentrations in the effluent.

By-product recovery in the fish processing industry made a large step forward in the early 1950's with the recovery of stickwater (Food Industries, 1950). Previously the stickwater was discharged in the plant effluent. It was found that stickwater contained B-complex vitamins that are desirable supplements in fish meal that is sold as animal feed (Carrick, 1971). In order to obtain the maximum value from the stickwater it is condensed to about 50 percent solids, it can then be marketed as condensed fish solubles or added to partially dried meal. Following addition to the meal, the drying process is completed and a fortified fish meal obtained.

The initial efforts at stickwater recovery involved four processes:

1) Clarification in centrifuges to remove additional suspended solids still contained in the stickwater following the press operation,

11) Recovering of fish oil by heating the stickwater to 200^{o}F and gravity feeding to a high speed centrifuge,

111) Addition of Sulphuric Acid to the stickwater to lower the pH from 6.5-7.0 to about 4.5. The acidulated stickwater is held in the tank for 30 minutes to coagulate the suspended solids. Centrifuging follows to remove the suspended solids (meal), and

1V) Condensing the stickwater. With the insoluble solids and oil removed, the clarified stickwater is delivered to the double-effect evaporators. The double-effect evaporators concentrate the stickwater from 7 percent soluble solids to 50 percent soluble solids.

In 1958 submerged evaporation was introduced (Carpenter, 1958). The short and sometimes erratic seasons encountered in the fishing industry mean that the amortization of the capital cost of the evaporator becomes an important component of the cost of operation. Secondly, scale formation presented a serious problem in steam evaporators operating in stickwater. A submerged evaporator with its low capital cost and particular mode of operation had a distinct advantage over the steam evaporators.

Tonseth and Berridge (1968) proposed the removal of proteinaceous material from waste water by chemical means. Dugal (1963) stated that the approximate composition of perch and smelt was 78 percent water, 17 percent protein, 3 percent fat and 2 percent ash (mineral content). Thus removal of the proteinaceous material from the waste water would substantially reduce the amount of polluting matter discharged from the fish processing plants. Tonseth and Berridge (1968) tested a number of protein precipitants on a wide range of waste materials including a fish filleting waste. The authors found that pure lignin sulphonic acid gave the best results. The waste from the fish filleting plant had an original BOD_5 of 1,240 mg/l, but following treatment with the pure lignin sulphonic acid the BOD_5 was reduced to 110 mg/L, a 91 percent removal of BOD_5. It was also found that the ratio of lignin sulphonic acid to soluble protein present in the waste was critical if the maximum degree of purification is to be achieved.

Following the chemical dosing of pure lignin sulphonic acid, the acidified waste was passed to a modified dissolved air flotation unit where the initial solid/liquid separation takes place. The liquid phase from the flotation unit was comparatively free from suspended matter and after neutralisation was suitable for further treatment or discharge. The concentration of the solids skimmed from the surface of the flotation unit varied between 3% and 6%. This sludge could be further thickened and following drying and cooking be marketed as fish meal.

This chemical treatment to remove proteinaceous material could be used in the treatment of both the waste water and the stickwater from fish processing plants. The waste water would be treated following screening to remove large solids. Tests on the chemical treatment of stickwater would have to be conducted to evaluate the effect of the pure lignin sulphonic acid on the oil and soluble content of the stickwater, as well as on the proteinaceous material.

Kempe et al (1968) studied the fish rendering industry in the Great Lakes area of the U. S. The majority of fish used in the rendering process are alewives. The authors classified current rendering processes as follows:

wet process,

dry process,

solvent processes, and

digestion processes,

The wet process is well adapted to the rendering of oily fish such as smelt. Because of its suitability forcontinuous operation the wet process is used in the fish meal plant at Omstead Fisheries. The advantage of this technique is both the fish oil and meal are produced as saleable products.

The major disadvantage is the production of strong odors and liquid wastes (stickwater). The discharge of this stickwater has caused numerous problems for fish rendering plants. Kempe et al (1968) stated that a 15-ton per hour fish reduction plant of the wet rendering kind will produce 1800 gallons of stickwater with an average 5-day BOD of 47,000 mg/L. If we assume a population equivalent of 0.17 lbs of 5-day BOD, this plant will have a polluting capacity equivalent to that of a city of approximately 100,000 people.

The dry process in only suitable for small operations. Solvent and digestion processess are as yet not widely used, however such processess will probably gain importance in the future.

Kempe et al (1968) also examined various processes for concentrating stickwater. These included:

Multiple effect evaporators,

Submerged combustion,

Submerged evaporation,

Vincent evaporation, and

Drum drying.

Multiple effect evaporators are steam heated and operate under vacuum. More than a pound of waste can be handled per pound of steam applied. They are best used in large volume plants because of high capital cost, the need for trained operators, and the necessity for continuous operation. Disadvantages of the process include scale formation, corrosiveness of the product,and unstable product quality due to poor operation

Submerged combustion and submerged evaporation systems and the Vincent evaporators all are direct fired; that is the heat present in the combustion gases is used directly to evaporate the water. The disadvantages of these systems as applied to the evaporation of stickwater include:

1) gray and black particles develop in the solubles,
2) the excessive production of noxious odors,
3) lower heat exchange efficiencies than multiple effect evaporators, and
4) Maximum soluble solids concentrations of 30 to 35 percent are produced

The main advantage of these systems is there simplicity and low capital cost. Drum driers are simple and reliable to use. However heat exchange efficiency is low and the steam pressure required is quite high

Kato and Ishikawa (1969) reported on the selection and installation of a system to recover fish oil and protein from fish processing effluent. Both gravitational and pressure flotation for oil separation were examined as possible means of oil recovery from the effluent prior to protein separation. Pressure flotation formed an unfavorable protein layer beneath the oil layer which prevented further agglomeration of the oil Separation of oil was therefore conducted by the skimming of the frothy surface layer which was subsequently purified. Heating and centrifugation were the final steps to yield purified fish oil. The authors tried a number of physiochemical methods in attempting to separate protein from the effluent. It was found that the additon of a high molecular weight synthetic coagulant aid, "Meat Floc". to the effluent formed a floc. However prior pH adjustment to 5.0 and agitation following coagulant additon, was necessary to form a good floc. Flotation, using pressurized recycle of supernatant, yielded a protein with a solids content of 5 percent.

The authors further reported on the performance of a recovery plant designed on the basis of the study mentioned previously. The plant gave an 86 percent decrease in suspended solids and a 77 percent decrease in BOD_5. However the suspended solids were still in excess of 700 mg/l and the BOD_5 in excess of 3,500 mg/l, thus further effluent treatment would be necessary before the waste could be discharged into a river.

The anaerobic treatment of alewife-processing wastes was studied by Borchardt and Pohland (1970). Their study concerned the laboratory digestion of alewife processing stickliquor either as a sole substrate or in combination with fresh primary domestic wastewater.

Table 2.1. Characteristics of Alewife Processing Stickliquor

		(Borchardt and Pohland, 1970)
Total solids	mg/l	60,500
Volatile solids	mg/l	52,400
Total alkalinity	mg/ as Ca CO_3	4,820
Total Volatile Acids	mg/l as CH_5COOH	8,925
Total Organic Carbon	mg/l	44,000
Ether Extractables	mg/l	5,000
Total Nitrogen	mg/l	1,200

The authors stated that alewife processing wastes could be treated in part by controlled anaerobic digestion and, in conjunction with domestic wastewater sludges, in either single or two-stage digestion systems. The authors did not mention that the high concentration of volatile acids in the final effluent and the low gas production in the second digester possibly indicated a breakdown of the anaerobic treatment of the waste. The authors concluded that if the loading rate of volatile solids in the stickliquor were not greater than 0.05 lb/day/cu. ft. of digestor capacity, the process could be handled by a two-stage digestion system.

Pigott <u>et al</u> (1969) proposed development of a non-organic solvent extraction technique to process fish waste. In order to be practical commercially the process should:

1) be capable of handling any portion of fish scrap as well as whole industrial fish,
2) require low cost facilities, making this process available to small, as well as large, companies,
3) not require highly technical operating personnel, and
4) not leave a waste portion that will contribute to the pollution problem.

Figure 2.1 shows a diagram of the proposed acidified brine extraction process. The material is ground and homogenized in various concentrations of brine and hydrochloric acid. The sodium chloride tends to decrease the solubility of various constituents and the acid minimizes the protein solubility. After varying incubation times the material is centrifuged to

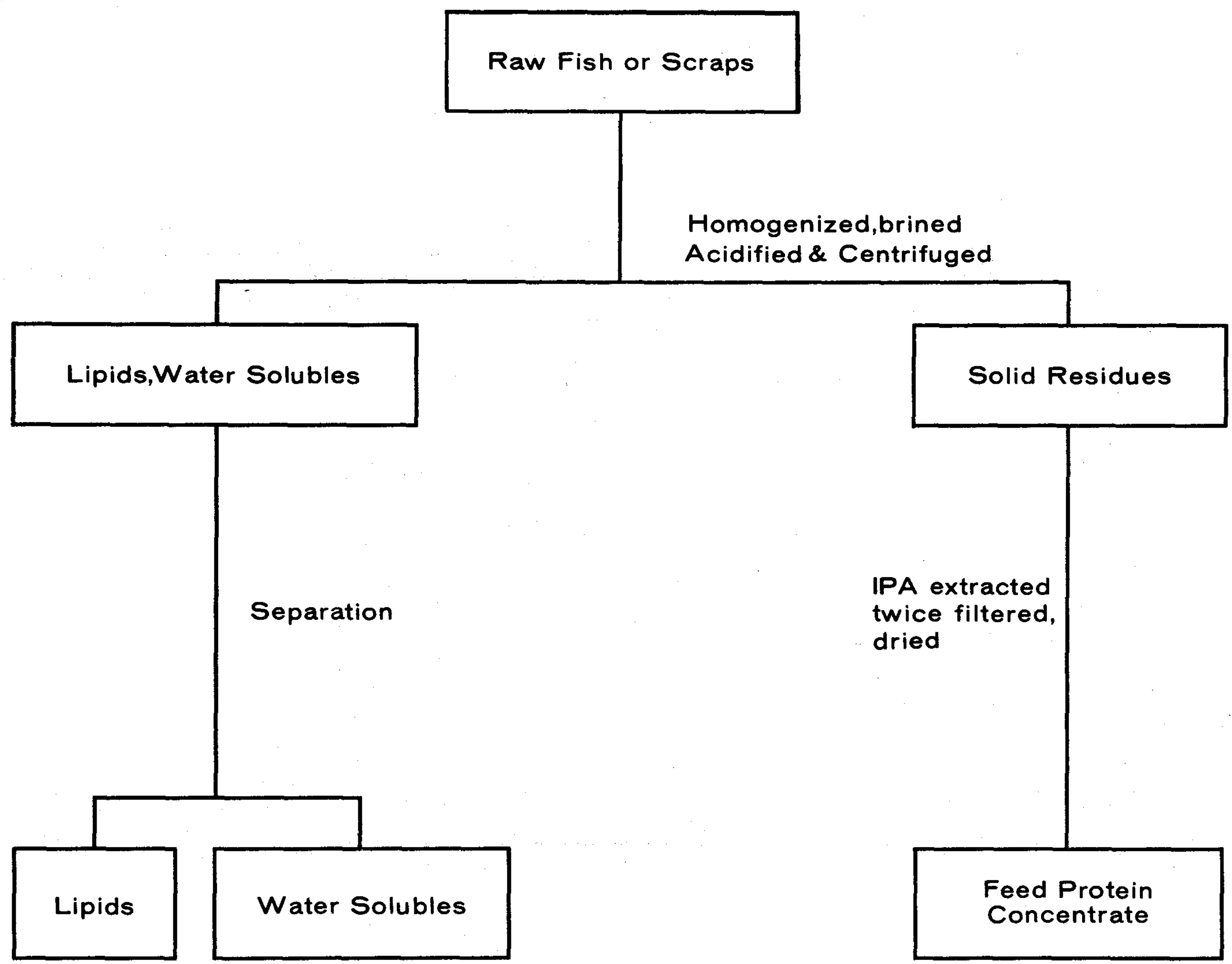


Figure 2.1 Acidified Brine Extraction Process (Pigott et al, 1969)

separate the lipid and water fraction from the solid residue. Further processing of the residue is necessary if the product is for human consumption.

Pigott et al (1970) reported the results of experimental work on the aqueous extraction process. Acid concentrations of one part acid to fifty parts fish in a brine concentration of 8 percent chloride gave optimum product yield with hake and herring. A finish extraction using an organic solvent was necessary to lower the lipid content before the material could be used for human consumption.

This technique is presently in the pilot plant stage and data on the commercial viability of this process should be available at the end of the 1971 fishing season.

From the studies mentioned in this section it is obvious that by-product recovery is an essential part of a fish processing plant. The condensing of stickwater to produce condensed solubles is a necessity as the discharge of stickwater produces a serious pollution problem.

2.2. Characterization and treatability studies of the effluent from fish processing plants.

Fish processing wastes vary considerably in pollutional strength. This variation is due in part to:

1) the species of fish being processed,
2) the processing technique,
3) the plant size, and
4) water usage.

The Washington State Water Pollution Control Commission (1969) characterized fish processing wastes in general terms as shown in table 2.2.

Table 2.2: Fish Processing Wastewater Characteristics (Nunnallee and Mar 1969)

Parameter	Unit	Value
Water Volume	gal/1000 lbs of fish processed	233 - 4,500
BOD_5	mg/l	2,700 - 3,440
BOD_5	lbs/1000 of fish processed	4 - 60
Suspended Solids	mg/l	2,200 - 3,020
Total Solids	mg/l	4,198 - 21,820

The report did not mention the species of fish processed, the processing techniques nor the plant sizes.

Limprich (1966) surveyed a number of fish processing plants in Germany. These plants were involved in the canning of herring, processing and freezing red perch and producing fish meal. The results are shown in table 2.3 below.

Table 2.3: German Fish Processing Wastewater Characteristics (Limprich, 1966)

Parameter	Unit	Value
Water Volume	gal/1000 lbs of fish processed	2,900
BOD_5	mg/l	2,658
BOD_5	lbs/1000 lbs of fish processed	41
Ammonia Nitrogen	mg/l	6.0
Nitrate Nitrogen	mg/l	0
Total Nitrogen	mg/l	710

Limprich noted that the high level of total nitrogen could lead to nitrification contributing significantly to the oxygen demand in the BOD test.

Soderquist et al (1970) commented on work carried out in Gernamy by Buczowska and Dabaska (1956). The German authors noted that nitrification begins in fish processing wastewater sooner than in normal sewage. The effect is likely to be significant in the 5-day BOD tests.

Soderquist et al (1970) gave values for flow, BOD_5 and suspended solids in the waste water of bottom fish processing plants. Bottom fish include haddock, cod, ocean perch, whiting, flounder, hake and pollock. Table 2.4 below gives the values.

Table 2.4: Waste Characterisation from Bottom Fish Processing Plants.

(Soderquist et al, 1970)

Parameter	Unit	Value
Water Flow	g.p.m.	100 - 450
BOD_5	mg/1	192 -1,726
Suspended Solids	mg/1	300

The waste water from menhaden fish oil and meal processing plants were examined by Paessler and Davis (1956). Studies previously indicated that the pollution load in the effluent was reduced by over 90 percent when stickwater recovery was practised. The remaining pollution load was still large enough to warrant a detailed study of a plants remaining waste. The authors examined each phase of the process giving approximate quantities of water used together with their BOD_5 loadings. It was recommended that waste water with varying levels of BOD_5 be collected in a central system and conveyed to the stickwater storage tanks for evaporation. Water used for cooling or with a low BOD_5 loading was discharged direct to the stream. This paper emphasized the effect "good housekeeping" had on the pollutional load of the effluent.

Matusky et al (1965) studied the treatability of fish processing wastes. The results of this treatability study were used in the design of a treatment plant with estimated loadings of 40,000 tons/year raw fish; 3,000 lbs/hour potato sticks and a town population of 4,000.

The fish wastes studied by Matusky et al (1965) and Paessler and Davis (1956) can be characterised as high flows with medium BOD_5 levels or low flows with high BOD_5 levels. Table 2.5 gives the flows, BOD_5 and suspended solids of various wastes from the results given by Matusky et al (1965) and Paessler and Davis (1956).

The treatment system anticipated must include provision for removal of coarse solids, oil removal, conversion of dissolved solids into sludge, sludge separation and disposal, and final effluent sterilization and disposal. Matusky et al designed a treatment facility on the assumption that stickwater would be evaporated and that oil and grease removal would take place in the fish processing plant. The treatment facility was designed to handle 600 U.S. G.P.M. flow with a BOD_5 of 760 mg/l and suspended solids of 425 mg/l, which represented the loading on the facility from the fish plant only.

The authors state that prior to final design a pilot treatment facility of at least bench scale proportions should be operated to obtain specific process design data, as only limited full-scale treatment expe-

Table 2.5: Summary of Waste Characteristics from Fish Processing

Water Source	Menhaden Processing (Paessler & Davis) Flow (g.p.m.)	BOD$_5$ (mg/1)	Total Solids (mg/1)	Survey Plant (Matusky *et al*) Flow (g.p.m.)	BOD$_5$ (mg/1)	Suspended Solids (mg/1)
Makeup Tank and Rawbox Leakage	300	3000 - 67,000	18,000 - 64,000	-	-	-
Washwater and Fish Scaling	-	-	-	700	1000	425
Conveyor Waste Water	-	-	-	140	16,300	11,200
Floor Drain	-	-	-	140	720	500
Stickwater	40	56,000 - 112,000	33,000 - 79,000	10	110,000	125,000
Deodorizer Spray Water	250	120 - 300	16,000	80	800	2,000
Evaporator	-	500	14,000	200	-	-

rience exists for fish processing effluents. The nature of fish processing wastes are such as to require special consideration in the design of several major treatment operation. These consideration include:

1) activated sludge kinetics,
2) oxygen demand and transfer requirements,
3) digester loading and sulphide build-up, and
4) sludge dewatering characteristics.

The authors conclude their paper with treatability studies on digestion and dewatering using a combined fish, potato and municipal waste.

Chun et al (1968) attempted to characterise the waste from a tuna packing plant. The authors indicated the necessary parameters which were used for characterisation:

1) Dissolved oxygen, pH and temperature - to determine the state of biological activity within the waste,
2) Total and volatile solids, suspended and volatile suspended solids, chemical oxygen demand, and five day biochemical oxygen demand - to determine organic matter present,
3) Organic nitrogen and phosphate analysis - to determine the presence of sufficient nutrients for bacterial growth, and
4) Chloride and grease contents - due to high chloride content of part of the water used in the processing and the oily nature of the final product.

The Warburg respirometer was used to conduct tests on the relative treatability of the cannery wastes. These tests involved the tuna waste alone and the tuna waste mixed with domestic sewage. Table 2.6 gives the tuna waste organic and solids characteristics, the values given are the average of 25 daily values.

Table 2.6: Tuna Waste, Organic and Solids Characteristics.

(Chun *et al*, 1968)

Parameter	Unit	Value
COD	mg/l	2,273
BOD_5	mg/l	895
Total Solids,	mg/l	17,900
Total Volatile Solids,	percent of Total Solids	37
Suspended Solids,	mg/l	1,091
Grease	mg/l	287

The values in table 2.6 can be compared to the values used by Matusky *et al* (1965) in the design of a treatment facility - 760 mg/l BOD_5 and 425 mg/l suspended solids.

Chun *et al* (1968) concluded that the biodegradation of the tuna waste was limited as indicated by the BOD: COD ratio of 0.4. This compares with a BOD_5:COD ratio of 0.5 for domestic sewage (Hunter and Henkelekian,1965). This was confirmed in the treatability studies conducted on the waste. An excess of nutrient material, phosphorus and nitrogen, was present, with a BOD_5 N:P ratio of 100:68:7. The authors further concluded that the tuna waste alone is not conducive to aerobic biological treatment due to some inhibitory or toxic reaction. Dilution with domestic sewage in a ratio of 4:1 resulted in a material that can be treated to about 60 percent of theoretical oxygen demand. Long-term BOD studies indicated that the nitrogenous oxygen demand was about 40 percent of the total demand.

Soderquist et al (1970) reported on the variability of the waste characteristics from salmon processing and sardine packing plants. Table 2.7 lists the waste from salmon processing plants. It should be noted that caviar production results in extremelystrong wastes, but of small volume, similar to stickwater production. These wastes should be recovered and not discharged from the plant.

The sardine wastes can be divided into four categories: pump water, flume water, hold water, and processing wastes flume water. Table 2.8 gives the flows and waste strengths for each category.

Pump water was used to transfer the fish from the ships to screen separators in the plant. This water has a relatively low BOD_5 of between 10-45 mg/l, however it comprises the largest flow. The flume water is used to convey fish through the plant, this water becomes heavily polluted. The waste flume water is used to convey the waste fish material to a fishmeal plant or to trucks for land disposal. Soderquist et al (1970) suggest this waste flow could be reduced by the use of dry capture techniques.

In a study of fish processing waste for the New Brunswick Water Authority (Canadian Plant and Process Engineering Limited, 1970) the

Table 2.7: Salmon Processing Wastewater Characteristics (Soderquist *et al*, 1970)

Process	Flow (m.g.d.)	BOD_5 (mg/l)	BOD_5 (lbs. BOD_5/1000 lbs. of fish processed)	Suspended Solids (mg/l)	Total Solids (mg/l)	Volatile Solids (mg/l)
Canning	0.043-0.046	3660-3900	3.2 - 89.0	508-4780	1188-7444	1048-7278
Canning	0.33	3,860	-	2,470	-	-
Caviar	-	270,000	-	92,600	386,000	292,000
Mild Curing	0.018-0.066	173-1320	5.0 - 40.0	44-456	258-2,712	98-2508
Mild Curing and Fresh	0.011-0.036	206-2218	1.6 - 18.0	112-820	484-2940	184-1756
Mild Curing or Freezing	0.014-0.046	397-3082	1.9 - 9.5	40-1824	88-3422	67-2866

Table 2.8: Sardine Packing Wastewater Characteristics (Soderquist *et al*, 1970)

Source	COD (mg/l)	BOD_5 (mg/l)	Suspended Solids (mg/l)	Oil and grease (mg/l)	Flow (g.p.m.)
Flume water	500 - 1400	200 - 1,150	400	300 - 360	130 - 300
Hold water	800	370	-	-	-
Pump water	170 - 340	10 - 45	-	-	800 - 1,000
Waste Flume water	240 - 1,700	100 - 2,100	100 - 2,100	60 - 1,340	40 - 180

wastes from groundfish and fishmeal plant were characterized. Table 2.9 summarizes these values. An explanation of the terminology used in table 2.9 is given below.

In the holding room of fishmeal plants herring or offal is stored following unloading and prior to processing. The weight of material creates a sufficient pressure on the lower layer to press a considerable quantity of liquid from the herring or offal. This drainage from stored herring or offal is referred to as blood water. Although this bloodwater is a strong waste the quantity produced is relatively small.

The press liquid from the fish is centrifuged to remove stick - water, oil and sludge. Ths stickwater and oil are further processed for useful by-products, however the sludge and associated cleaning water are wasted.

The majority of fishmeal plants attempt to control air pollution by using deodorizers. The gases from the fishmeal driers are passed through scrubbers, thus removing odors and particulate matter. The waste water from this process is referred to as deodorizer wastes.

Shaffner (1970) studied the waste flow from the same processing plants as the New Brunswick Water Authority study (1970). Table 2.10 tabulates Shaffner's results in the same manner as the results presented in table 2.9. The results shown in tables 2.9 and 2.10 are comparable with the exceptions of BOD_5, COD and suspended solids of the separator sludge and effluent composite and the COD of the stickwater. In fact the agreement between the two sets of values is good. It should be borne in mind that the major interest is in trends and ranges and not absolute

Table 2.9: Groundfish and Fishmeal Plant Wastes

(Canadian Plant and Process Engineering Ltd, 1970)

Source	BOD_5 (mg/l)	COD (mg/l)	Suspended Solids (mg/l)
Groundfish Plant	130 - 780	1,100 - 6,200	60 - 1,120
Fishmeal Plant			
1) Pump-out water	9,600 - 21,800	37,000 - 96,000	8,600
2) Bloodwater	55,000 - 90,000	5.6 million	40,000 - 55,000
3) Stickwater	25,000 - 72,000	800,000 - 1 million	6,500 - 47,000
4) Separator Sludge	188,000	1.5 million	163,000
5) Deodorizer Water	680	2,040	780
6) Effluent Composite	18,400 - 42,500	160,000 - 530,100	8,638 - 23,910

Table 2.10: Groundfish and Fishmeal Plant Wastes (Shaffner, 1970)

Source	BOD_5 (mg/l)	COD (mg/l)	Suspended Solids (mg/l)
Groundfish Plant	390 - 850	1800 - 6,240	330 - 1705
Fishmeal Plant			
1) Pump-out water	5,885	9120 - 58,000	2,160 - 15,400
2) Bloodwater	-	-	-
3) Stickwater	34,000	90,900	13,270 - 53,880
4) Separator Sludge	4,400	41,300	6,100
5) Deodorizer Water	490	8,000	390
6) Effluent	4,400	10,600	4,300

values.

Delaney (1971) reported the strength of a number of waste streams from a fish processing plant in Prince Edward Island. Table 2.11 below gives a summary of the results. The analyses were carried out on grab samples, they therefore indicate an order of magnitude but not average values.

Sample #1 - Water used for lifting fish from the trawler and for the subsequent descaling operation.

Sample #2 Taken below screen used to separate solids, used for fishmeal production, from the waste water.

Sample #3 Waste water from the fishmeal plant, and containing a proportion of stickwater.

Sample #4 Deodorizer water.

A water resource study of Newfoundland and Labrador (Shawinigan Engineering Co. Ltd, 1968) gave the relative strength of some typical wastewaters from fish processing plants; table 2.12 gives a summary of those values.

Brodersen (1971) reported on a study of the waste characteristics of fish processing plants located in New Brunswick. The operations investigated included groundfish processing, shellfish processing, combined groundfish and shellfish operations, herring processing and fish meal operations. The following waste characteristics were determined at the 18 plants analysed:

1) BOD_5 ,
2) suspended solids,

Table 2.11: Waste Characteristics from a Filleting and Fish Meal Plant (Delaney, 1971)

Sample no.	1	2	3	4
BOD_5, mg/l	390	140	3180	47
BOD_5 - settled, mg/l	210	190	3120	47
COD, mg/l	1320	740	8900	380
Suspended Solids, mg/l	300	140	1020	0
Volatile Suspended Solids, mg/l	264	95	760	0
Total Solids, mg/l	800	590	3740	230
Total Volatile Solids, mg/l	160	350	3140	190
pH	7.0	6.8	6.8	8.4
Total Nitrogen, mg/l	54	29	450	traces

Table 2.12: Cod and Sole Processing Plant Wastes
(Shawinigan Engineering Co. Ltd, 1968)

Source	BOD_5 (mg/1)	COD (mg/1)	Suspended Solids (mg/1)
Total effluent (cod line)	110	273	-
Total effluent (sole line)	400	1,163	27,100
Effluent from filleting line	-	107	6,940
Total effluent (cod and sole filleting lines)	174	370	10,190
Effluent from spray washing fish	450	1,165	1,306
Stickwater (fish meal plant)	38,000	45,112	68,010
Effluent from fish meal plant	257	756	33,500
Waste flume water from filleting lines	852	1,145	870

3) oil content, and

4) water usage.

The results obtained are summarized in tables 2.13 and 2.14. It should be noted that the values given in table 2.13 are in pounds of parameter per 1000 pounds of fish landed and produced (following processing). The variation in the waste characteristics is shown on table 2.15, which gives the standard deviation of each parameter determined.

Brodersen (1971) concluded from the study that:

1) the BOD_5 of wastes from both groundfish and shellfish processing plants can be estimated using:

$$BOD_5 = 0.35\ COD.$$

2) the BOD_5 of wastes from the herring filleting and marinated herring processes can be estimated using.

$$BOD_5 = 0.68\ COD - 186$$

3) for the plants studied, the rate at which water was used by any particular process is relatively constant regardless of the quantity of fish processed.

The problem of comparing the strength of wastes from various plants is magnified by:

1) the different processing techniques used,

2) the varied species of fish processed,

3) plant size, and

4) water usage.

Table 2.13. Summary of Waste Characteristics

Groundfish, Shellfish, Combined, and Herring Processing Plants (Brodersen, 1971)

Process	Lbs. of Parameter/1000 lbs. Fish landed or produced						Gallons H_2O/1000 lb.			
	BOD_5		Suspended solids		Oil		Fresh		Salt	
	land	prod.	land	prod.	land	prod.	land	prod.	land	prod.
Groundfish filleting (wet line)	15	44	7	20	13	41	159	485	1,324	4,187
Groundfish filleting (dry line)	5	7	1	2	1	2	504	1,596	-	-
							(combined fresh and salt)			
Groundfish filleting and crab	18	65	4	14	7	23	179	626	1,317	4,607
Shellfish Lobster	26	110	4	18	5	20	2,613	10,745	-	-
							(combined fresh and salt)			
Shellfish Crab	40	270	19	84	21	93	739	3,312	5,447	24,567
Herring Filleting	22	68	21	37	10	29	599	1,786		
							(combined fresh and salt)			
Herring Marinated	215	527	85	210	83	215	2,460	6,179	0	0

Table 2.14. Summary of Waste Characteristics Fish Meal Process (Brodersen, 1971)

Waste Stream	Average Concentrations BOD$_5$ (mg/l)	SS (mg/l)	Oil %
Pumpout Water	33,500	7,955	.05
Bloodwater	245,000	11,805	.27
Separator Sludge	280.000	13,500	.22
Stickwater	198,700	15,500	.03
Solubles	184,250	41,163	.13
Evaporator Condenser Water	1,132	58	.01
Deodorizer Water	875	126	0

Table 2.15. Variations in Waste Characteristics of Groundfish, Shellfish, and Herring Processing Plants (Brodersen, 1971)

	Lbs. of Parameter / 1000 Lbs Fish Landed or Produced						Gallons H_2O / 1000 lb.			
	BOD_5		Suspended Solids		Oil		Fresh		Salt	
Process	Land	Stnd Dev.	Land	Stnd Dev.	Land	Stnd Dev.	Land	Stnd Dev.	Land	Stnd Dev.
Groundfish Filleting (dry line)	5	3	1	0.1	1	0.5	504 (Combined fresh and salt)	224	-	-
Groundfish Filleting and Crab	18	5	4	1	7	5	179	24	1,317	178
Shellfish Lobster	26	2	4	0.6	5	5	2,613 (Combined fresh and salt)	248	-	-
Shellfish Crab	40	16	19	5	21		739	149	5,447	965
Herring Filleting	22	7	21	15	10	4	599 (Combined fresh and salt)	138		
Herring Marinated	215	59	85	14	83	70	2,460	290	-	-

2.3 Methods of Effluent Treatment.

The difficulties in the treatment of wastes from fish processing plants are attribuatable in the main to:

1) high flows,

2) medium to high BOD_5 and suspended solids, and

3) high grease and protein levels.

Frequently the short processing season, high peak loadings and rapid biodegradability of the wastes cause treatment problems.

The treatment of fish wastes will be considered under the following headings:

1) Screens,

2) Clarifiers,

3) Flotation, and

4) Biological treatment - both aerobic and anaerobic.

2.3.1. Screens

Claggett and Wong (1969) tested both rotary and tangential screens as a form of pretreatment for fish processing wastes prior to flotation. The rotary screen, made of stainless steel 34-mesh screen, was 4 feet long and rated at 100 U.S.G.P.M. Solids were removed by a screw conveyor and the screen was cleaned by high pressure water sprays.

Two tangential screens were tested, one of 20 mesh and the other of 35 mesh. Their operatimg capacities were 20 to 35 U.S.G.P.M. respectively. Both the tangential and rotary screens worked well on salmon canning wastewater. Table 2.16 indicates that with the low capital and operating cost of screening, a processor could expect removal of over half of the total solids in his waste water. Frequently these reclaimed solids can be processed in the fish meal plant to become valuable by-products.

Table 2.16: Solids Romoval from Salmon Waste Water by screening. (Claggett and Wong, 1969)

Screen	Mesh Size	Raw Waste mg/l	Underflow mg/l	Overflow mg/l
Rotary	34	4,200	2,400	105,100
Tangential	40	4,500	2,500	164,000

The study for the New Brunswidk Water Authority (1970) indicated that the removal of BOD_5, COD and suspended solids by screening was variable. The effectiveness of screening the waste from a groundfish plant varied, with a BOD_5 removal of up to 60 percent reported for both 10 and 40 mesh screening. However the median value for both screens was approximately 33 percent. The 40 mesh screen provided approximately 25 percent removal of BOD_5 from deodorizer water and effluent composites from fish meal plants.

Shaffner (1970) concluded that passing the wastewater over 20 mesh screens would remove approximately 20 percent of the BOD_5 and 16 percent of the suspended solids from the effluent of all plants studied.

2.3.2. Clarifiers

Claggett and Wong (1969) during the course of experiments in flotation observed that when the waste water was treated with "F-Flok", the resulting floc formed slowly. However, once it was fully formed sedimentation rates of 4 feet per hour could be achieved with a good separation. "F-Flok" is a commercial coagulant marketed by the Georgia

Pacific Corporation and is derived from lignosulfonic acid. A summary of the results achieved is given below in table 2.17.

Table 2.17: Gravity Clarification of Salmon Water Using F-Flok Coagulant. (Claggett and Wong, 1969)

Coagulant (F-Flok) Concentration (mg/l)	Total Solids Recovery (%)	Protein Recovery (%)	Overflow BOD_5 (mg/l)
5020	68	92	100
4710	60	80	100
2390	47	69	100

The New Brunswick study (1970) included the effect of sedimentation on BOD_5, COD and suspended solids removal. Sedimentation removed approximately 35 percent of BOD_5 from the waste from a groundfish plant this was not markedly different to screening the waste through 10 and 40 mesh screens. For fishmeal plant pump-out water sedimentation removed 40 percent of COD and 70 percent of BOD_5. The screening of this waste had no effect on the values of BOD_5, COD and suspended solids. Sedimentation also removed an average of 58 percent of COD from stickwater and 60 percent BOD_5 and 70 percent COD from a composite effluent of a fishmeal plant.

Shaffner (1970) concluded that settling proved to be the most effective method of reducing BOD_5 and suspended solids from fish plant wastes. He found that sedimentation reduced BOD_5 and suspended solids by an average of 33 percent.

2.3.3. Flotation

Dreosti and Waseman (1967) reported that the cleaning of turbid seawater was best effected by flocculation with aluminum sulphate, a mixture of 50 mg/l aluminum sulphate and 50 mg/l lime, or 60 mg/l aluminum sulphate and 40 mg/l lime. The seawater, required for factory washing purposes, had become turbid following the discharge of effluent from a fish processing plant directly into the harbour.

The treatment described by the authors not only gave good size floc which settled rapidly, but had least effect on the pH of the water. The addition of aluminum sulphate was followed by five minutes of slow stirring, whereas for lime the time for stirring had to be increased to half an hour for satisfactory results. The aluminum sulphate or the mixture of aluminum sulphate and lime required approximately 1 to 1 1/2 hours to effect removal, whereas the lime requires 3 hours. Finally, flocculation not only cleared the water, but also reduced the amount of chlorine required for purification.

Dreosti (1967) reported on a study concerned with the flotation of fish waste. The author stated that the present process of flotation by aeration involved vacuumization, compression of air into part or all of the liquor to be treated, followed by release of the pressure in the flotation tank. The author suggested that it might be possible to "whip" air into the liquor without the need of any air or water pressure system. This technique was tried with "spectacular results" on fish factory effluent, presummably due to the foaming characteristics of the waste.

Air can be entrained by surface mixing equipment giving sufficiently vigorous beating of air into the liquid. For instance, in the laboratory good results were obtained by means of a high speed (20,000 r.p.m.) rotary-blade blender or a centrifugal pump (4,550 r.p.m.) with a suitable air leak at or near the intake.

This paper contained little quantitative information on this process. The author did state that good results were obtained with fish factory effluents containing flocculable solids concentrations up to about 0.8 percent. The method proved fully satisfactory with all effluents investigated.

Claggett has done considerable work in the treatment of wastes from fish processing plants in British Columbia. Claggett and Wong (1968) studied the effect of flotation by total flow pressurization on the waste water from a salmon canning operation. The authors carried out their experimental work on a continuous 50 U.S.G.P.M. total flow pressurization flotation cell. The authors suggest that flotation should follow a screening operation which would recover large solid particles. The remaining solids in the waste water could then be removed by flotation either with or without chemical coagulation.

Alum can be used as a flocculant where the primary consideration is the reduction of the insoluble solids load of the waste water. Claggett and Wong (1968) also tested the flocculant called "F-flok". It characteristically reacts strongly with proteins at a pH of 3.8 to 4.0. It was found that the addition of "F-flok" reduced both the nitrogen content and BOD level of the water to a greater extent than alum.

The authors concluded as follows:

> "Because of the difficulties we encountered, and because of our lack of experience in the functioning of flotation cells, we are hesitant to draw rigid conclusions from the data we have obtained. We feel that it is imperative that further tests be made with flotation cells of different design, in order to determine whether the floc carry over is due to the design of equipment, the heavy loading of solids in water, or to the method of operation."

Claggett and Wong (1969) continued their study on flotation using a more flexible flotation unit than that used in their initial study reported above. The second flotation unit had the following advantages over their original unit:

1) the air was injected by compressor rather than by aspirator, and
2) auxiliary equipment was supplied to allow recycling of effluent from the unit and partial pressurization of the feed stream.

The authors also tested 34 mesh rotary screens together with 20 and 40 mesh tangential screens as a pretreatment to flotation. As reported earlier a 50 percent reduction in solids loading of salmon canning waste water or herring pump water has been achieved by using screens of the type tested.

Following a number of tests Claggett and Wong (1969) decided that aluminum hydroxide and a modified form of "F-Flok" yielded the best results. This modified form of "F-Flok, called "F-Flok 98" should improve protein removal over the standard "F-Flok", however, total solids removal was not substantially improved.

The precipitated aluminium hydroxide worked well physically, with little floc carry over, a problem when using "F-Flok". The effluent water was clear, with only a slight yellowish tinge remaining. The dosage rates over the test period averaged 375 mg/l aluminum sulphate and 75 mg/l sodium hydroxide.

Claggett and Wong (1969) concluded their report with an economic analysis of flotation as a method of by-product recovery and waste treatment of salmon cannery wastes and herring pump water.

The treatment of herring pumpwater was examined by Davis and McKinney (1970). The water was used to transport the herring from the boats to the process equipment. The pumpwater solids content ranged from 26,000 mg/l to 35,000 mg/l, with a BOD_5 range of 5,000 mg/l to 21,000 mg/l. The pumpwater was screened to remove large particles of solid. Chemical flocculation and flotation followed by sludge concentration was used to remove the oil and solids remaining in the effluent.

The organic matter was concentrated from 0.4 percent to a 1.0 percent sludge by pressurized air flotation of a recycled portion of the clarified effluent. The authors concluded that flotation could recover at least half of the small amount of solids remaining in the screened pumpwater. However, the flotation process did not appear to be practical for pumpwater waste recovery because of its complex operation and its creation of a sludge handling problem.

2.4. Biological Treatment

Soderquist et al (1970) reported that the carbon: nitrogen ratio of fish processing wastewater indicated that biological treatment should be successful. The biochemical oxidation rate was found to be similar to sewage, however nitrification began sooner and was more significant. Soderquist et al (1970) further reported that a number of authors had found that oil and grease interfered with the oxygen transfer in an activated sludge system. In the authors opinion pretreatment to remove high solids, grease and oil contents is a necessity if biological treatment is to be successful.

Ventz and Zanger (1966) reported the results of bench scale experiments on the physiochemical and biological treatment of waste from a German fish processing plant. Table 2.18 below indicates the approximate strength of the wastes.

2.18 Characteristics of The Raw Fish Waste (Ventz and Zanger, 1966)

Parameter	Unit	Value
BOD_5	mg/l	800-4,000
Chlorides	mg/l	500-6,000
pH		4-8.5

Ventz and Zanger (1966) commented on the necessity of removal of fats and protein by physical treatment prior to biological treatment. Previous workers had shown the necessity of diluting the fish waste with domestic sewage - for the best treatment 5 parts of domestic sewage should be added to 1 part of fish waste. In general the lack of large quantities of domestic sewage near fish processing plants makes such a proposal inoperative.

The effluent from fish processing plants are characterized by their high fat and protein contents which are partially present in the form of a stable fat-protein emulsion. Ventz and Zanger proposed the breakdown of this emulsion by addition of chemicals to form a chemical precipitate. The authors used ferric chloride ($Fe\ Cl_3$) as their chemical. The dosages used varied from 60-300 mg/l $Fe\ Cl_3$ depending on the strength of the waste; an average value of 150-175 mg/l was considered acceptable. During experiments with vaious dosages of $Fe\ Cl_3$ the BOD_5 removal by chemical precipitation varied from 4.0 to 60.0 percent, with an average of 30 percent.

The effluent from the chemical precipitation process was fed into a trickling filter. The maximum volumetric load on the filter was approximately 3 lbs BOD_5/cu ft / day, which resulted in a 32 percent removal of BOD_5. However, when the average influent BOD_5 concentration was 1100 mg/l, the resulting BOD_5 removal exceeded 50 percent. The problem with a trickling filter is its unreliable operation, the biological growth on the filter material quickly caused plugging. The authors could not overcome this problem.

The third stage of the treatment process was an activated sludge unit. Ventz and Zanger (1966) found that with a 3.5 hour detention time and a solids content of 16 to 20 percent, by volume they obtained a 70 percent BOD_5 removal. It was found that the average BOD_5 removal for the complete system proposed was 88.1 percent.

Matusky _et al_ (1965) stated that fish solids and oil digested readily and the resultant sludge dewatered easily. The digester loading rates varied from 0.1 to 0.36 pounds volatile solids per cubic foot per day.

Hopkins and Einarsson (1961) described a system in which clarified wastewater was effectively treated in a series of septic tanks.

This literature review gives an indication of the current knowledge and process technology involved in the characterization and treatment of wastes from fish processing plants. The characterization of wastes from various types of fish plants has been the subject of a number of studies, but all the plants studied handled seafood as opposed to freshwater fish. Further the information on treatment is mainly confined to screening and flotation, in other words physical treatment, of waste from seafood processing plants. There is very little information available on biological treatment as applied to any type of fish wastes. The present study was undertaken to provide the freshwater fish processing industry with data on waste characterization and information on the application of physical and biological treatment to their fish processing wastewater.

CHAPTER 3

OMSTEAD FISHERIES PLANT

Omstead Fisheries, 1961, Limited contacted the newly formed Federal Department of the Environment in May 1971 with the object of obtaining support for a joint company-government study of the waste water from their plant. This action by Omstead Fisheries stemmed from their efforts to obtain information on the methods available to treat their waste water. It appeared that little information was available, and what information did exist was based on work in seafood processing. This fact was later reinforced during a literature search undertaken for this study.

The Federal Department of the Environment, with the cooperation of the Department of Chemical Engineering, McMaster University, agreed to undertake this study, the objectives of which are outlined in the Introduction.

Omstead Fisheries, is situated about one mile south of the village of Wheatley, Ontario. The plant is some twenty miles south east of Windsor, on the Lake Erie shoreline. The company is privately owned and is operated by the relatives of the founder, who started his fish processing business in the early 1900's.

The company has three main enterprises

1) Fresh water fish processing - the majority of the fish processed are marketed fresh (frozen).

2) The cooking of fish and vegetable products - seafoods, such as scallops, are imported for cooking, as are a number of other items e.g. onion rings.

3) Vegetable processing.

This study was concerned solely with the characteristics and treatability of the waste water from the fish processing plant.

The plant processes two species of fresh water fish, perch and smelt. These fish are either unloaded at the Wheatley harbor and are taken directly into the plant for storage or processing or refrigerated trucks transport fish from other harbors on the Lake Erie shoreline. Approximately one hundred fishing boats supply the plant with raw product.

3.1. Perch and Smelt Processing

The methods of processing perch and smelt differ somewhat. Figure 3.1 shows the perch filleting operation. Following receipt of the raw product the fish are graded and weighed. The perch are then packed in boxes with ice for short-term storage prior to processing.

The company attempts to keep a steady flow of perch through the filleting machines, thus the quantity of fish in storage at any time will depend on the rate of processing of the fish and the day's catch. The filleting operations are carried out by machine unless the supply of perch is low, in this case the operations are performed by hand. Following filleting the fish are placed on trays in large boxes for freezing. The perch are eventually packaged in small boxes for the consumer market.

The smelt processing operations are shown in figure 3.2. The smelt are initially handled in approximately the same manner as the perch.

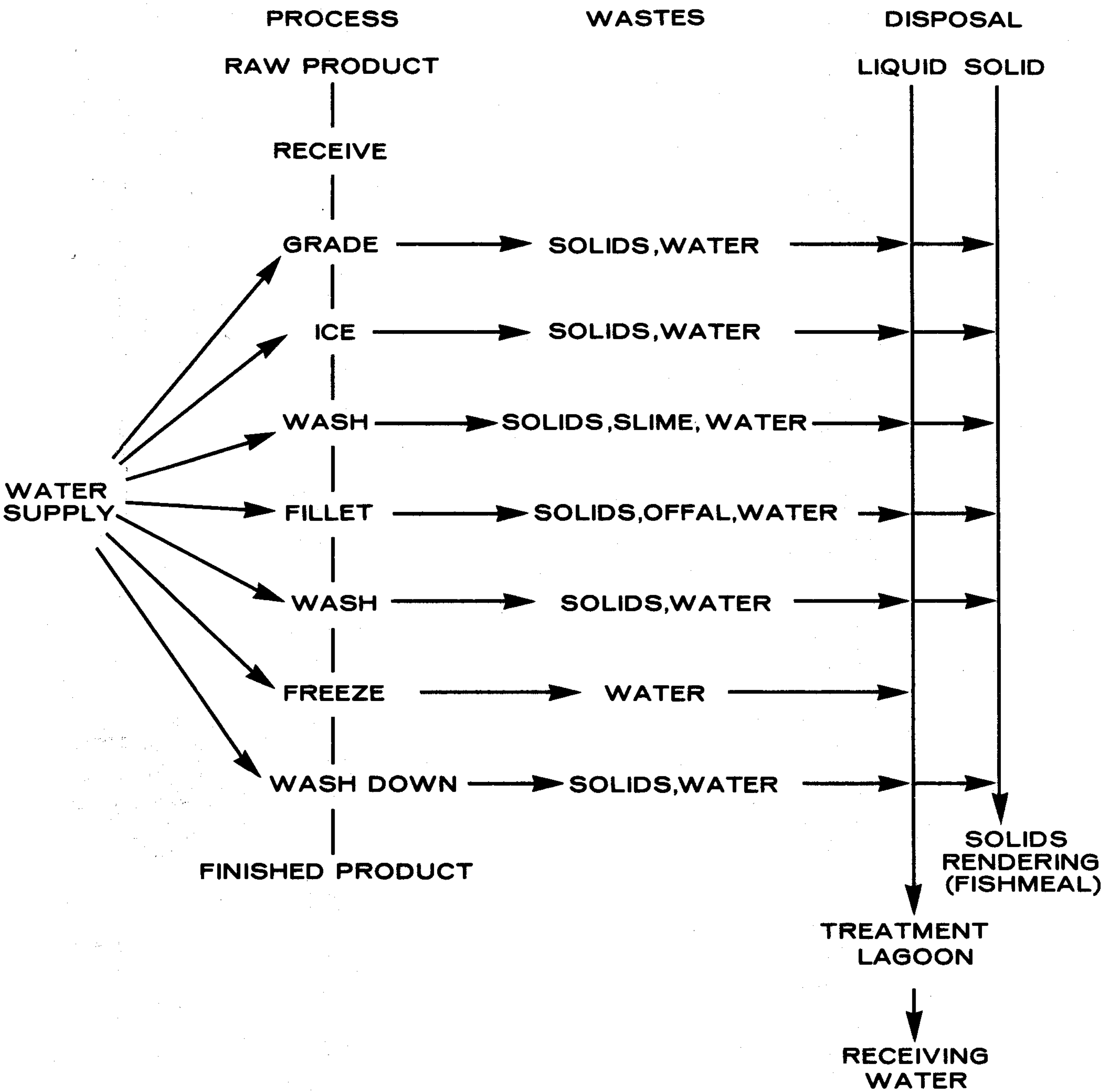


Figure 3.1 Perch Filleting Operation

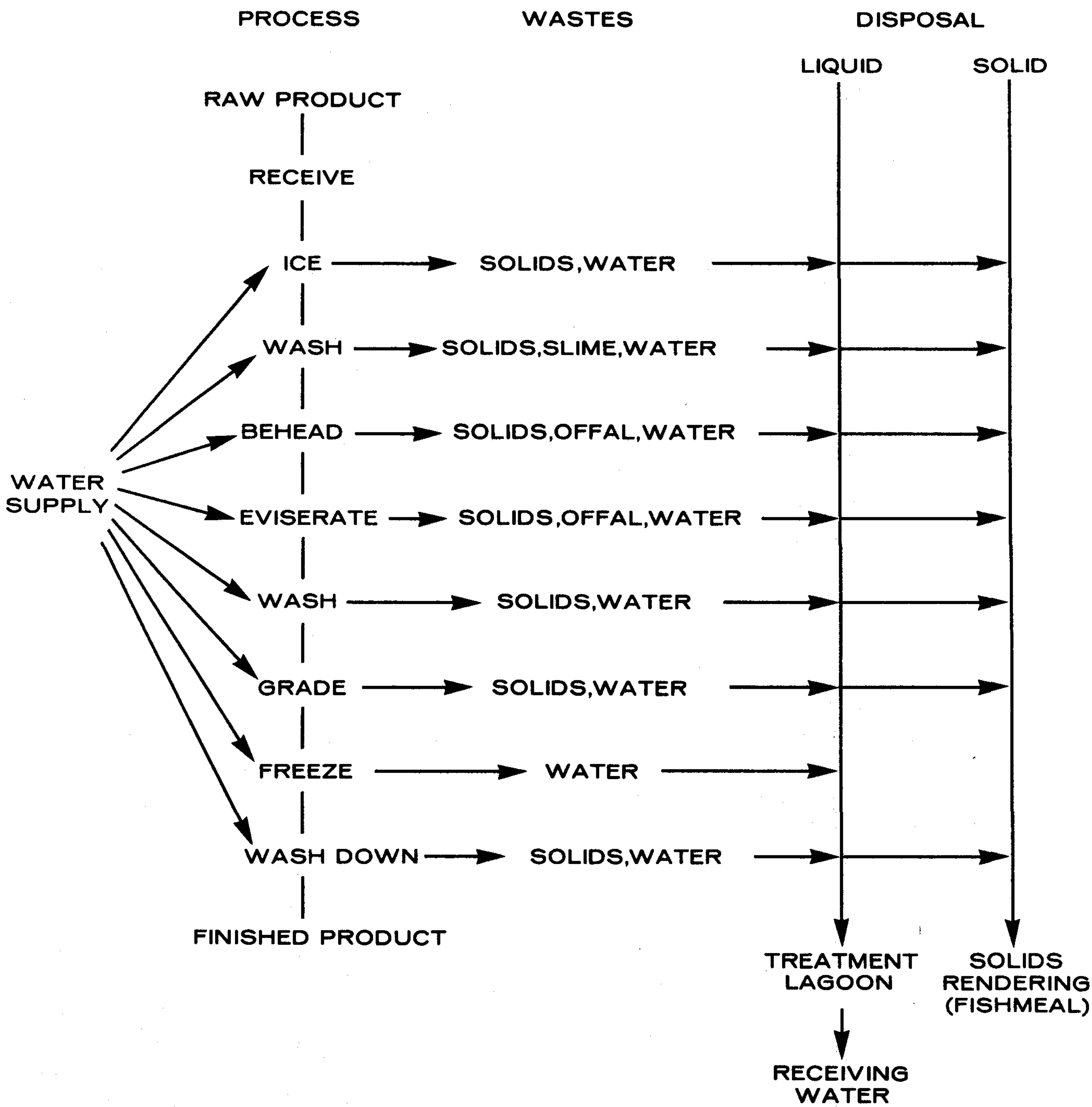


Figure 3.2 Smelt Processing Operation

However smelt are not filleted, they are beheaded and eviserated by machine. If the supply of smelt is low, the smelt processing machines are shut down, no hand processing of smelt is undertaken. Following eviseration the smelt are graded and frozen. The smelt are then packaged in small boxes for the consumer market.

3.2. Water Use

The principal uses of water in the plant are:

1) fluming offal from filleting area to screw conveyors, for transportation to fish meal plant,
2) continuous washing of fish during filleting operations,
3) clean-up operations on wharves and processing plant,
4) equipment requirements, including cooling water for condensers and water for air scrubbers,
5) domestic uses, such as washrooms,
6) production of ice, and
7) fire protection systems.

All the water use in the plant whether fresh or from Lake Erie, should conform to the following requirements:

1) the water must be bacteriologically and chemically safe, i.e. free from harmful bacteria and toxic concentrations of chemicals, and
2) the water must be cool, preferably less than 19^{o} C and relatively free from turbidity.

Omstead Fisheries obtain its water from two sources. The water which comes into contact with the fish is pumped from a nearby filter, plant whereas plant cleanup water usually comes direct from Lake Erie. The Lake Erie water is chlorinated to the extent that the free chlorine residual is approximately 50 mg/l.

A study to relate water use at the plant with the total quantity of fish processed was attempted. Figure 3.3, a graph of water use per day against total fish processed per day, indicates that water use does not vary with the quantity of fish processed. This fact is surprising in the light of the fact that the majority of the water is used for fish washing and plant cleanup, operations where one would expect water use to be proportional to the quantity of fish processed.

The reasons for this apparent lack of a relationship between water use and fish production appear to be that apart from cleanup and fish wash water no additional water is used for fluming offal to the fish meal plant. In fact every effort is made to separate the offal from the water as quickly as possible in an effort to reduce the pollutional load of the waste water. The offal is transported to the fish meal plant by auger. In many fish processing plants fluming water represents in excess of 50 percent of their water use, this use would increase with increased fish processing. The fish wash water is generally metered directly through the filleting and eviserating machines, and therefore water use would be proportional to the amount of fish processed. However the volume of cleanup water used both during and following each shift is felt to be considerably greater in volume than the fish wash water. The

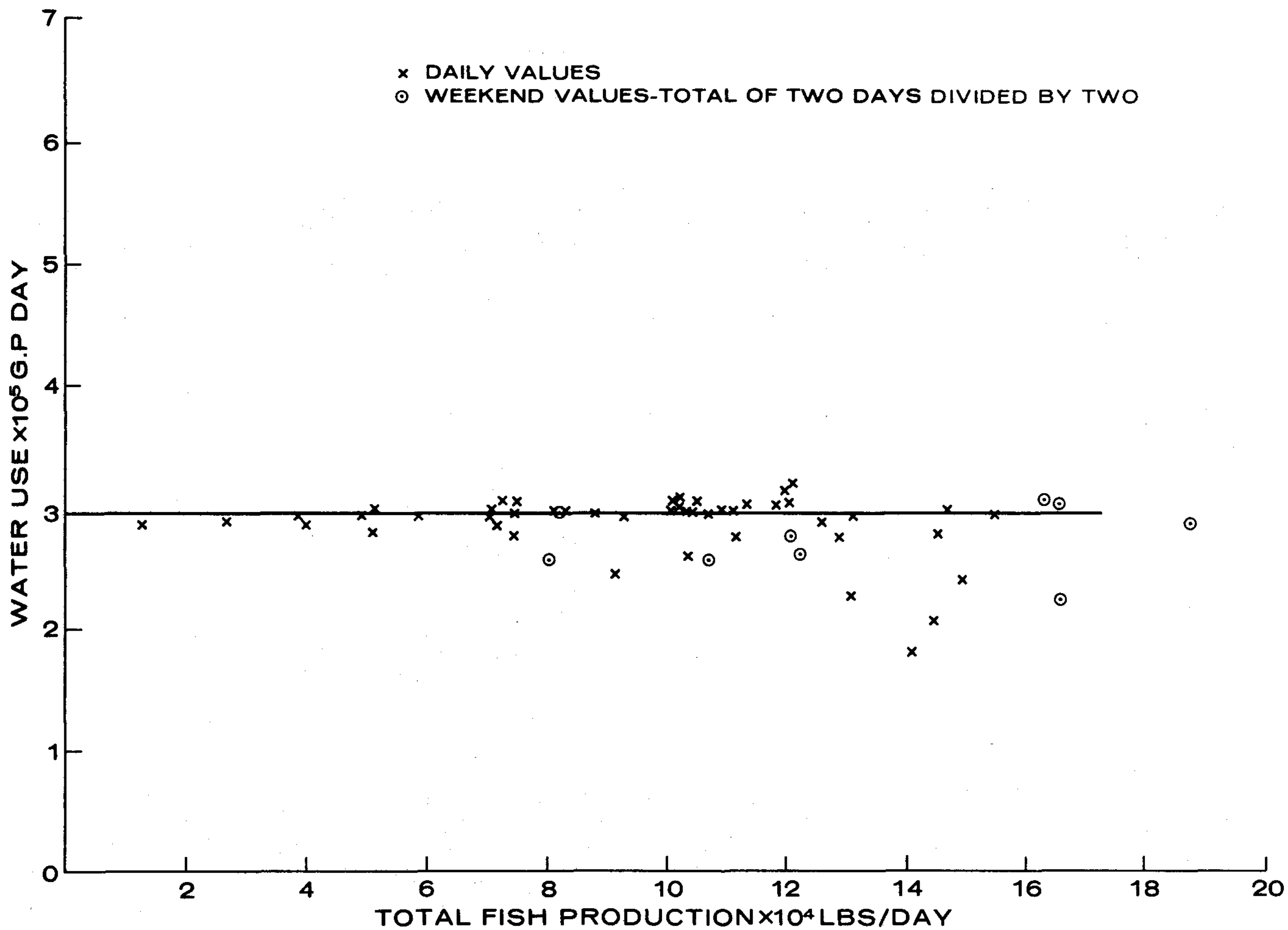


Figure 3.3 Water Use Against Total Fish Processed Per Day

volume of cleanup water used would not, in general, be proportional to the amount of fish processed.

A water resource study of Newfoundland and Labrador (1969) gave the following table of water use (Table 3.1) in a large fish processing plant which is compared to the water use at Omstead Fisheries.

Table 3.1. Water use in Fish Processing Plants

PROCESS	NEWFOUNDLAND-LABRADOR	OMSTEAD FISHERIES
Fluming of whole fish, fillets and offal	50 to 60 percent	Not practised
Fish washing, scaling, filleting and skinning	15 to 25 percent	Fish washing 60 to 80 percent
Cleanup operations in plant and wharf	12 to 18 percent	Plant cleanup 60 to 80 percent
Fish meal plant, ice making and other uses.	6 to 13 percent	5 to 10 percent

Omstead Fisheries use between 2 to 6 gallons of water per pound of fish processed, this is in reasonable agreement with figures given in the Newfoundland and Labrador study (1969) which varied from 3.6 to 4.9 gallons of water per pound of fish processed. However a number of plants in this study indicated a much higher water use, varying from 11 to 16 gallons per pound of fish processed. The report states that explanations for these differences are not readily apparent, but output variables from plant to plant were believed to be the practical cause. This report states that within the same plants there is not a linear relationship between water usage and tonnage of fish processed, because certain operations such as plant and vessel cleanup, require essentially the same volume of water regardless of whether the plant is operating at half or full capacity.

It is believed that, as far as Omstead Fisheries are concerned, little can be done at present to reduce the volume of waste water in the light of the sanitary requirements by various government inspection branches.

3.3. Fish meal Plant

Omstead Fisheries processes its' offal to produce fish meal for animal feed and high grade fish oil. Figure 3.4 shows the processes involved in the fish meal plant. The offal is transported to the fish meal plant by auger. Following grinding of the offal, it is cooked by injecting steam at 200 p.s.i. into the offal. The cooked offal is then pressed, the liquid obtained is called stickliquor (or stickwater) and is removed for further processing by centrifuging to remove the oil. After oil removal the stickliquor is evaporated to increase the solids from 7 percent to about 50 percent, the stickliquor is now referred to as condensed fish solubles.

Omstead Fisheries produces about 3,500 gallons per day of stickliquor. The majority of stickliquor, following evaporation, is added to the recently pressed offal prior to drying. The offal is dried in a rotary drier until it reaches 8 percent moisture content. The fish meal is trucked away and used as animal feed supplement. The steam from the

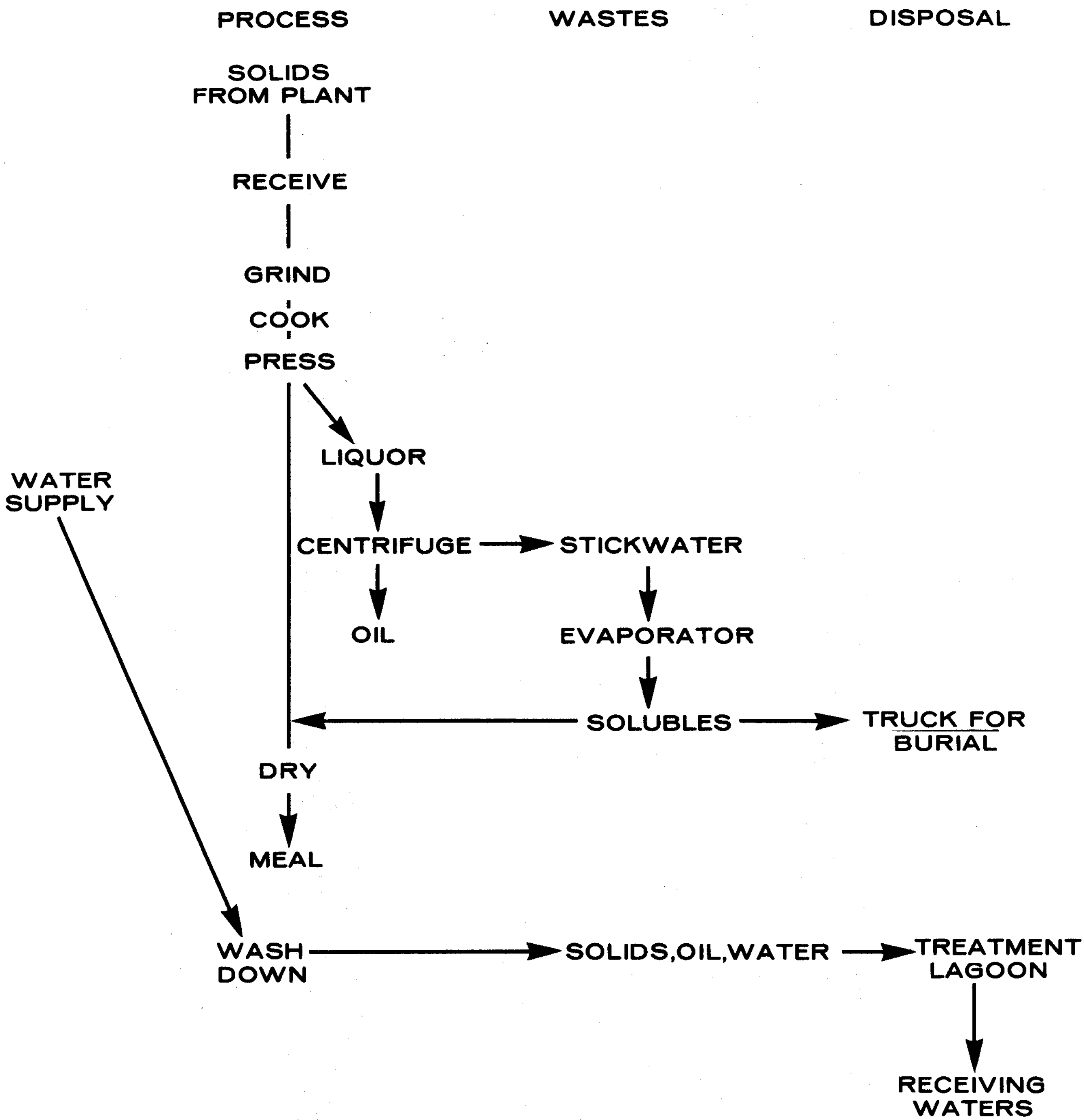


Figure 3.4 Fish Meal Plant Operation

stickliquor evaporators and the offal drier is scrubbed and discharged to atmosphere. The wash water used to scrub the steam is recirculated, following the addition of chlorine. The only waste water discharged from the fish meal plant was used for wash down.

3.4. Waste Water Treatment

The waste water from the fish processing lines is screened through 20 mesh tangential screens and passed through 28 mesh vibrating screens prior to pumping to an aerated lagoon. Solids removed by the screens and vibrators are augered to the fish meal plant.

Prior to entry to the lagoon the fish waste water is mixed with the waste water from Omsteads vegetable processing plant. A composite sample of the mixed waste is analysed in Omsteads' laboratory for BOD_5, COD, suspended and volatile suspended solids; a daily grab sample is taken of the lagoon effluent and analysed in the same manner.

The aerated lagoon has a volume of approximately 560,000 gallons and is aerated by one 50 horsepower surface aerator. The effluent from the lagoon flows over a weir and discharges into Lake Erie.

CHAPTER 4

METHOD OF DATA COLLECTION

4.1. General Problems

At the outset of the project it was decided that the laboratory facilities at Omstead Fisheries, with technical support from the Canada Centre for Inland Waters, Burlington, could not perform the necessary volume of analyses. A decision was therefore taken to locate a laboratory trailer at Omstead Fisheries. The trailer facilities were supplemented by a ten foot square wooden building.

In general BOD and solids analyses were carried out in the trailer whereas the wooden building housed the COD apparatus and the batch and continuous biological reactors. Attempts were made to keep the use of Omsteads' laboratory facilities to a minimum, however the incubator for the BOD bottles, the analytical balance and 550^0F oven were located there.

The analyses for total soluble organic carbon, nitrate, nitrite, phosphates, and total Kjeldahl nitrogen had to be performed at either McMaster University, Hamilton, or the Canada Centre for Inland Waters, Burlington. In general samples were transported to the Hamilton area once a week. The total soluble organic carbon samples were preserved by acidifying to pH 2 and freezing,whereas the nutrient samples were preserved by the addition of approximately 40 mg per liter of mercuric chloride followed by refrigeration at 4^0C.

The following analyses were carried out according to the procedures outlined in Standard Methods, 12 edition (1965):

1) 5 and 20 day biochemical oxygen demand using both the Winkler Method and a probe to determine dissolved oxygen,
2) Chemical oxygen demand,
3) Total and Total volatile solids,
4) Suspended and volatile suspended solids,
5) Total Kjeldahl nitrogen,
6) Nitrate, and
7) pH.

The standard methods procedure for biochemical oxygen demand was, however, modified slightly. The standard 250-300 mls BOD bottle was not available at the beginning of the project. Square 8 ounce bottles with plastic caps and special conical liners were used as replacements. The capacity of these bottles was approximately 230 mls. Comparative tests between standard BOD bottles and the 8 ounce square replacements were carried out. It was found that the differences in the BOD_5 results were within experimental error.

The analyses for total phosphate, orthophosphate and nitrate were performed automatically on a Technicon. A brief description of each method is given below:

1) total phosphate - the total phosphate content includes all the soluble orthophosphate and polyphosphates, and insoluble phosphates precipitated during storage. The sample is digested using a strong-acid solution to hydrolyse the polyphosphates to orthophosphate and also to dissolve the insoluble phosphates. The sample is introduced to the Technicon where

it is changed to an ammonium phospho-molybdate form prior to reduction using ascorbic acid. The sample then passes through an automated colorimetric sensing device.

2) orthosphosphate - the sample is filtered using 0.45 micron membrane filters, and is introduced into the Technicon. The automated procedure is the same as described above for total phosphate analyses.

3) nitrate - the nitrate sample is introduced into the Technicon where the nitrate is reduced to nitrite using cadmium, the resulting nitrite is used for diazotization and dye formation. The sample is then passed through a colorimetric sensing device.

The soluble organic carbon determinations were made using a Beckman automatic total carbon analyser. The samples which had been acidified for storage where neutralised by the addition of sodium hydroxide solution. Samples were subsequently filtered and injected into the analyser. Both total soluble and inorganic carbon could be determined on the Beckman analyser. The difference between the total and inorganic readings gave the soluble organic carbon determination.

The determination of oil and grease contents of the various wastes was proposed in the initial project proposal, samples were to be taken and analysed twice weekly. Problem in analysis and the heavy work load resulted in a delay in oil and grease analysis until early November. The analysis was performed at the Canada Centre for Inland Waters, Burlington. Samples were preserved by the additon of 2 mls, of sulphuric acid per liter and subsequent storage at $4^{0}C$.

The oil and grease analysis was performed according to Standard Methods, 12 edition (1965). This entailed adjusting the sample to pH 4.0, and the subsequent extraction of oil and grease in a separatory funnel using petroleum ether. Following the drainage of the ether, oil and grease from the separatory funnel, the ether was evaporated and the remaining contents cooled and weighed.

The anylysis outlined above were, with the exception of oil and grease analysis, performed on a regular basis in the characterization of the various fish wastes. During the treatability study the majority of the above analysis were performed together with a number of other tests. The analysis and tests carried out in the characterization and treatability studies will be covered in more detail in the following pages.

4.2. Waste Characterization

The method, locations and frequency of sampling were selected to provide representative samples while maintaining a reasonable time limit for sampling. In order for the waste characteristics to be applicable to future situations, it was decided that wherever possible parameters would be expressed in terms of pounds per 1000 pounds of fish landed. To this end waste flows and production figures were obtained.

4.2.1. Locations for Sampling

Omstead Fisheries process two species of fish, perch and smelt. It was therefore decided to sample waste from each process area, as well as a combined waste. In order that day to day samples could be compared, the sampling locations never varied. The smelt samples were collected directly below the same smelt processing machine every day. The perch samples were collected from an underfloor drain situated some fifteen feet from the automatic filleting machines. The underfloor drain carried the process water from the filleting machines. In both cases the solid fish waste had been removed from the wastewater. Screw conveyors recessed in the underfloor drains, carry the solid waste to the fish meal plant.

The perch and smelt wastewater are mixed when their respective underfloor drains meet in the processing plant. The combined wastewater is discharged into a large sump from which it is pumped into the aerated lagoon. The combined wastewater samples were taken from a valve located on the main pipe close to the pump.

The stickliquor was sampled following oil removal by centrifuging and just prior to condensing in the evaporators.

It was felt that while this scheme of sampling would not give comprehensive in-plant data, it would provide sufficient information to allow each main wastewater stream to be characterized, the initial intent of this part of the project.

4.2.2. Frequency of Sampling

Initially a sample program was drawn up which stipulated sampling twice a day taking 8 samples each time - 3 perch wastewater, 3 smelt wastewater and 2 combined wastewater. Each sample was taken at a different location. It soon became obvious that the laboratory facilities and technicians could not handle such an exhaustive sampling program as well as the necessary analysis.

The sampling program was reduced to taking 2 litre grab samples once per day on the perch wastewater, smelt wastewater, combined wastewater and stickliquor. This proved to be satisfactory from the work load standpoint. This procedure provided sufficient data, in excess of 35 daily values, to allow for a statistical analysis of the major parameters determined.

4.2.3. Analyses of Samples

The analyses performed fall into two broad categories; analyses carried out on a regular basis and analyses carried out intermittently. The following analyses were carried out on a regular basis:

1) 5 day biochemical oxygen demand at 20^0C,
2) chemical oxygen demand,
3) total soluble organic carbon,
4) temperature,
5) pH,
6) total and total volatile solids, and
7) suspended and volatile suspended solids.

The remaining analyses were carried out twice every 5 day work week. Attempts were made to perform these analyses listed below, on the same days every week; due to the varying work load this was not always possible.

1) 20 day biochemical oxygen demand at 20^0C,
2) total Kjeldahl nitrogen,
3) nitrate,
4) nitrite, and
5) total and ortho phosphate (listed as unfiltered and filtered

phosphate).

The analyses listed above were performed on each waste - smelt, perch, combined and stickliquor.

4.2.4. Flow Measurements

The metering devices inside the plant where not sufficient to enable the determination of the quantitites of water used on each fish processing line. The wastewater flow from the plant to the aerated lagoon could be metered by two methods. Firstly, a time device showing the number of hours of pump operation for the pumps used to carry the wastewater from a sump inside the plant to the aerated lagoon. The rating of the pumps was known and hence a daily flow of wastewater could be computed. Secondly a Parshall flume measured the flow of wastewater into the lagoon, the flume was connected to a float recorder and an intergrator which was read daily to give the total daily flows.

The flume and recording device were checked against the manufacturer rating curves and found to be about 20 percent in error. All daily flow readings from the flume were increased by 20 percent to compensate for this error.

A plot (figure 4.1) was made of the calculated pump flow against the flow measured by the flume. This figure indicates that the pump flow gave slightly higher values of flow than the flume. If the pump was not pumping against the rated head, the rating would be inaccurate. Similarly, flumes should be located in a long channel to provide dependable flow measurement. In this case the flume was situated immediately adjacent to

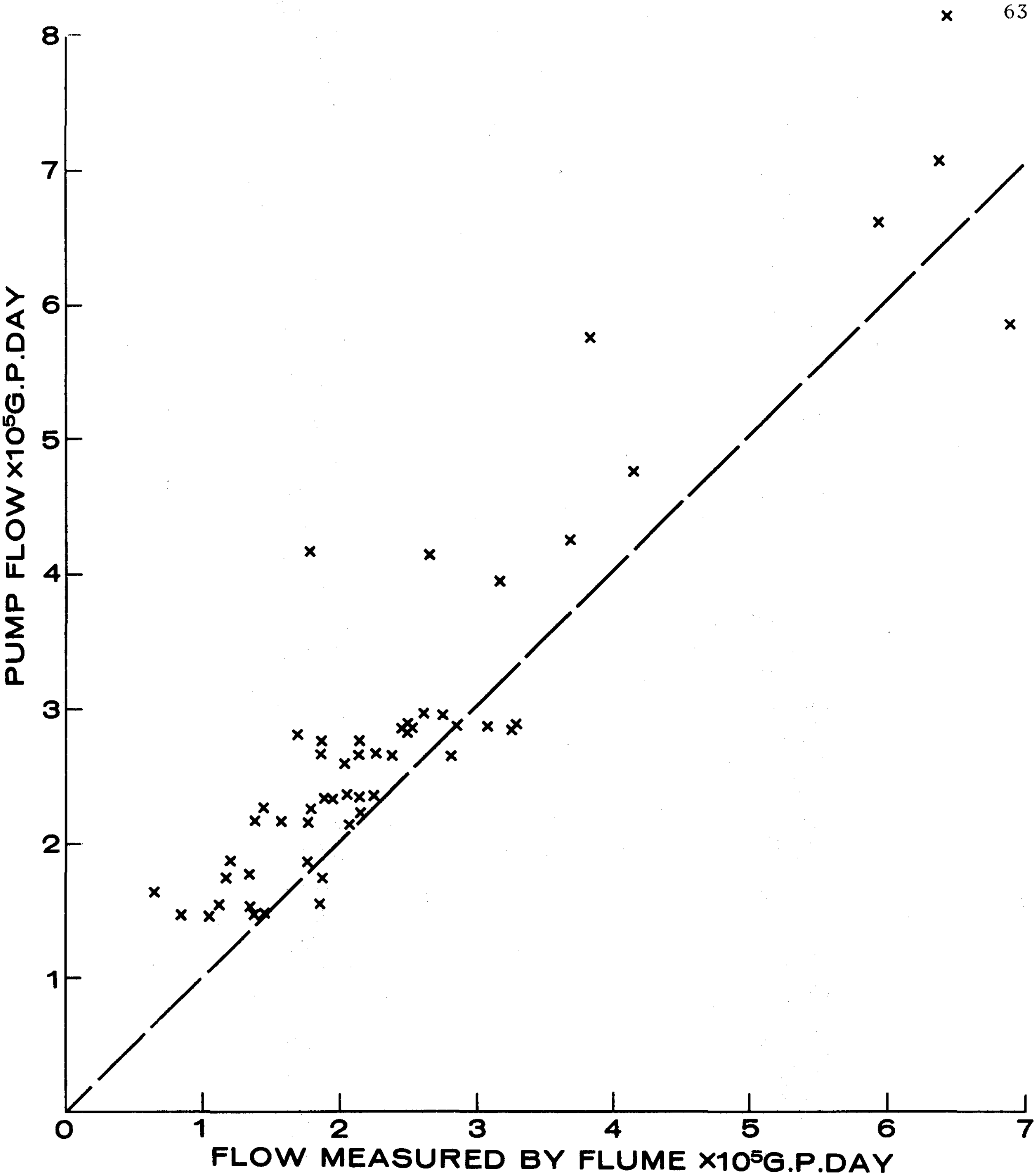


Figure 4.1 Calculated Pump Flow Against Flume Flow

a stilling well receiving the pumped discharge from the fish and vegetable plants.

To calculate the waste loading the flow was evaluated from the pump discharge.

4.2.5. Production Data

Figures on the daily volumes (landed weight) of perch and smelt processed were obtained from the management of Omstead Fisheries (1961) Limited.

4.3. Treatability Studies

4.3.1. Physical Treatment.

The physical treatment was limited to settling and flotation tests. The object of these tests was a preliminary assessment as to the effectiveness of physical treatment on the various fish wastes.

4.3.1.1. Settling Tests.

The settling column was constructed of 4 inch lucite tubing. Three sampling ports were positioned at intervals of 6 inches - the bottom port being 6 inches above the lucite base. Four liters of waste were used for each test; the surface waste was approximately 23.5 inches above the base, giving a coverage of 5.5 inches above the top port.

Sampling was done at times 0,30,60 and 120 minutes. Following each set of samples the height of the surface of the waste from the base was measured. The ports were sampled in the order top, middle and bottom. Each sample was analysed for BOD_5, COD and suspended solids.

Settling tests were carried out on perch, smelt and combined waste.

4.3.1.2. Flotation Tests.

A commercially available flotation cell was used for the flotation tests (see figure 4.2.). The transparent cell had a capacity of 2 liters. A bicycle pump was used to pressurize the cell up to a maximum of about 45 p.s.i.

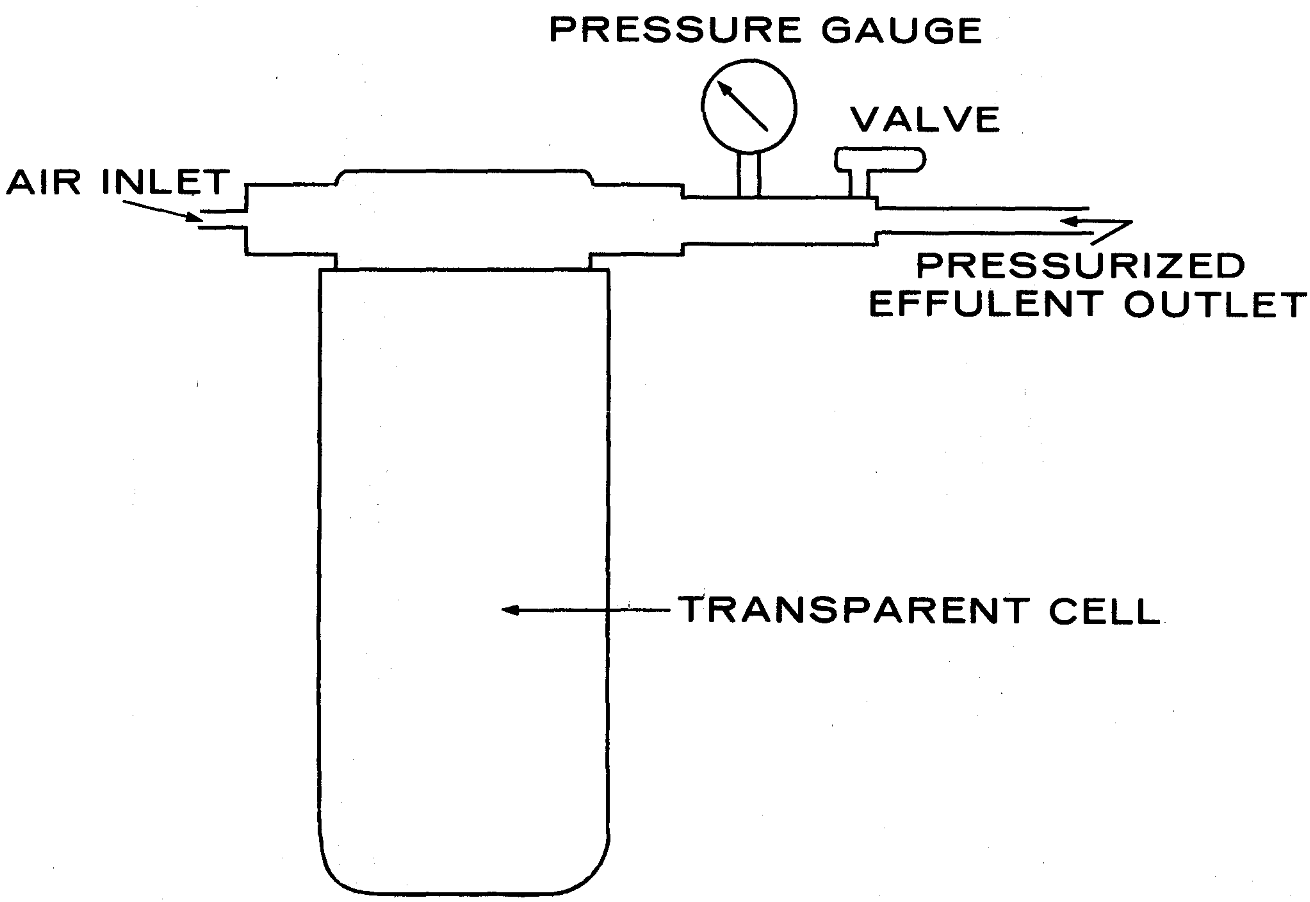
The wastewater to be pressurized was placed in the transparent flotation cell. Following the sealing of the cell, the bicycle pump was used to pressurize the cell to the desired level, shown on the pressure gauge. Ensuring that the pressure in the cell did not vary, the cell and contents were shaken vigorously for about one minute to allow the air to dissolve into the wastewater. The cell and contents were then allowed to stand for 3 minutes to ensure complete saturation of air in the water. The pressurized effluent was then released into a 1000 ml. graduate cylinder.

Samples were taken from the graduate cylinder using a wide mouth pipette, usually about 25 mls of sample was taken, at times 0, 5 and 15 minutes. Sampling at each time period was carried out at approximately 70 percent and 25 percent of the total height of wastewater in the cylinder. The samples were analysed for BOD_5, COD and suspended solids.

The following flotation tests were completed, in all cases only the combined waste was used:

1) total flow pressurized to 30 p. s. i.,

2) total flow pressurized to 20 p. s. i.,



TRANSPARENT LABORATORY FLOTATION CELL

Figure 4.2 Flotation Cell

3) 1/3 recycle pressurized to 40 p. s. i.,

4) 1/3 recycle pressurized to 30 p. s. i.,

In the case of tests # 1 and # 2 the complete flow, in this case 1,000 mls. was pressurized. In tests # 3 and # 4 only 250 mls of subnatant was pressurized and this was released into a 1,000 ml. graduate cylinder which contained 750 mls. of combined wastewater.

4.3.2. Biological Treatment.

4.3.2.1. Batch Reactors.

In order to determine the biodegradability of the various fish wastes batch reactors were set up and the biological degradation of the wastes monitored.

The batch reactors used were filled with 15 liters of fish waste and 2 liters of liquor from the aerated lagoon. This lagoon liquor provided the source of acclimatized micro-organisms necessary for each batch test. Air was supplied to the reactor at a rate of 3,500 c.c. per minute. The air supply has two functions:

1) to keep the batch reactor well mixed at all times, and
2) to supply sufficient oxygen for the micro-organisms to grow.

It was calculated that approximately 250 cc of air per minute would supply sufficient oxygen to meet the requirements of the micro-organisms. The remaining air flow, in excess of 3000 cc per minute, was for mixing purposes.

The biological degradation of the wastes were followed by monitoring the following parameters on a daily basis:

1) temperature,

2) pH,

(Both of the above should be kept at a constant level.)

3) BOD_5 - filtered and unfiltered,

4) COD - filtered and unfiltered,

5) TOC - filtered,

6) suspended solids, and

7) volatile suspended solids.

In addition phosphates, filtered and unfiltered, and total Kjeldahl nitrogen were determined at the beginning and at the end of a batch run. Each batch reactor was run for at least 20 days.

Batch biological degradation studies were performed on the following wastes:

1) perch wastewater,

2) smelt wastewater,

3) combined perch and smelt wastewater,

4) perch wastewater + 5 percent by volume of stickliquor,

5) smelt wastewater + 5 percent by volume of stickliquor, and

6) combined perch and smelt wastewater + 5 percent by volume of stickliquor.

Stickliquor was introduced to three batch reactors to determine its effect on the biological degradation of the wastes. In most fish processing plants stickliquor is recovered and thus does not become a waste product, however in a number of plants stickliquor is wasted. The volume of stickliquor is small compared to the total wastewater flow from a fish processing plant, a maximum of 5 percent by volume at Omsteads plant. However high BOD_5 and suspended solids values indicated that stickliquor would produce problems if introduced into a biological treatment system. The amount of stickliquor introduced to the batch reactors was in direct proportion to its maximum volume contribution to the total wastewater flow.

4.3.2.2. Continuous Reactors

A preliminary analysis of the batch reactor data indicated that a continuous reactor with a detention time of between 5 and 10 days would be necessary to effect good BOD_5 removal. On the basis of the waste characterization and the batch reactor data it was decided to limit the continuous reactors to inputs of combined wastewater only.

In order to obtain sufficient insight into the effect of detention time on biological degradation, four continuous reactors were set up. Three of these reactors had detention times of 5, 10 and 15 days with no sludge recycle, whereas a fourth had a 17 hour detention time with sludge recycle. The reactors each had a capacity of 15 liters, the remaining parameter are listed below:

1) 5 days detention time - combined waste,
   feed rate to reactor: 108 mls per hour,
   no sludge recycle,
   air supply: 3500 c.c. per minute,
2) 10 days detention time - combined waste,

feed rate to reactor: 54 mls per hour,

no sludge recycle,

air supply: 3,500 c.c. per minute, and

3) 15 days detention time - combined waste,

feed rate to reactor: 36 mls per hour,

no sludge recycle,

air supply: 3,500 c.c. per minute.

The above reactors can all be classed as completely mixed and thus the composition of the effluent is identical to the composition of the contents of the reactors. The feed to the 5 day detention time reactor was continuously pumped from a supply tank which was filled each day. However, due to the lower feed rates to the 10 and 15 day detention time reactors, the tubing carrying the feed became blocked by solid material. These reactors were thus fed three times daily.

4a) 17 hour detention time - combined waste,

feed rate to reactor: 1 liter per hour,

clarifier size: approximately 1 liter,

sludge age: 1) 3 days,

2) 5 days,

air supply: 8,000 c.c. per minute, and

b) 8.5 hour detention time - combined waste,

feed rate to reactor: 2 liters per hour,

clarifier size: approximately 1 liter,

sludge age: 3 days,

air supply: 8,000 c.c. per minute.

The clarifier was designed to give an overflow rate of 600 gallons per square foot of surface area per day. The volume of sludge recycled to the reactor depended on the sludge age required. Sludge age is the solids residence time of the reactor. This residence time is longer than the liquid residence time if sludge is recycled. Sludge age can be defined:

$$\text{Sludge Age} = \frac{\text{Mass of solids in the reactor}}{\text{Mass flow rate of solids discarded.}}$$

Initially 2 liters of lagoon liquor were placed in each continuous reactor to serve as a source of acclimatized micro-organisms. Following a period of continuous feeding equal to one detention time, samples were taken from the feed and the reactor in the case of the 5, 10 and 15 day detention time reactors, and in addition from the underflow sludge and effluent in the case of the 17 hour detention time reactor. The analyses carried out on each sample are listed in table 4.1.

The sampling of each reactor was continued until steady state conditions were reached. The sampling continued for another 3 or 4 days after this steady state condition had been reached. The object was to ensure that the steady state condition had in fact been reached and to monitor the effect of slight day to day changes in feed on the reactors. After this period of sampling the 5, 10 and 15 day detention time reactors were shut down.

The initial sludge age in the 17 hour detention time reactor was 3 days. Following the above procedure, when the reactor reached steady

Table 4.1. Analysis Performed On Each Sample Taken From Continuous Reactors

Parameter / Sample	pH	Temp	BOD_5 filtered	BOD_5 unfiltered	COD filtered	COD unfiltered	TOC filtered	Suspended Solids	Volatile Suspended Solids
Feed to 5,10,15 day reactors	-	-	-	-	-	X	-	-	-
5,10,15 day reactors	X	X	X	X	X	X	X	X	X
Feed to 17 hour reactor	-	-	X	X	X	X	X	X	X
17 hour reactor	X	X	X	X	X	X	X	X	X
Clarifier Sludge	-	-	-	-	X	X	X	X	X
Clarifier Effluent	-	-	-	X	X	X	X	X	X

state, the sludge age was changed to 5 days. This was achieved by changing the quantity of sludge recycled from the clarifier to the reactor. The sampling was again continued until steady state conditions occurred in the reactor.

The 5 days sludge age was then reduced to 3 days by altering hydraulic loading on the reactor, while keeping the volume of sludge recycled equal to that recycled for a sludge age of 5 days.

4.3.3. In Plant Analyses.

Two tests were carried out inside the plant, these were to determine:

1) the effect of time of contact between solid waste material and the wastewater on BOD_5, COD, T.O.C. and suspended solids.

2) The effect of 20 mesh tangential screens on solids removal from wastewater.

4.3.3.1. Contact Time.

These tests were carried out on the waste from both the perch and smelt lines. A large sample of waste was collected in a bucket- this waste included the water with the solid material, heads, guts, bones and so on. Samples were taken from this bucket at times 0, 15, 30, 60 and 120 minutes. These samples were analysed for BOD_5, COD, TOC and suspended solids. In general two or three tests were carried out for each waste.

4.3.3.2. Screening.

Omstead Fisheries have been investigating the amount of solids removal from their wastewater by using 20 mesh tangential screens. These screens have been placed at the end of two smelt processing lines and a perch processing line. Samples of waste water were taken four times daily before and after screening. These samples were analysed for suspended solids by Omsteads own laboratory technicians.

CHAPTER 5

DISCUSSION OF RESULTS

5.1 Characteristics of Wastes

Characterization of each waste involved a statistical analysis of each of the major parameters determined. To obtain a representative sampling for this type of analysis at least 20 observations for each parameter were obtained. In most cases in excess of 20 observations were obtained for the major parameters, BOD_5, COD, filtered total organic carbon, suspended solids, total solids and total volatile solids. The exceptions for the perch, smelt and combined wastewater were the volatile suspended solids and nutrient determinations.

Initially problems were encountered with the volatile suspended solids determinations. The lack of a muffle furnace in the mobile laboratory and problems with filter paper contributed to inaccurate results. Considerable care had to be exercised in handling the glass-fibre GF/A filter papers--all filter papers were pre-washed in distilled water and were thoroughly rinsed prior to removal from the filtration apparatus.

The small number of nutrient observation resulted from the twice per week analytical program, whereas the major paramaters were determined daily. Despite the lower number of observations the nutrient and volatile suspended solids results were statistically analysed for comparative reasons.

5.1.1. Smelt Wastewater

The characteristics of this waste are shown in table 5.1. The coefficient of variation, defined as the standard deviation expressed as a percentage of the mean, is in excess of 50 percent for all parameters except the volatile suspended solids and the nutrients. These high values of the coefficient of variation reflect the large variability of the waste on a day to day basis. It should be noted that the coefficient of variation for BOD_5, COD, filtered total organic carbon and total solids are of the same order of magnitude, between 54 and 62 percent, however the coefficient of variation of the suspended solids is in excess of 80 percent. This indicates either a larger variability in day to day suspended solids values than the other parameters or inaccuracies in the suspended solids analyses. Since the other wastes analysed did not show the same pattern for coefficient of variation values, the high values for suspended solids would appear to be day to day variations in the smelt wastewater.

A convenient method of presenting a large sample of observations from a population of observations is on a log-probability plot. Each event is ranked according to magnitude. The probability of occurence of an event of less than or equal magnitude to a known event can be calculated from:

$$\text{Probability} = \frac{(M)}{n+1} \times 100$$

where: n= number of observations

M= rank of observation

Table 5.1: Smelt Wastewater Characteristics

	BOD_5 (mg/l)	COD (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (As% of SS)	Total Solids (mg/l)	Total Volatile Solids (As% of T.S.)
Mean	1152	1965	213	599	85.3%	1311	68.4%
Standard Deviation	±631	±1216	±117	±492	±13.2%	±685	±15.5%
Coefficient of Variation	54.7%	61.9%	54.8%	82.2%	15.5%	52.3%	22.7%
Number of Samples	36	40	27	38	15	34	25

	Phosphate (mg/l)		Nitrite (mg/l)	Nitrate (mg/l)	Total Kjeldahl Nitrogen (mg/l)	Oil & Grease (mg/l)
	Unfiltered	Filtered				
Mean	22.2	19.1	0.010	0.323	119.5	37.5
Standard Deviation	±5.6	±5.4	±0.004	±0.068	±42.4	±5.0
Coefficient of Variation	25.2%	28.4%	40.0%	21.1%	35.5%	13.4%
Number of Samples	10	10	3	3	9	4

Figure 5.1. shows a log-probability plot for smelt wastewater for BOD_5, COD, total organic carbon, and suspended solids. If the sample observations are all equally representative of operating conditions, then the log-probability plot will be a straight line. Examination of figure 5.1 indicates that this is the case.

A number of statistical parameters can be determined from a log-probability plot. The geometric mean is the value of the transform parameter at X_{50}. The arithmetic mean can be calculated from the geometric mean by the following relationship:

$$\bar{x} = e^{a_x + b_x^2/2}$$

where $\bar{x}$ = arithmetic mean

a_x = Value of X_{50} from log-probability plot, geometric mean.

b_x = Difference between $X_{84.1}$ and X_{50} where $X_{84.1}$ gives the value of X with 84.1 percent probability of occurring.

Similarly the standard deviation, b, can be determined from:

$$b = \bar{x}(e^{b_x^2} - 1)^{1/2}$$

The best fit straight line was drawn through the points, and values for X_{50} and $X_{84.1}$ were determined. Using the equations given above, the values of arithmetic mean and standard deviation were

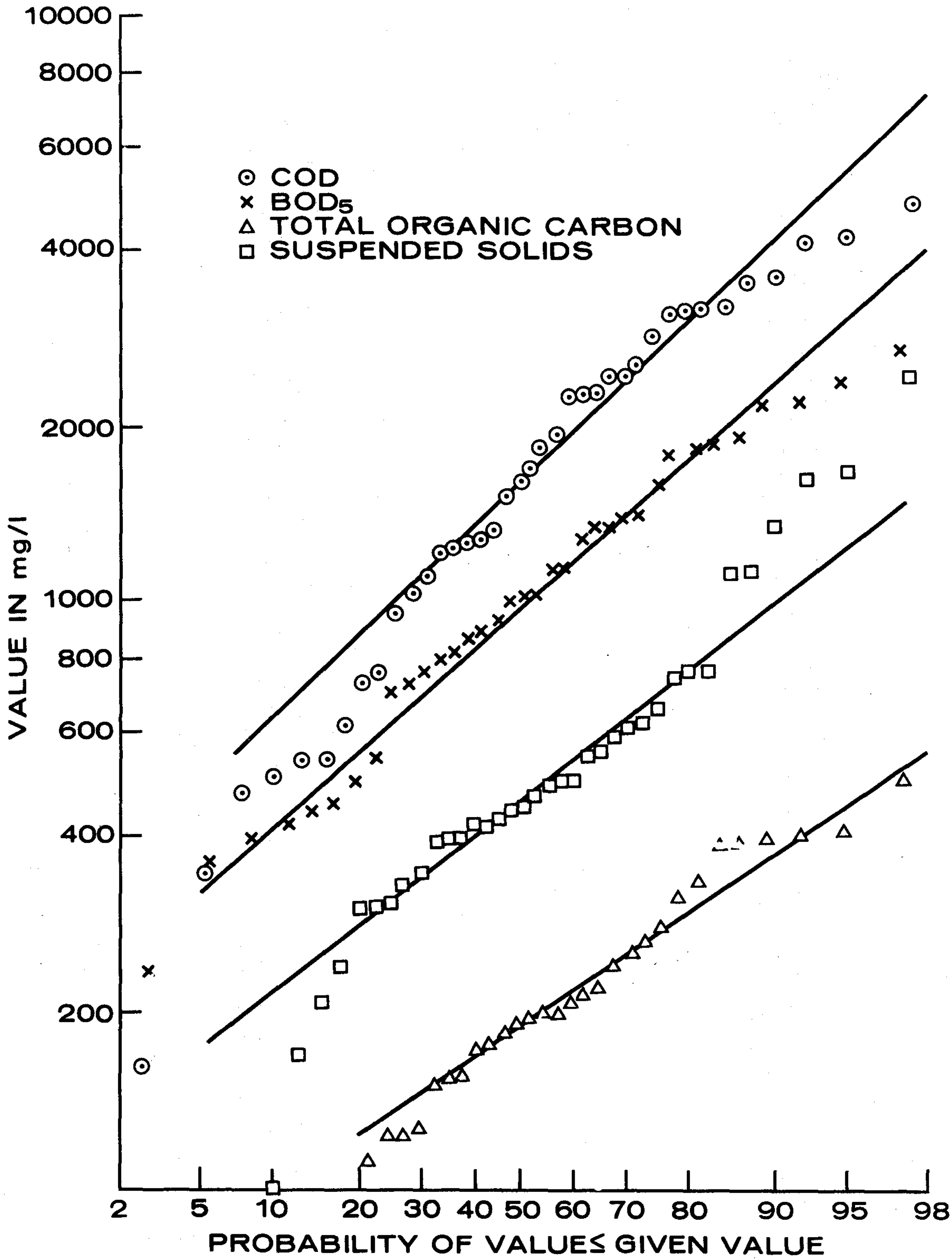


Figure 5.1 Smelt Wastewater Probability Plot

calculated and compared to the values obtained by computation using the raw data (table 5.2).

Table 5.2: Comparison of Arithmetic Means and Standard Deviation for Smelt Wastewater

	Computed Mean and Standard Deviation (using original data) (mg/l)	Calculated Mean and Standard Deviation (using log-probability plots) (mg/l)
BOD_5	1152 ± 631	1187 ± 790
COD	1965 ± 1216	1827 ± 975
Filtered TOC	213 ± 117	204 ± 73
Suspended Solids	599 ± 492	503 ± 208

It should be noted from table 5.2 that there is reasonable agreement between the computed and calculated means, especially considering the lines of best fit were filted visually. However, there does appear to be greater variation between the computed and calculated standard deviation, especially with regard to suspended solids. The reason for these variations is that a small number of high values of a parameter will have a disproportionate effect on its computed standard deviation. However on a log-probability plot these high values would not fall on a line of best fit for the remainder of the observations (see figure 5.1, suspended solids plot), from which the standard deviations would be calculated.

The raw data was further analysed by linear regression to determine the relationship between BOD_5 and COD. The correlation coefficient, r = 0.63 (r^2= 0.40), indicated a poor correlation between these two parameters. Figure 5.2, a plot of BOD_5 against COD, shows the scatter of the raw data.

Since it was not possible to measure the flow of smelt wastewater, the raw data was expressed in terms of concentration (mg/1) and not pounds of parameter per 1000 pounds of fish landed.

The concentration of nutrients present gave a BOD_5: N:P ratio of approximately 60:6:1. The majority of phosphate present in the waste is in the soluble form--in excess of 85 percent of unfiltered phosphate is present in the filtered samples. The levels of both nitrate and nitrite are low. The organic nitrogen present in the waste was determined using the total Kjeldahl nitrogen technique. The values obtained were predictably high as fish flesh is a protein.

5.1.2. Perch Wastewater

The characteristics of this waste are shown in table 5.3. As in the case of the smelt wastewater, the high values of coefficients of variation indicate the large variability of the waste on a day to day basis. In general perch wastewater has high values and greater variability in BOD_5 and COD than smelt wastewater. Filtered total organic carbon, suspended solids, volatile suspended solids, total and total volatile solids all have larger mean values than the smelt wastewater, but their coefficients of variations for each parameter are

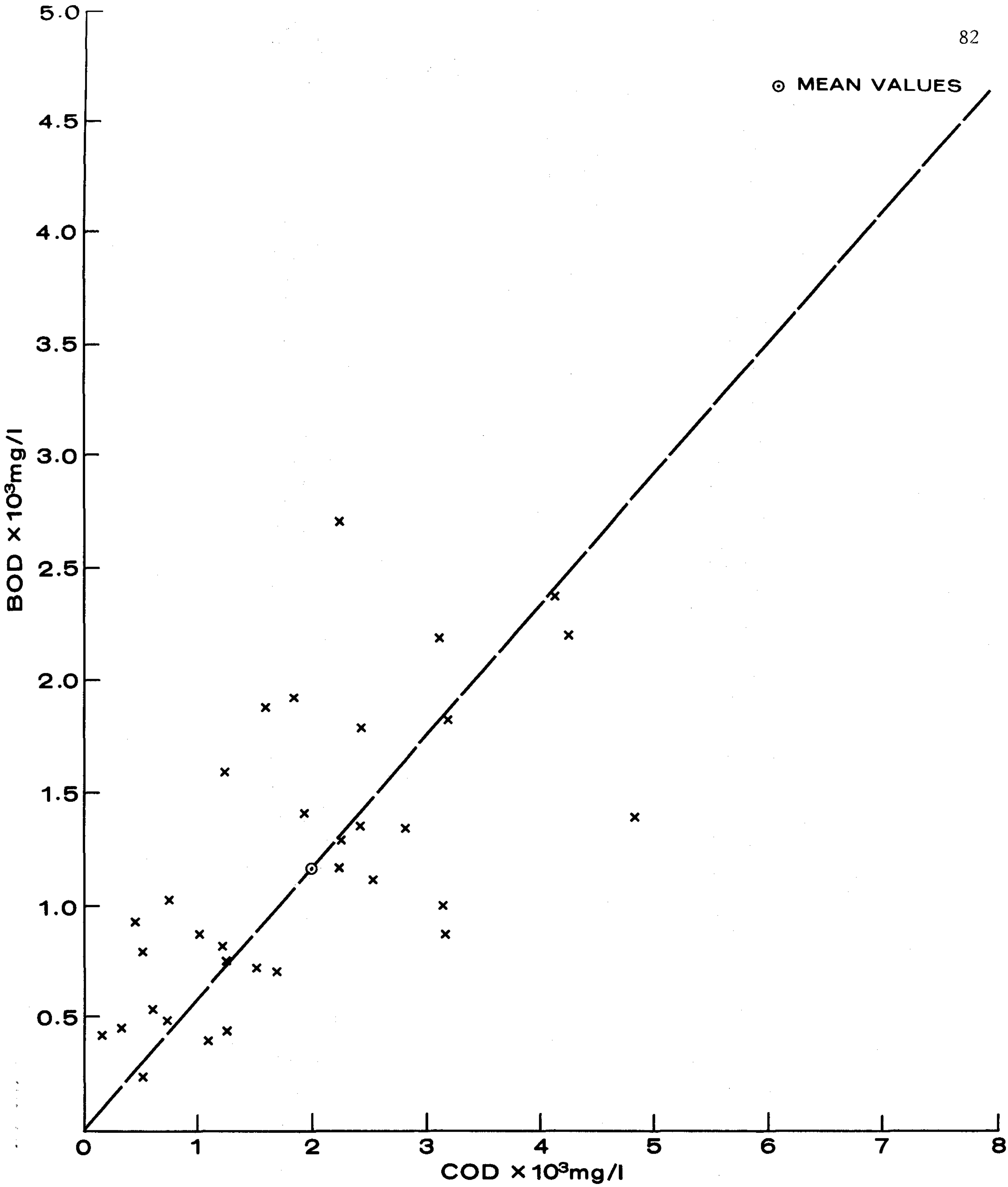


Figure 5.2 BOD Against COD For Smelt Wastewater

Table 5.3: Perch Wastewater Characteristics

	BOD_5 (mg/1)	COD (mg/1)	Filtered TOC (mg/1)	Suspended Solids (mg/1)	Volatile Suspended Solids (As % of S.S.)	Total Solids (mg/1)	Total Volatile Solids (As % of T.S.)
Mean	1847	3350	283	935	87.4%	1810	78.4%
Standard Deviation	±1793	±2894	±147	±745	±16.0%	±925	±10.2%
Coefficient of Variation	97.1%	86.4%	50.8%	79.7%	18.3%	36.0%	13.0%
Number of Samples	38	41	35	39	15	36	27

	Phospahte (mg/1) unfiltered	filtered	Nitrite (mg/1)	Nitrate (mg/1)	Total Kjedahl Nitrogen(mg/1)	Oil and Grease (mg/1)
Mean	17.9	15.1	0.0288	0.500	122.5	24.0
Standard Deviation	±7.7	±9.4	±0.0200	±0.282	±63.0	±12.0
Coefficient of variation	43.0%	62.3%	69.1%	56.2%	51.4%	50.0%
No of samples	12	12	4	4	11	5

approximately the same.

An analysis of variance was undertaken to statistically determine if there were differences in the variance between the perch and smelt wastewater. The results are given in Appendix 3. The "F" values determined for each parameter, BOD_5, COD, filtered total organic carbon, suspended solids and total solids, indicated no significant difference between the perch and smelt wastewater.

The "Student t" test was then used to examine whether the mean values of the two samples (Perch and Smelt Wastewater), drawn from different sources, were indicative of a real difference between the parent populations. As Null hypothesis was proposed that the two samples were drawn from populations identical both as to mean and variance. The values for "t" determined for BOD_5, COD, filtered total organic carbon and suspended solids are given in Appendix 3. In all cases no significant difference could be found between the two sets of data, perch and smelt wastewater.

Figure 5.3 shows a log-probability plot for the perch wastewater for BOD_5, COD, filtered total organic carbon and suspended solids. Table 5.4 below compares the mean and standard deviations obtained by computation of the raw data and by calculation from log-probability plots.

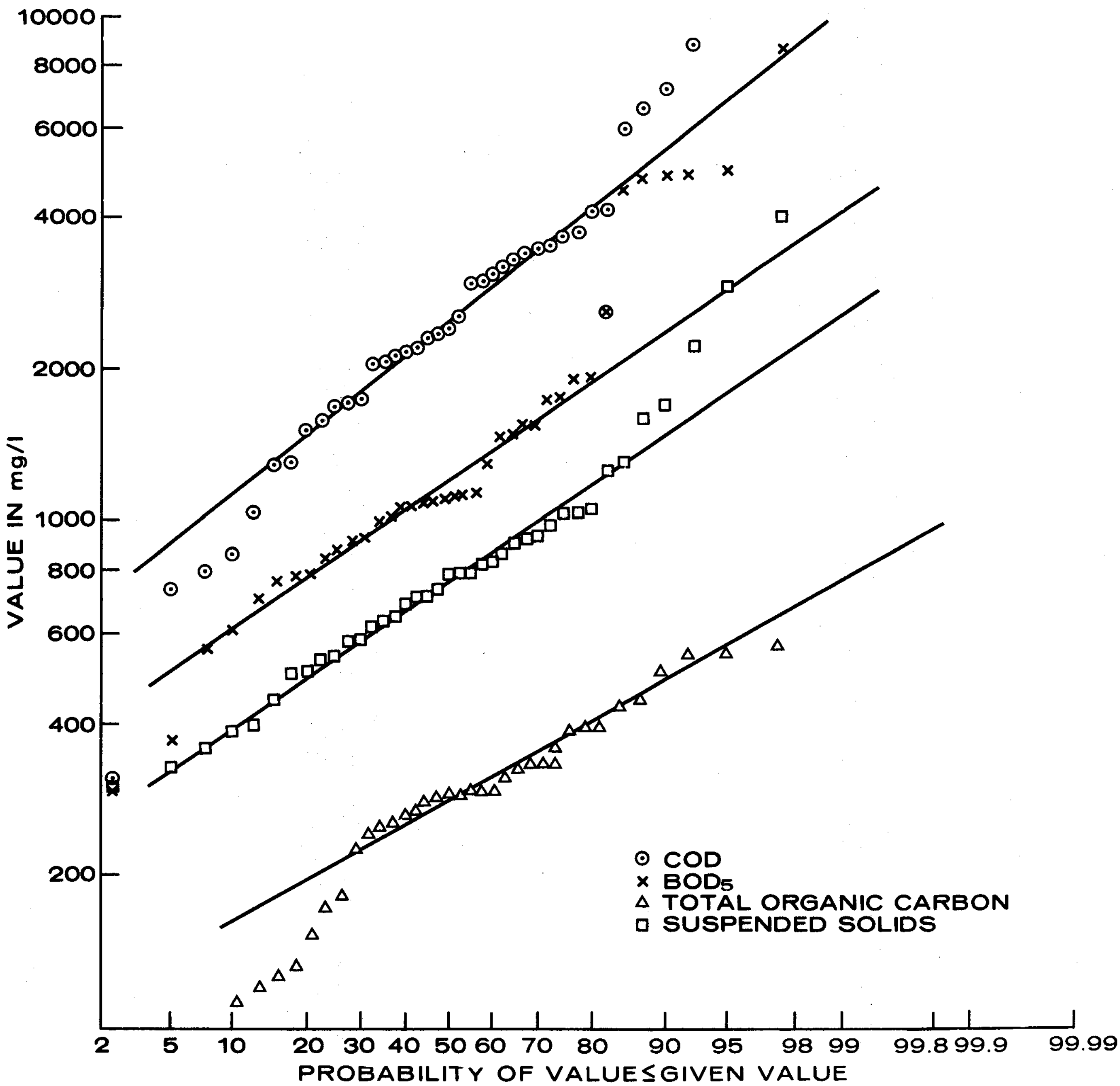


Figure 5.3 Perch Wastewater Probability Plot

Table 5.4: Comparison of Arithmetic Mean and Standard Deviation for Perch Wastewater

	Computed Means and Standard Deviation (using original data) (mg/l)	Calculated Means and Standard Deviations (using log-probability plots) (mg/l)
BOD_5	1847 ± 1793	1285 ± 461
COD	3350 ± 2894	2718 ± 1160
Filtered TOC	283 ± 147	294 ± 88
Suspended Solids	935 ± 745	806 ± 286

The agreement between the means and standard deviations, as given in table 5.4, is not as good as for the smelt wastewater. It will be noted from figure 5.3 that the high values of COD, BOD_5 and suspended solids are plotted well above the best fit line for the remaining data. As previously, these high values will effect the computed means and standard deviations but will not effect the values calculated from the log-probability plot. This is borne out by the calculated means and standard deviation being lower in value than their corresponding computed values (table 5.4).

A linear regression analysis between BOD_5 and COD was attempted using the raw data. The correlation coefficient, r=0.5 (r^2=0.25), again indicated a poor relationshpp existed between BOD_5 and COD. Figure 5.4, a plot of BOD_5 against COD, indicates the scatter of the raw data.

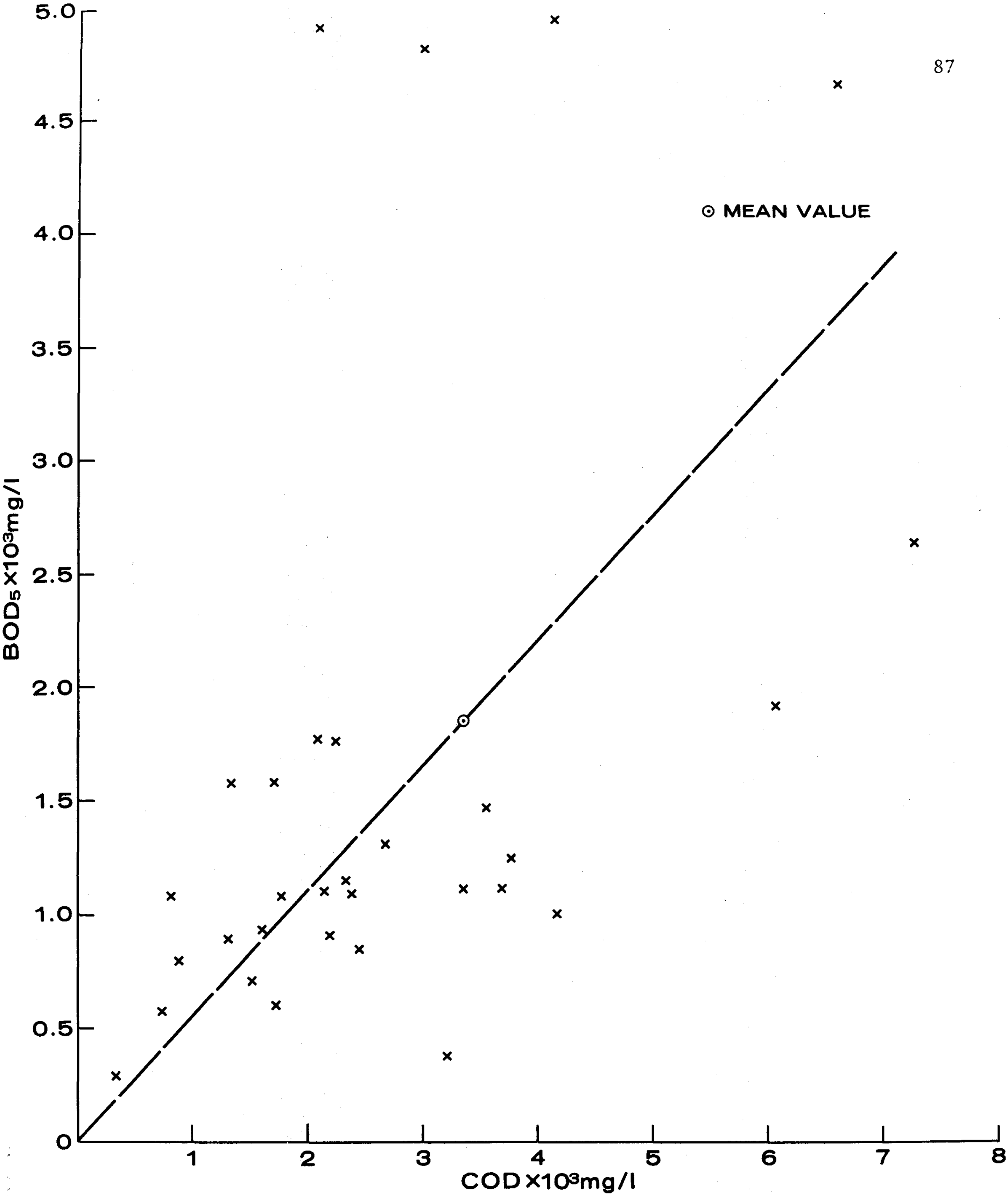


Figure 5.4 BOD_5 Against COD For Perch Wastewater

As in the case of the smelt wastewater, flows of perch wastewater could not be measured. Data is therefore expressed in terms of concentration in mg/1.

Table 5.2 also gives values for the nutrients in the perch wastewater. The mean BOD_5: N:P ratios is 100:6:1, compared with 60:6:1 for the smelt wastewater and 100:20:1 for domestic wastes (Eckenfelder,1970). As in the case for the smelt wastewater, the majority of phosphate is in the soluble form and the values of nitrite and nitrate are again low. Total Kjedahl nitrogen values are high with a mean value of 122.5 $\pm$ 63.0 mg/1, this compares to about 30 mg/1 in domestic wastes (Hunter and Heukelekian, 1965). The nutrient values determined for both perch and smelt wastewater are comparable, with smelt wastewater having a slightly higher phosphate content but the total Kjeldahl nitrogen values are about equal.

5.1.3. Combined Perch and Smelt Wastewater

The characteristics of the combined waste are shown on table 5.5. All the major parameters have higher mean values for the combined waste than either the perch or smelt wastewaters. However the coefficient of variations are lower for each parameter, with the exception of COD, total and total volatile solids. This would indicate a dampening effect of the component flows when mixed to form the combined wastewater. The combined wastewater is stronger, but less variable on a day to day basis, than its component parts.

Table 5.5: Combined Perch and Smelt Wastewater Characteristics

	BOD_5 (mg/l)	COD (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (As % of S.S)	Total Solids (mg/l)	Total Volatile Solids (As % of T.S.)
Mean	3044	4796	366	1397	89.0%	3070	81.7%
Standard Deviation	±1413	±4339	±113	± 724	±13.1	±2383	± 8.7%
Coeficient of Variation	46.4%	90.5%	30.9	51.8%	14.7%	77.6%	10.7%
Number of sample	40	39	36	40	19	36	28

	Phosphate (mg/l)		Nitrite (mg/l)	Nitrate (mg/l)	Total Kjeldahl Nitrogen (mg/l)	Oil and Grease
	Unfiltered	Filtered				
Mean	21.6	18.9	0.031	1.057	135.6	46.0
Standard Deviation	±9.4	±6.2	±0.016	±0.734	± 48.7	±28.0
Coefficient of Variation	43.7%	32.8%	51.6%	69.4%	38.9%	61.1%
Number of Samples	13	13	4	4	11	7

Figures 5.5 shows a plot of log-probability for BOD_5, COD, filtered total organic carbon and suspended solids. Table 5.6 below compares the computed and calculated means and standard deviation for the combined wastewater.

Table 5.6: Comparison of Arithmetic Mean and Standard Deviation for Combined Wastewater

	Computed Mean and Standard Deviation (using original data) (mg/l)	Calculated Mean and Standard Deviation (using log-probability plots) (mg/l)
BOD_5	3044 $\pm$ 1413	2824 $\pm$ 860
COD	4796 $\pm$ 4339	4660 $\pm$ 1620
Filtered TOC	366 $\pm$ 113	352 $\pm$ 85
Suspended Solids	1397 $\pm$ 724	1298 $\pm$ 540

As is the case for the smelt and perch wastewater, a small number of high values of BOD_5, COD, filtered TOC and suspended solids have caused differences in the calculated and computed means and standard deviations.

A number of linear regressions were undertaken to attempt to relate the parameters measured, expressed in concentration, to production parameters and to examine the relationship between BOD_5 and COD. The correlation coefficient, r=0.4 (r^2=0.16), indicated a poor relationship between BOD_5 and COD. Figure 5.6, a plot of BOD_5 against COD, gives an indication of the scatter of the raw data.

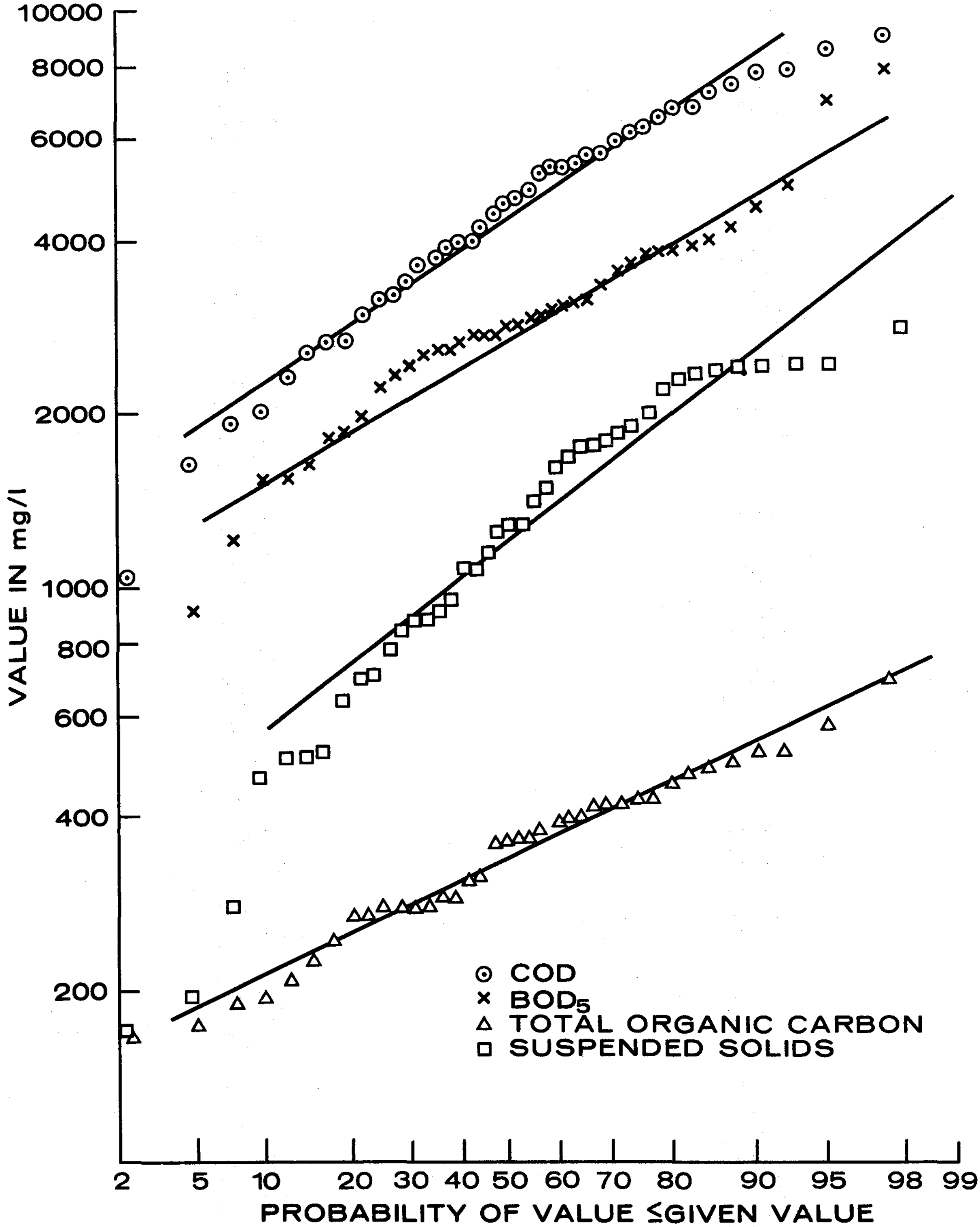


Figure 5.5 Combined Wastewater Probability Plot

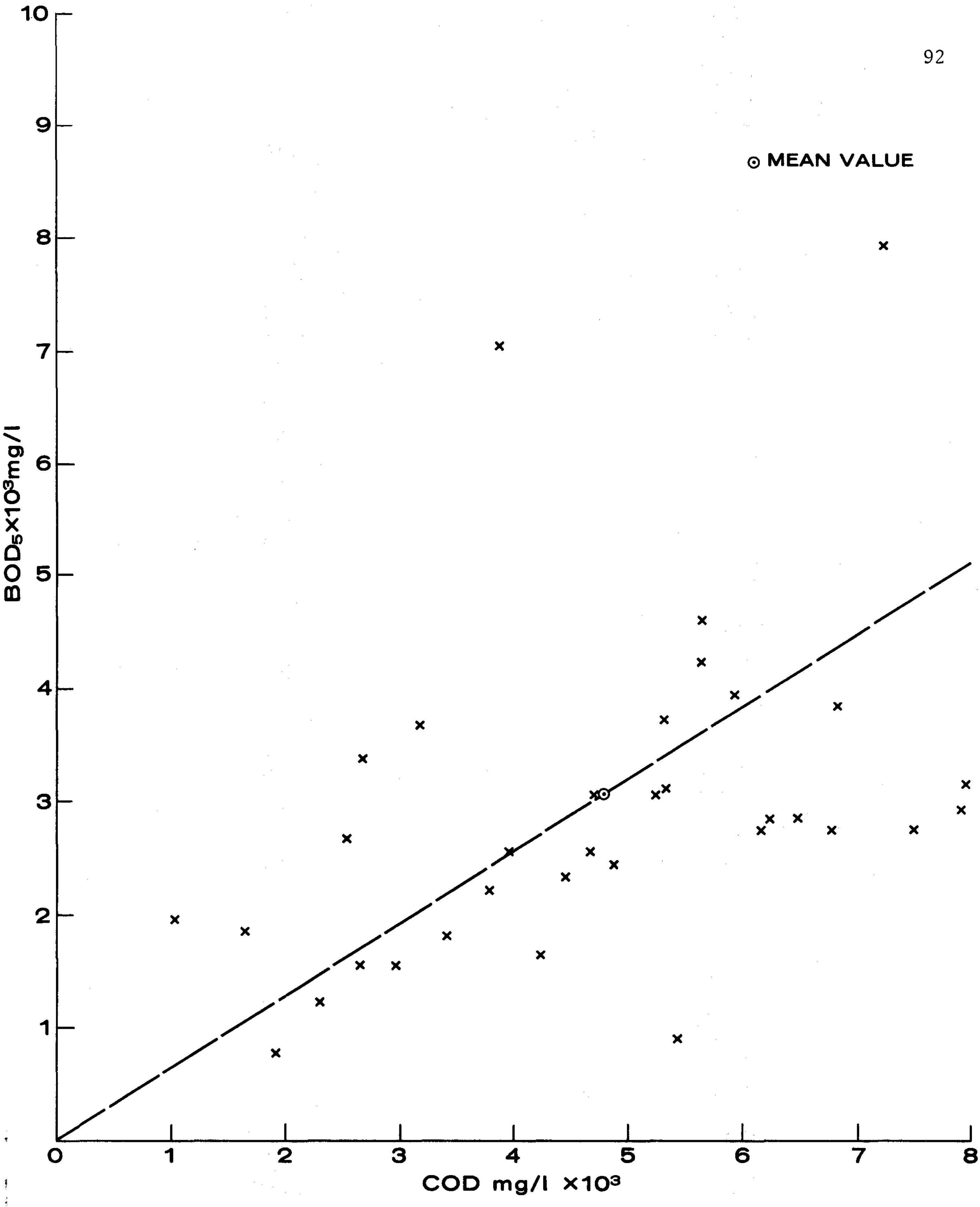


Figure 5.6 BOD_5 Against COD For Combined Wastewater

It was previously stated that water use in the plant studied was relatively constant at about 295,000 gallons per day. It was thought that the waste strength should vary as fish production varied. A linear regression between BOD_5, COD and suspended solids against pounds of fish processed (landed weight) was undertaken. The respective correlation coefficients of r=0.2 (r^2=0.04), r=0.10 (r^2=0.01) and r=0.14 (r^2=0.02) indicated poor relationships between the parameters chosen and pounds of fish processed.

As the total waste flow from the plant could be monitored daily, it was possible to determine parameters in units of pounds of parameter per 1000 pounds of fish processed (landed weight), instead of in units of concentration.

It was felt that the large coefficients of variation found throughout this characterization study where due in part to variations, albeit minor, in water usage and pounds of fish processed. Expressing parameters determined in terms of pounds of parameters per 1000 pounds of fish processed (landed weight), instead of concentration, should markedly reduce the coefficient of variation. Table 5.7 gives values for BOD_5, COD, filtered total organic carbon, suspended and total solids in terms of pounds per 1000 pounds of fish landed. Comparing the values of coefficient of variation on tables 5.5 and 5.7 it can be seen that there is little or no change. The exception is the COD coefficient of variation which has been reduced from 90.5% when COD values were expressed in mg/l to 44.7% when expressed as lbs/1000 lbs of fish processed (landed weight). It may be concluded that expressing

Table 5.7. Combined Perch and Smelt Wastewater Characteristics

Units Pounds/1000 pounds of fish processed (landed weight)

	BOD_5	COD	Filtered TOC	S.S.
Mean	4.49	7.95	0.57	2.25
Standard Deviation	±2.04	±3.55	±0.22	±1.32
Coefficient of Variation	45.4%	44.7%	38.0%	58.7%
Number of Samples	29	27	26	29

the parameters in terms of either concentration or lbs of parameter/ 1000 lbs of fish processed, had no effect on the variability of the data.

The mean BOD_5:N:P ratio of the combined waste is approximately 150:7:1, this compares with 100:7:1 for perch wastewater and 60:6:1 for smelt wastewater. As stated previously the majority of phosphate was in the soluble form, and the amount is comparable to that found in perch and smelt wastewater. Total Kjeldahl nitrogen values are also comparable to those found in perch and smelt wastewater, the value being 315.6 $\pm$ 48.7 mg/l. Nitrite and nitrate values are again low, and were not determined following initial characterization.

5.1.4 Stickliquor

Stickliquor is not usually regarded as a waste product. In many plants stickliquor is condensed to form solubles which are then sold or mixed with fish meal prior to drying. However a number of plants do waste their stickliquor and as such it was thought desirable to characterize this liquid especially in the light of its high strength.

Table 5.8 shows the characteristics of this stickliquor. The mean values of BOD_5 and COD for the stickliquor are numerically very close when compared to BOD_5 and COD values of the perch, smelt and combined wastewaters. The BOD_5/COD ratio of 0.98, compared to a BOD_5/COD ratio of 0.5 for domestic waste (Hunter and Heukelekian, 1965), indicates the high degree of degradability of the stickliquor.

Table 5.8: Stickliquor Characteristics

	BOD_5 (mg/l)	COD (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Total Solids (mg/l)	Total Volatile Solids (As% of T.S)
Mean	156,086	159,111	20,145	66,400	89,035	88.4%
Standard Deviation	± 90,000	± 97,000	±12,364	±34,507	±34,342	± 4.3%
Coefficient of Variation	57.7%	60.4%	61.4%	52.0%	38.6	4.8%
Number of Samples	11	14	10	2	11	10

	Phosphate Unfiltered (mg/l)	Nitrate (mg/l)	Total Kjeldahl Nitrogen (mg/l)	Oil and Grease (mg/l)
Mean	632.7	5.0	5513	1210.0
Standard Deviation	±235.7	±2.3	±2835.2	± 410.0
Coefficient of Variation	37.3%	45.6%	51.4%	38.8%
Number of Samples	7	4	5	2

The coefficients of variations for the parameters are comparable to those for the other wastes characterized.

The nutrient values determined give a mean BOD_5:N:P ratio of approximately 240:8:1, compared to 150:7:1 for the combined wastewater. Stickliquor can be characterized as extremely strong, but with low flows. Omstead Fisheries (1961) Ltd. produce about 3500 gallons of stickliquor per day. If this were discharged to the aerated lagoon it would exert an average load of 270 pounds BOD_5/day compared to an average load of 440 pounds BOD_5/day exerted by the 300,000 gallons of combined waste.

5.1.5. Comparison of Waste Characteristics

A review of the literature indicated that no characterization of perch, smelt or combined perch and smelt wastewater had been carried out. However, of the studies mentioned in the Literature Review (Chapter 2), a number dealt with wastes whose characteristics might be expected to be similar to the characteristics of the wastes from Omstead Fisheries (1961) Limited. Table 5.9 summarizes the waste characteristics determined from seven different studies and reports. It should be noted that the BOD_5 values are all of the same order of magnitude, however greater fluctuations occur in the suspended and total solids values. Differences in these parameters are due to factors as species of fish processed, processing techniques and water usage.

In order to appreciate the problems of obtaining reproducible data from waste characterization studies, the results of three independent

Table 5.9: Review of Data from the Literature

Author (Fish Processed)	BOD_5 (mg/1)	Suspended Solids (mg/1)	Total Solids (mg/1)
Washington State Pollution Control Commission (1969) (Species of fish not specified)	2700-3400	2200-3020	4198-21,820
Limprich (1966) (Herring, Red Perch, Fish Meal)	2658	-	-
Soderquist et al (1970) (Bottom fish processing)	192-1,726	300	-
Matusky et al (1956) (Wastewater)	1000	425	-
Chun et al (1968) (Tuna fish processing)	895	1091	17,900
Soderquist et al (1970)			
(Salmon Processing)	397-3082	40-1824	88-3422
(Sardine Packing)	100-2200	100-2100	-
Omstead Fisheries Ltd.			
Perch	1847	935	1810
Smelt	1152	599	1311
Combined	3044	1397	3070

studies of fish processing plants in the Shippegan, Caraquet and Lameque region of New Brunswick are presented in table 5.10. Where possible this table compares the three studies on the basis of BOD_5 and suspended solids data, analysed from samples taken from the same process. The agreement between the three sets of data should be noted. As stated previously, the data for each parameter has values of the same order of magnitude.

In the light of this study and those other studies mentioned previously fish processing wastewater can be characterized as of medium strength with highly variable day to day characteristics. Further, certain wastes have an extremely high strength, but these wastes are usually small in volume when compared to the total wastewater flows.

5.2. Treatability Studies

As fish processing wastewater is a high strength organic waste, similar to the wastes from other food processing industry, which should be amenable to biological degradation this study examined the possibility that biological processes could form the basis of a proposed treatment system.

Physical treatment of the fish waste was examined in a preliminary fashion. The work by Claggett and Wong (1969) had indicated significant reduction in BOD_5 and suspended solids in the waste by the use of flotation. An advantage of this method of treatment is the recovery of flotable solids for fish meal production.

Finally in-plant methods of reducing the strength of the waste

Table 5.10: Comparison of Data from three Studies of Fish Wastes Characteristics

Three studies all carried out in the Shippegan, Caraquet, and Lameque area of New Brunswick.

1) Canadian Plant and Process Engineering Ltd., 1970
2) Shaffner (1970)
3) Brodersen (1970)

Process		Study (mg/1) 1	2	3
Groundfish Flume Water	BOD_5	205-780	120-960	602-1,205
	S.S.	80-1120	210-1395	148-965
Herring Processing Filleting	BOD_5	-	-	32,000-5,800
	S.S.	-	-	1,150-5,310
Marinating	BOD_5	28,000	2,440-17,920	6,900-14,000
	S.S	470-2495	1,720- 5,833	1,508- 4,600
Fish Meal Plant Pumpout Water	BOD_5	9,600-21,800	6,470-17,280	33,500
	S.S.	8625	9,870-15,400	7,955
Bloodwater	BOD_5	61,000-89,00	-	190,000-315,000
	S.S.	40,500-56,625	-	4,168- 21,430
Stickliquor	BOD_5	24,500	34,000	46,000-490,000
	S.S.	6,450	13,270	7,600- 21,500
Deodorizer Water	BOD_5	680	490	450-1,349
	S.S.	782	390	12-275

were examined. In-plant modifications were aimed at reducing the contact time between the solid fish waste and the wastewater, with a consequent reduction in wastewater strength.

5.2.1. Biological Treatment

5.2.1.1. Batch Studies

Batch biological studies were carried out on the perch, smelt and combined perch and smelt wastewater. Sampling and analysis of the contents of the batch reactors were performed daily.

Figure 5.7 indicates the percentage of unfiltered BOD_5 remaining in the reactor for perch, smelt and combined wastewater. As the best fit could be obtained by a straight line on arithmetic paper for the three wastes considered, the reactions could be considered "zero-order" with respect to the degradation of unfiltered BOD_5. Figure 5.8, a plot of percentage of filtered total organic carbon remaining against time on arithmetic paper, indicates that the degradation of organic carbon could also be considered a "zero-order" reaction. The "zero-order" degradation of both unfiltered BOD_5 and filtered total organic carbon continues until removal essentially ceases. Both figures 5.7 and 5.8 indicate degradation of the wastes to residual values, after which the values of BOD_5 and total organic carbon remain relatively constant with time.

Since all the above reactions are of "zero-order", the rate of conversion is independent of the concentration of BOD_5 and filtered total organic carbon. The reaction rate can be expressed as:

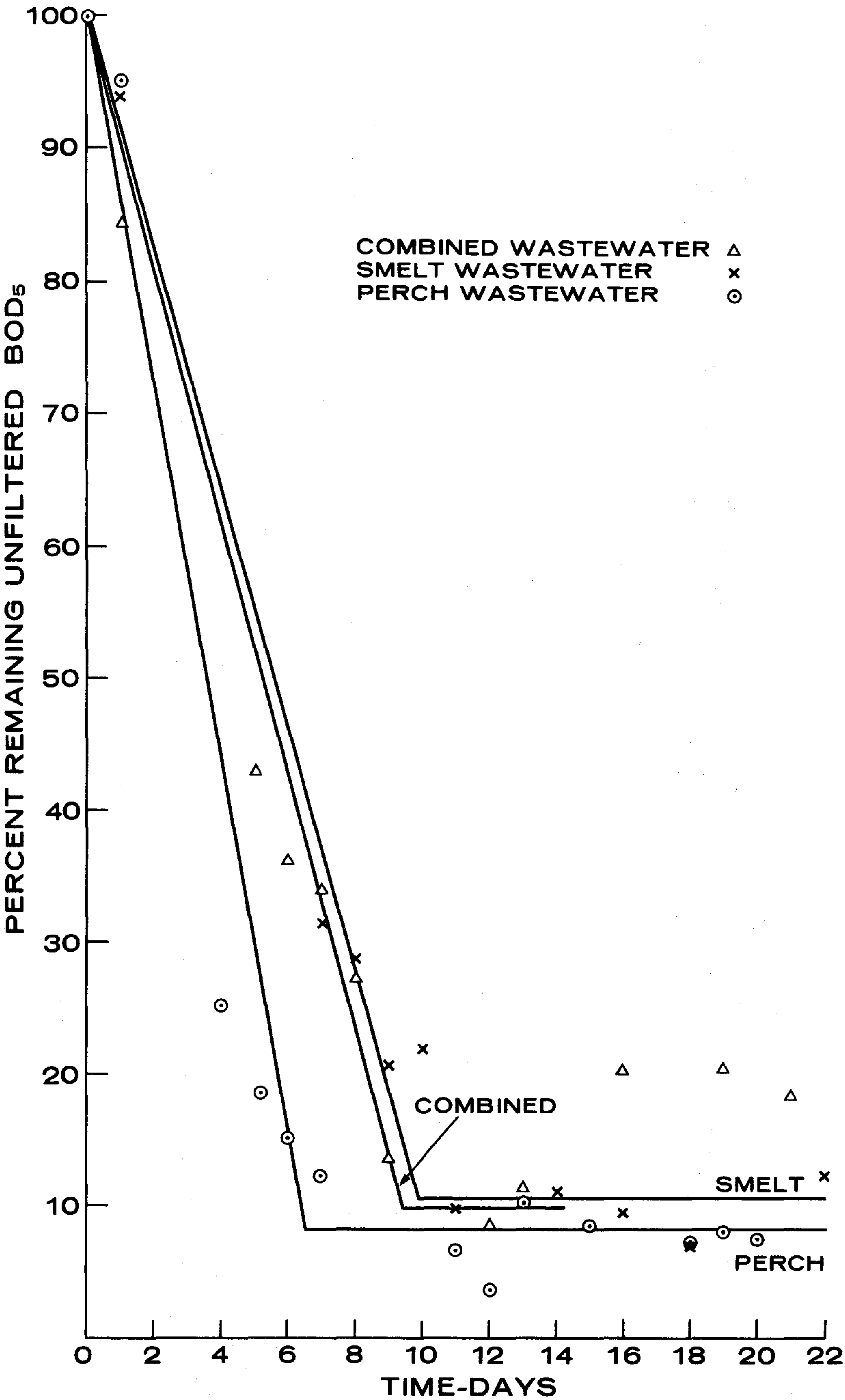


Figure 5.7 Batch Reactor Studies-BOD_5

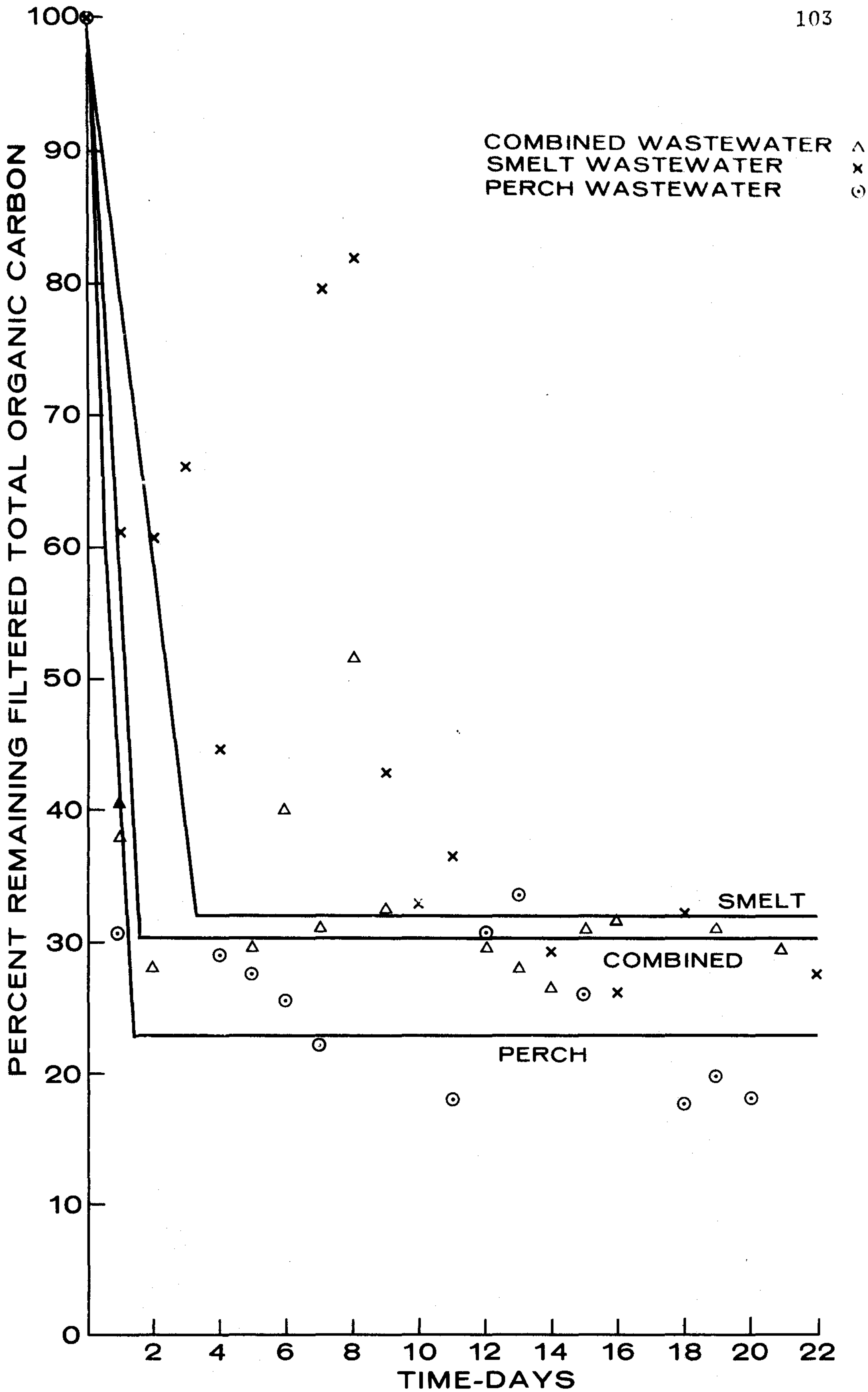


Figure 5.8 Batch Reactor Studies-Filtered Total Organic Carbon

$$-r_A = -\frac{1}{V}\frac{dN_A}{dt} = \frac{-dC_A}{dt} = k$$

where r_A = rate of recations based on volume of fluid

V = volume of fluid, litres

C_A = concentration of reactant A, mg/l, and

k = reaction rate constant, mg/l/time

Integrating the above equations we obtain directly:

$$C_{A_0} - C_A = C_{A_0} X_A = kt$$

where X_A = fraction of reactant A converted into product.

Table 5.11 gives the values of reaction rate, k, as determined from figures 5.7 and 5.8 for each waste. Because of scatter of experimental results k values should be treated as approximate. The unfiltered BOD_5 reaction rates vary from 9.1 percent removed/day for smelt wastewater to 14.0 percent removed/day for perch wastewater. This compares to values of reaction rates of between 10.0 to 3.0 percent removed/day for municipal sewage and many industrial wastes (Eckenfelder and O'Connor, 1961). The reaction rates for the filtered total organic carbon vary from 23.2 percent removed/day for smelt to 55.6 percent removed/day for perch wastewater. This represents a 2.5 to 4 fold increase over the unfiltered BOD_5 reaction rates.

Stickliquor was added to the three reactors to monitor its effect on the biological degradation of the waste material. Figures 5.9 and 5.10 are plots of the percentage of unfiltered BOD_5 remaining and the percentage of filtered total organic carbon remaining against time. The plots indicate a "zero-order" reaction for the degradation of both

Table 5.11: Reaction Rates for Batch Studies

	k, percent removed / day
Unfiltered BOD_5	
Perch Wastewater	14.0
Smelt Wastewater	9.1
Combined Wastewarer	9.6
Filtered total organic carbon	
Perch Wastewater	55.6
Smelt Wastewater	23.2
Combined Wastewater	33.5
Addition of 5 percent stickliquor to batch reactors	
Unfiltered BOD_5	
Perch Wastewater	9.7
Smelt Wastewater	6.2
Combined Wastewater	3.2
Filtered total organic carbon	
Perch Wastewater	4.3
Smelt Wastewater	6.0
Combined Wastewater	2.8

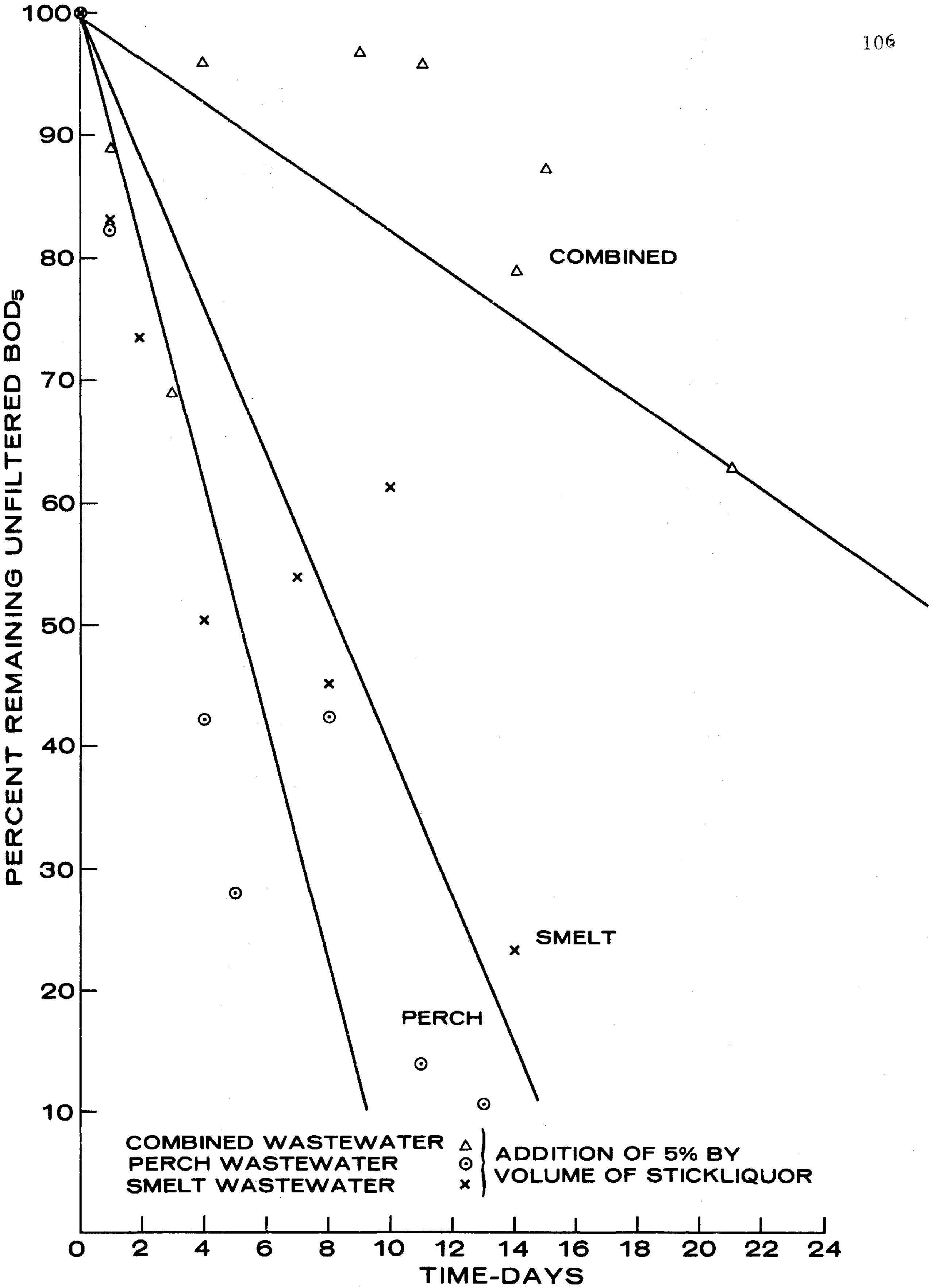


Figure 5.9 Batch Reactor Studies With Stickliquor Addition-BOD_5

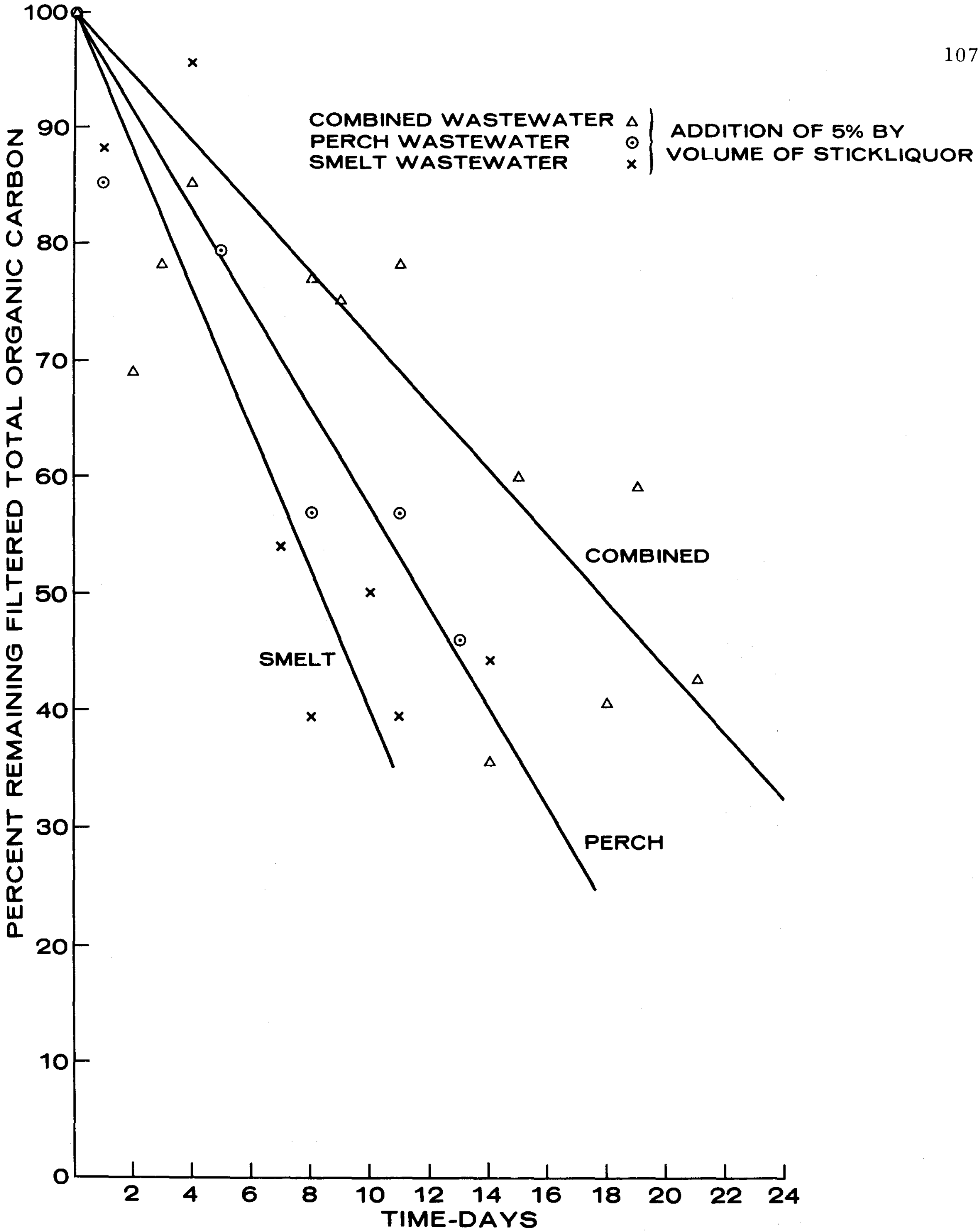


Figure 5.10 Batch Reactor Studies With Stickliquor Addition-Filtered Total Organic Carbon

unfiltered BOD_5 and filtered TOC. The addition of stickliquor did not appear to alter the "order" of the various reactions monitored.

The reaction rates obtained from figures 5.9 and 5.10 are given on table 5.11. The unfiltered BOD_5 reaction rates are decreased slightly by the addition of stickliquor to the waste material. However the filtered total organic carbon reaction rates are markedly decreased by stickliquor addition to the wastewater.

The addition of stickliquor to the perch and smelt wastewater reactors necessitated a period of acclimatization for the micro-organisms. This time for acclimatization was 7 days for the perch and smelt wastewater, however no acclimatization was required on the addition of stickliquor to the combined wastewater.

Table 5.12 lists the residual BOD_5 and total organic carbon in the batch reactors following 20 days of biological degradation--this does not take into account any period of micro-organism acclimatization. It will be noted from figures 5.7 and 5.8 that the unfiltered BOD_5 and the filtered total organic carbon values decrease rapidly until the levels of 10 percent remaining for BOD_5 (150-190 mg/1) and 25 to 30 percent remaining for total organic carbon (40-55 mg/1). These levels are reached within 10 days for unfiltered BOD_5 and 5 days for filtered total organic carbon. Following attainment of these values, the BOD_5 and total organic carbon values are relatively constant. It should be noted from table 5.12 that the residuals of filtered BOD_5 are below 20 mg/1.

Table 5.12: Residuals following Biological Treatment

Biological Treatment: Batch Reactors operated for 20 days

	BOD_5		TOC
	filtered (mg/l)	unfiltered (mg/l)	filtered (mg/l)
Perch Wastewater	10	150	40
Smelt Wastewater	20	150	55
Combined Wastewater	15	190	40
Addition of 5% sticklіquor			
Perch Wastewater	100	500	130
Smelt Wastewater	370	1100	230
Combined Wastewater	1500	3200	340

The addition of stickliquor leads to high residuals, as will be noted from table 5.12. Following the micro-organism acclimatization period the values of unfiltered BOD_5 for perch, smelt and combined wastewater (figure 5.9) decrease linearly to residuals of 10,20 and 60 percent remaining respectively. These percent residuals of unfiltered BOD_5 represent values of 500 mg/l for perch wastewater, 1100 mg/l for smelt wastewater and 3200 mg/l for combined wastewater. In all cases, especially for combined wastewater and stickliquor, it is believed that further biological treatment would reduce the BOD_5 of the wastes to a lower level.

The reduction of filtered total organic carbon in perch, smelt and combined wastewater, with stickliquor addition, is linear, to residual values of 130, 230 and 340 mg/l respectively. These residuals could be further reduced by additional biological treatment beyond the 20 day period.

The batch studies of perch, smelt and combined wastewater indicated 90 percent of BOD_5 and in excess of 65 percent of total organic carbon could be removed during 10 days of aeration. The addition of stickliquor markedly affected the biological system causing a drop in treatment efficiency. It is thought that the batch reactors did not reach a steady state in the 20 days following stickliquor addition.

5.2.1.2. Continuous Reactors

The continuous reactors had detention times of 17 hours, 5, 10 and 15 days. Since the 5, 10 and 15 day detention time, reactors had no sludge recycle, the sludge age equals the detention time. The 17 hour detention time reactor initially had a 3 day sludge age which was subsequently changed to 5 days by varying the amount of sludge recycled from the clarifier to the reactors (figure 5.11).

Figure 5.12 is a plot of average percent removal of unfiltered and filtered BOD_5 against sludge age. It is a combination plot derived from data obtained from each continuous reactor. The figure gives mean percent removal and the standard deviation. Figure 5.12 indicates that a sludge age in excess of 3 days is required for maximum percent removal of BOD_5, both filtered and unfiltered.

Figure 5.12 incorporates data from reactors with a short detention time and sludge recycle and data from long detention time reactors with no sludge recycle. Examination of figure 5.12 indicates that increasing sludge age above 3 days with or without sludge recycle did not markedly effect the percent removal of filtered and unfiltered BOD_5. The removal for filtered BOD_5 was approximately 80 percent for each sludge age tested, whereas the removal dropped to approximately 45 percent for unfiltered BOD_5. Maximum BOD_5 removal could be achieved by either a short detention time reactor (7.5 hours) with sludge recycle and a 3 day sludge age or a larger detention time reactor (5 days) with no sludge recycle.

Filtered total organic carbon was also monitored in the continuous reactors and the results are shown in figure 5.13. Contrary to the situations for BOD_5 removals, increasing the sludge age from 3 days to 10 days increased the percent removal of organic carbon from 60 percent to nearly 80 percent. The introduction of sludge recycle did not significantly

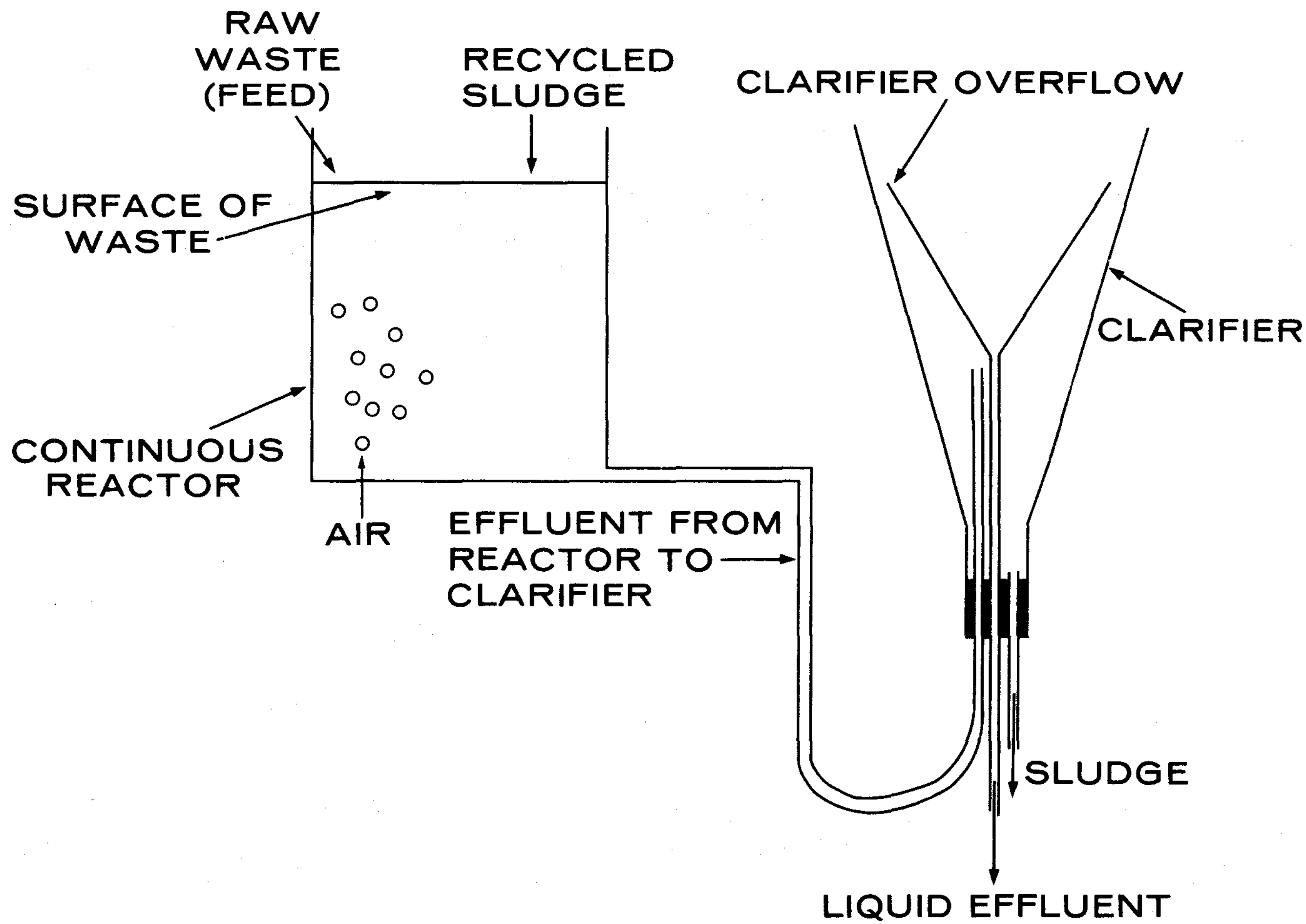


Figure 5.11 Continuous Reactor System

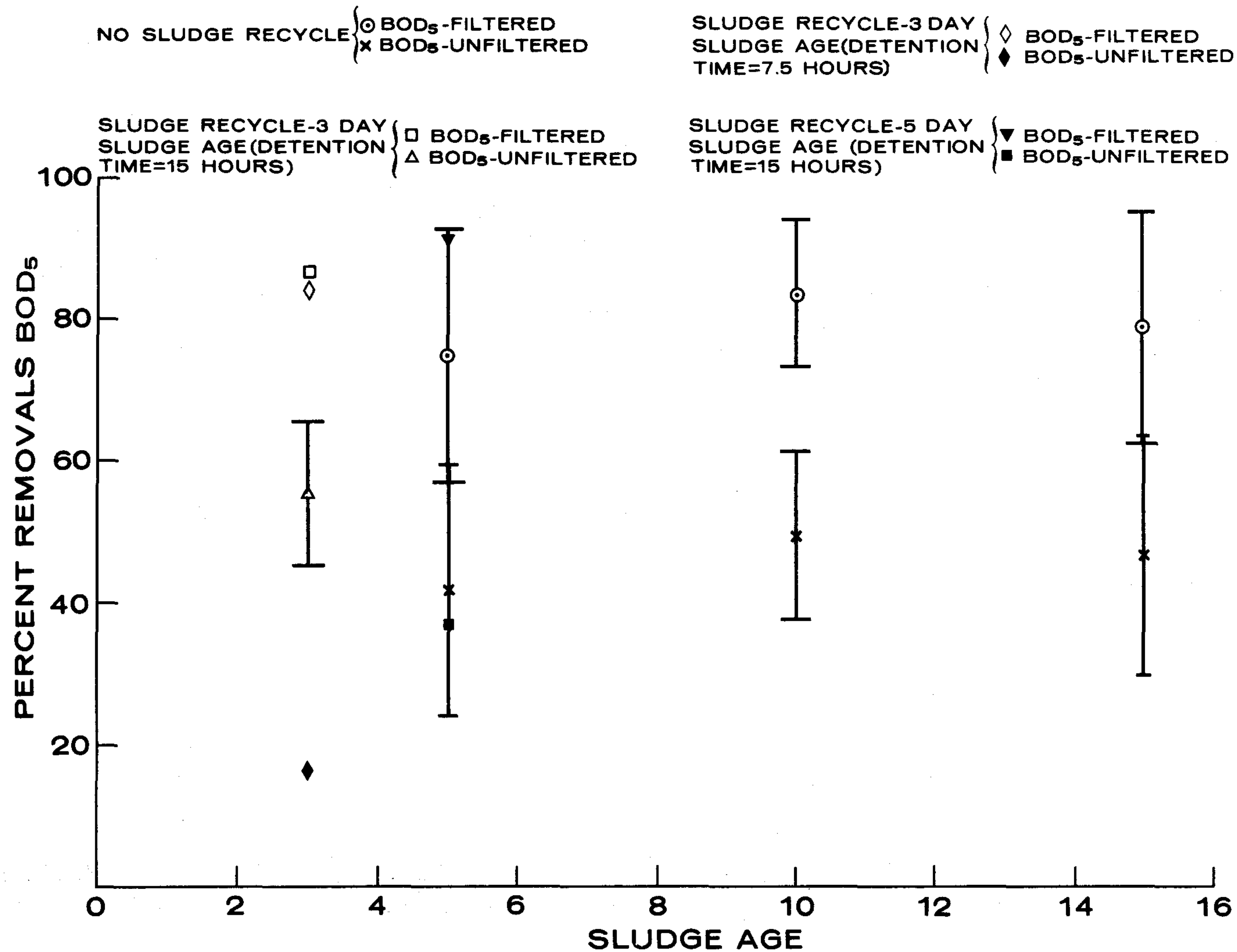


Figure 5.12 Continuous Reactor Studies-BOD_5 (Combined Wastewater)

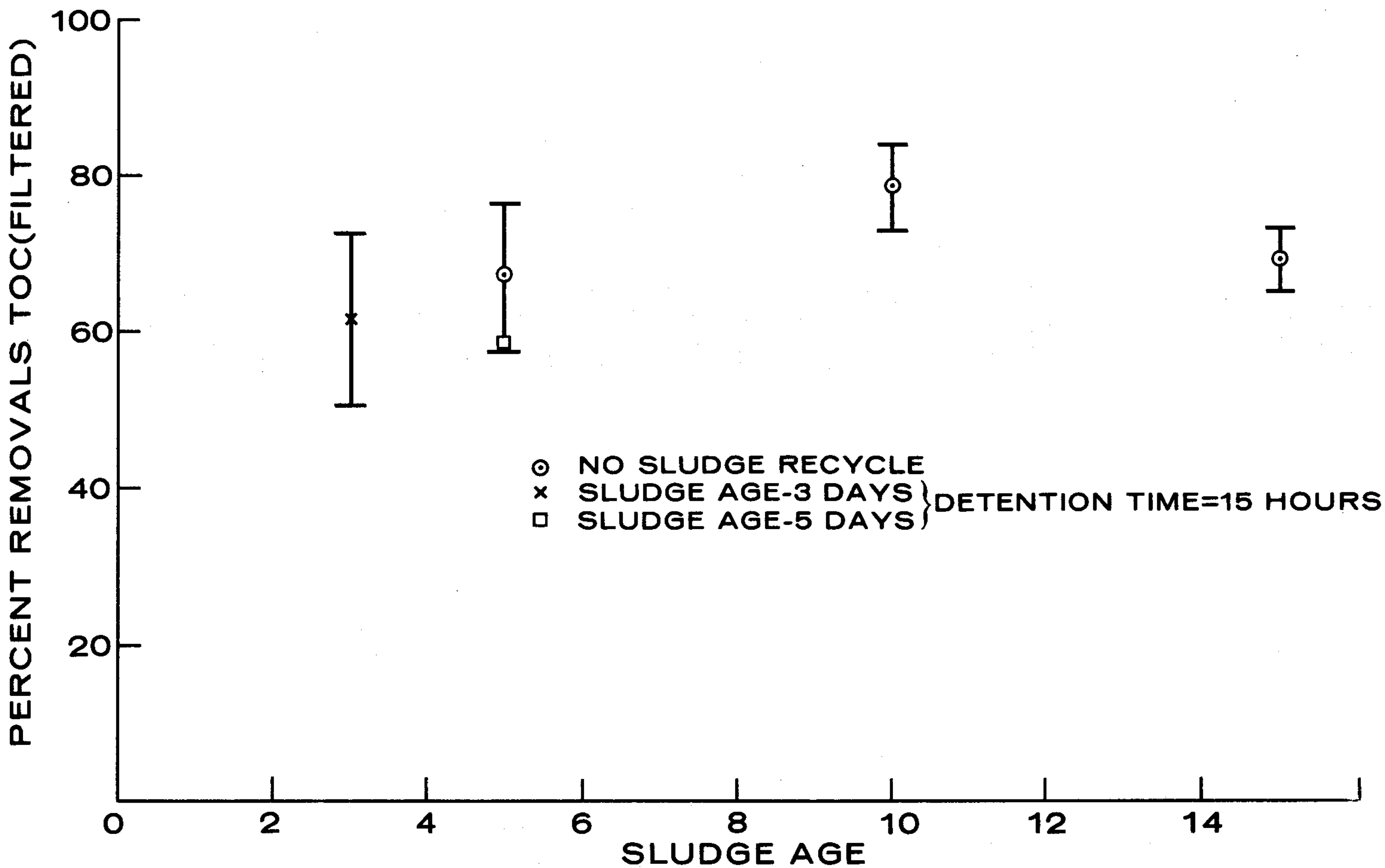


Figure 5.13 Continuous Reactor Studies-Filtered Total Organic Carbon (Combined Wastewater)

affect organic carbon removals.

It was decided to use the reaction rates obtained in the batch study to predict BOD_5 and filtered total organic carbon removals in the continuous reactors. The reaction rates determined from batch studies, and listed in table 5.11 should only be used to predict removals in reactors with the same level of volatile suspended solids as the original batch system. If the concentration of micro-organisms is not at the same level as in the original batch reactor, the reaction rate can be modified using the following relationship:

$$k = \frac{k^1 S_{a_2}}{S_{a_1}}$$

where k^1 = reaction rate determined from original system.

S_{a_1} = concentration of volatile suspended solids in original system.

S_{a_2} = concentration of volatile suspended solids in predictive system.

k = reaction rate in predictive system.

Table 5.13 tests the predicted and actual removals of filtered total organic carbon. It should be noted that 100 percent removal never occurred in the batch studies, - the residuals being 70 percent removal for filtered total organic carbon. Taking this residual into account it

Table 5.13: Prediction of Total Organic Carbon Removals using Reaction Rates obtained from Batch Studies

Detention Time	Predicted Removal Filtered TOC (%)	Actual Removal Filtered TOC (%)
7.5 hours (0.313 days)	10.5	-
15.0 hours (0.625 days)	21.0	60.0
5 days	70.0*	67.0
10 days	70.0*	79.0
15 days	70.0*	69.0

* Maximum removal in batch systems

would appear that the continuous system with a 5 day detention time had removed the majority of the available soluble carbon.

Figure 5.14 is a plot of oxygen utilized in pounds of oxygen per pound of volatile suspended solids against time in minutes. These respiration rate studies were carried out after the 5, 10 and 15 day detention time continuous reactors had reached steady state. Table 5.14 below lists the oxygen uptake rates in pounds of oxygen per pound of volatile suspended solids per day.

Table 5.14: Oxygen Uptake Rates

Detention Time	Oxygen Uptake Rates (lbs. oxygen/lb V.S.S./day)
5	0.432
10	0.302
15	0.288

The values in table 5.14 are comparable to the oxygen uptake rate of 0.4 lbs oxygen/lb V.S.S./ day given by Eckenfelder (1970) for domestic sewage. It should be noted that the oxygen uptake rates for the 10 and 15 day detention time reactors are similar, whereas the rate of the 5 day detention time reactor is somewhat higher. This would indicate a higher rate of organic removal in the 5 day detention time respiration study caused a higher residual organic concentration in the 5 day detention time reactor. This conclusion would indicate that a reactor

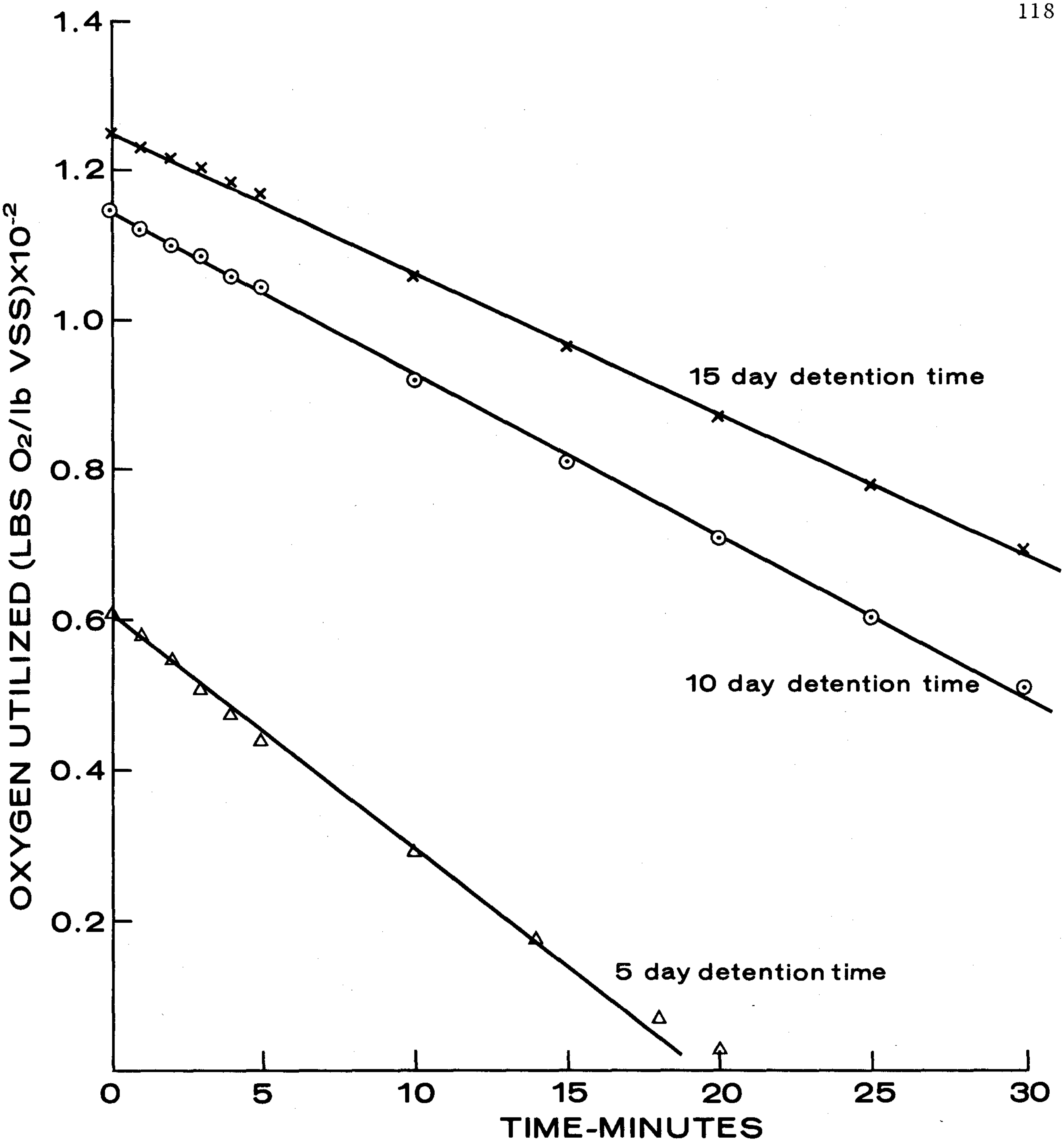


Figure 5.14 Respiration Rates For Continuous Reactors

with a detention time in excess of 5 days is necessary for maximum removal of organic material.

5.2.1.3. Nutrient Removal

Sawyer (1955) stated that the range of BOD_5:Nitrogen for good cell growth was 17:1 to 32:1. Similarly the BOD_5: Phosphorous ratio ranged from 90:1 to 150:1. These ratios, expressed in terms of BOD_5: N:P. ranged from 90:5:1 to 150:5:1. The nutrients in each waste are summarized below in table 5.15.

Table 5.15: Nutrient Ratios in Wastes Characterized

	BOD_5:N:P
Smelt	60:6:1
Perch	100:6:1
Combined	150:7:1
Stickliquor	240:8:1

With the exception of the stickliquor, the wastes have nutrient concentrations of sufficient proportions to allow biological treatment without nutrient addition.

The nutrients were sampled at the beginning and end of each batch study. Table 5.16 lists the removals of BOD_5:N:P, in terms of concentrations (mg/l), in both batch and continuous biological reactors. The batch reactor results are somewhat inconclusive due to a lack of data. However increasing the detention time of continuous reactors from 5 to 15 days resulted in a decrease in BOD_5 removal with respect to

Table 5.16: Nutrient Removals in Batch and Continuous Reactors

Removed BOD_5: N:P in mg/l

	BOD_5	N	P.
Batch Reactors			
Smelt Wastewater	188		1
Perch Wastewater	157	15	1
Combined Wastewater	322	11	1
Addition of 5% Stickliquor			
Smelt Wastewater	350	11	1
Perch Wastewater	29	1	
Combined Wastewater	131		1
Continuous Reactors (Combined Wastewater)			
5 Day Detention Time	183	15	1
10 Day Detention Time	120	17	1
15 Day Detention Time	100	18	1

phosphate removal, but yielded a slight increase in total Kjeldahl nitrogen removal with respect to phosphate removal.

If a 5 day detention time reactor is used for biological treatment of the combined wastewater, the nutrient concentrations in the effluent will be in the order of 140 mg/l for total Kjeldahl nitorgen and 30 mg/l for unfiltered phosphate. Increasing the detention time to 10 days would reduce the effluent concentration of total Kjeldahl nitrogen to about 85 mg/l, while having little effect on the phosphate concentration. A further increase in detention time to 15 days produces an effluent with approximately the same nutrient concentration as from the 10 day detention time reactor.

5.2.2. Physical Treatment

Sedimentation and flotation tests were carried out in a preliminary study of the physical treatability of the wastes. Table 5.17 summarizes the results of these tests. The flotation and sedimentation were carried out on the combined perch and smelt wastewater.

It would appear that, no recycle and an air/solids ratio of between 2.0 and 3.0, about 40 percent of the BOD_5 and about 20 percent of suspended solids can be removed by flotation. The relatively large volumes of flow of wastewater from fish processing plants might lead to problems in total flow pressurization thus a 1/3 recycle system was also examined. It was found that for an air/solids ratio of about 1.0, the BOD_5 removal was approprozimately 35 percent with a suspended

Table 5.17: Physical Treatment - Sedimentation and Flotation.

Flotation (after 15 minutes)	Percent BOD_5	Removal. Suspended Solids
Combined waste (1/3 recycle)		
A/S= 0.81	41.7	-
A/S= 1.10	29.0	26.7.
No recycle		
A/S= 1.92	39.5	28.8
A/S= 3.28	41.1	13.0
Sedimentation (after 60 minutes)		
Combined waste	19.4	8.6

solid removal of about 26 percent. These results would indicate that pressurizing a 1/3 recycle of subnatant to an air/solids ratio of about 1.0 would produce an effluent which could then be treated biologically.

In order to obtain higher removals of BOD_5 and suspended solids from flotation, coagulants would have to be added to the wastewater. Claggett and Wong (1969) have done considerable work in this area. Following this study, work is to be undertaken at the Canada Centre for Inland Waters, Burlington, to examine the effect of various coagulants aids on flotation as a treatment process.

The results of sedimentation tests, on combined wastewater, shown in table 5.17, indicate that an average of approximately 20 percent of BOD_5 and 9 percent of suspended solids were removed following 60 minutes of settling.

Considering the combined wastewater it would appear that sedimentation would not be a particularly efficient treatment process, whereas flotation does show some promise.

5.3 In Plant Work

Omstead Fisheries (1961) Limited have instituted a number of in-plant process modifications, on a trial basis, in an attempt to reduce the strength of the combined wastewater leaving the plant. The Company hopes that these modifications will have a twofold purpose:

1) reduce the contact time between the solid and liquid waste leaving the processing machines, and
2) reduce the suspended solids in the wastewater.

5.3.1. Contact Time

Figures 5.15 and 5.16 are plots of percent increase of BOD_5, COD, and suspended solids against time for smelt and perch wastewater. In the case of smelt wastewater the COD concentrations increase markedly with time, to a value in excess of 170 percent of the initial concentration, after a 2 hour holding period. The suspended solids and BOD_5 concentrations increase by about 50 percent of the initial value after the same holding time.

The increase in BOD_5, COD and suspended solids are not nearly as large for perch wastewater as for the smelt wastewater - the maximum increase, over the 2 hour period, being about 30 percent for COD, 20 percent for BOD_5 and 10 percent for suspended solids. With the exception of the COD of the smelt wastewater, the parameters for both wastewaters have reached their maximum percent increase after a 75 minute holding period. Attempts to remove the solids waste from the liquid waste at the process machine would certainly lower the pollutional strength of the wastewater, especially in the case of the smelt wastewater.

5.3.2. Screening

Omstead Fisheries (1961) Limited have undertaken a thorough study of the effect of 20 mesh tangential screens on suspended solids removal, the results are shown on figures 5.17 and 5.18, log-probability plots of suspended solids in mg/l. Table 5.18 summarizes the results obtained.

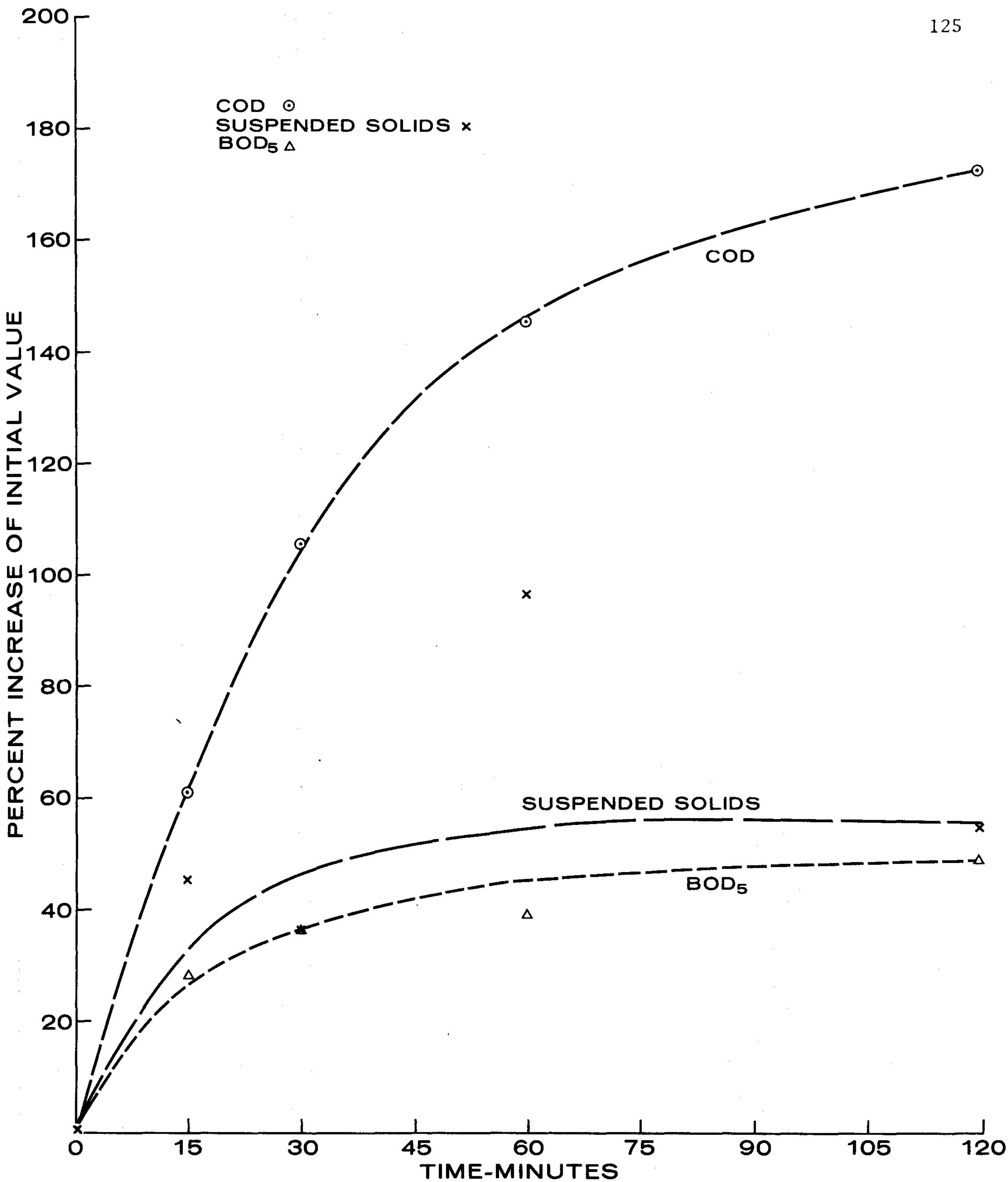


Figure 5.15 Contact Time-Smelt Wastewater

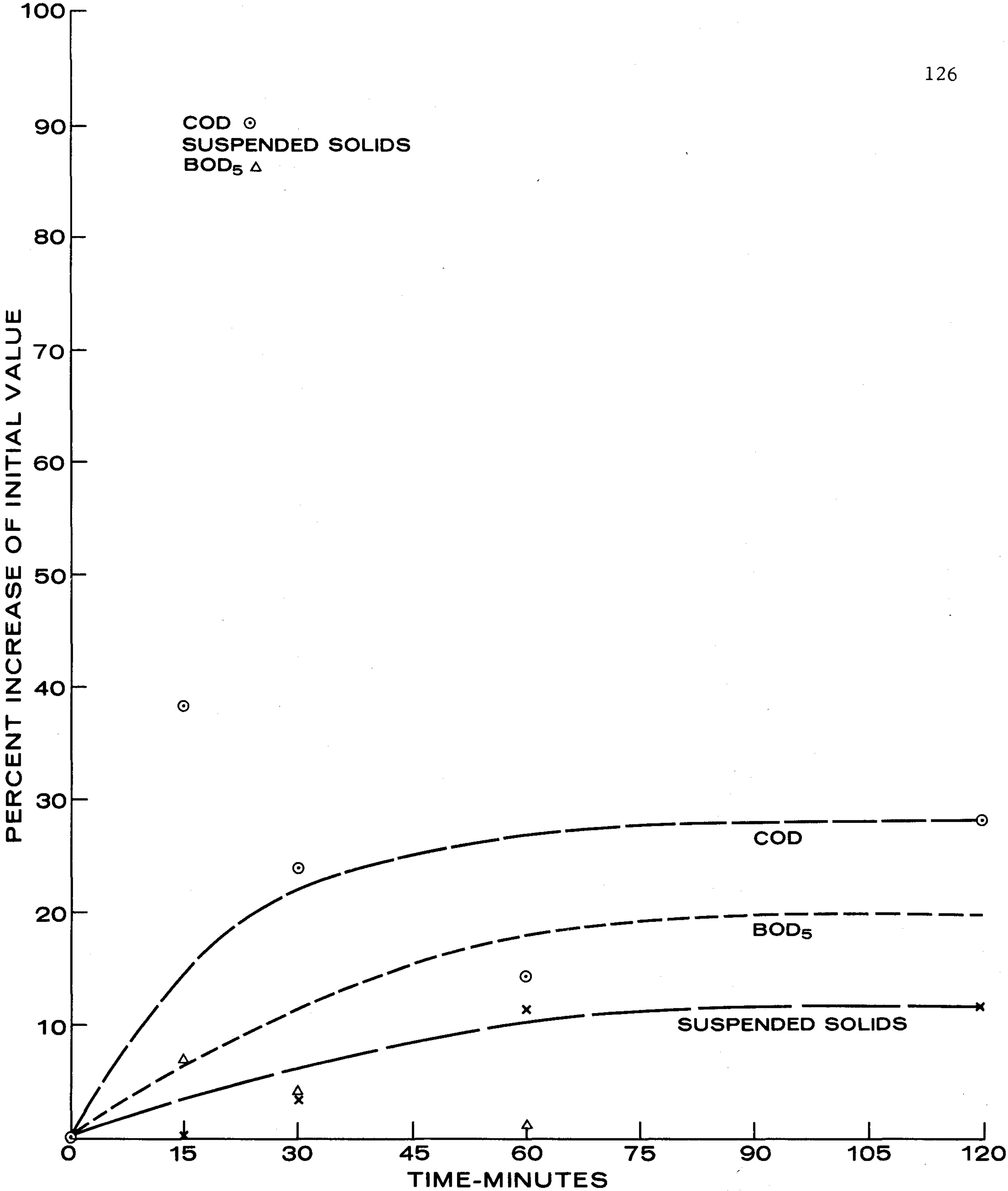


Figure 5.16 Contact Time-Perch Wastewater

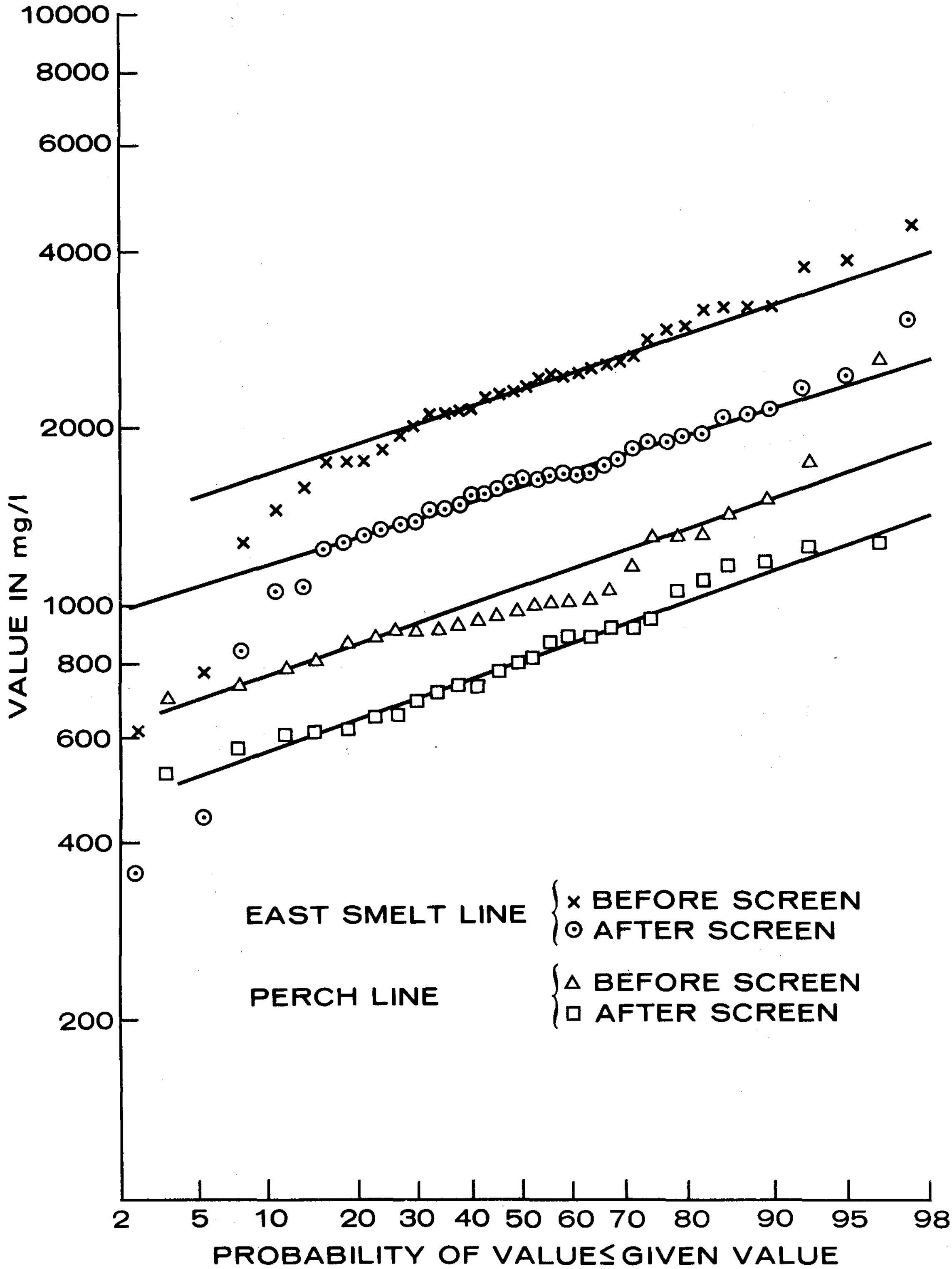


Figure 5.17 In-plant Suspended Solids Probability Plot

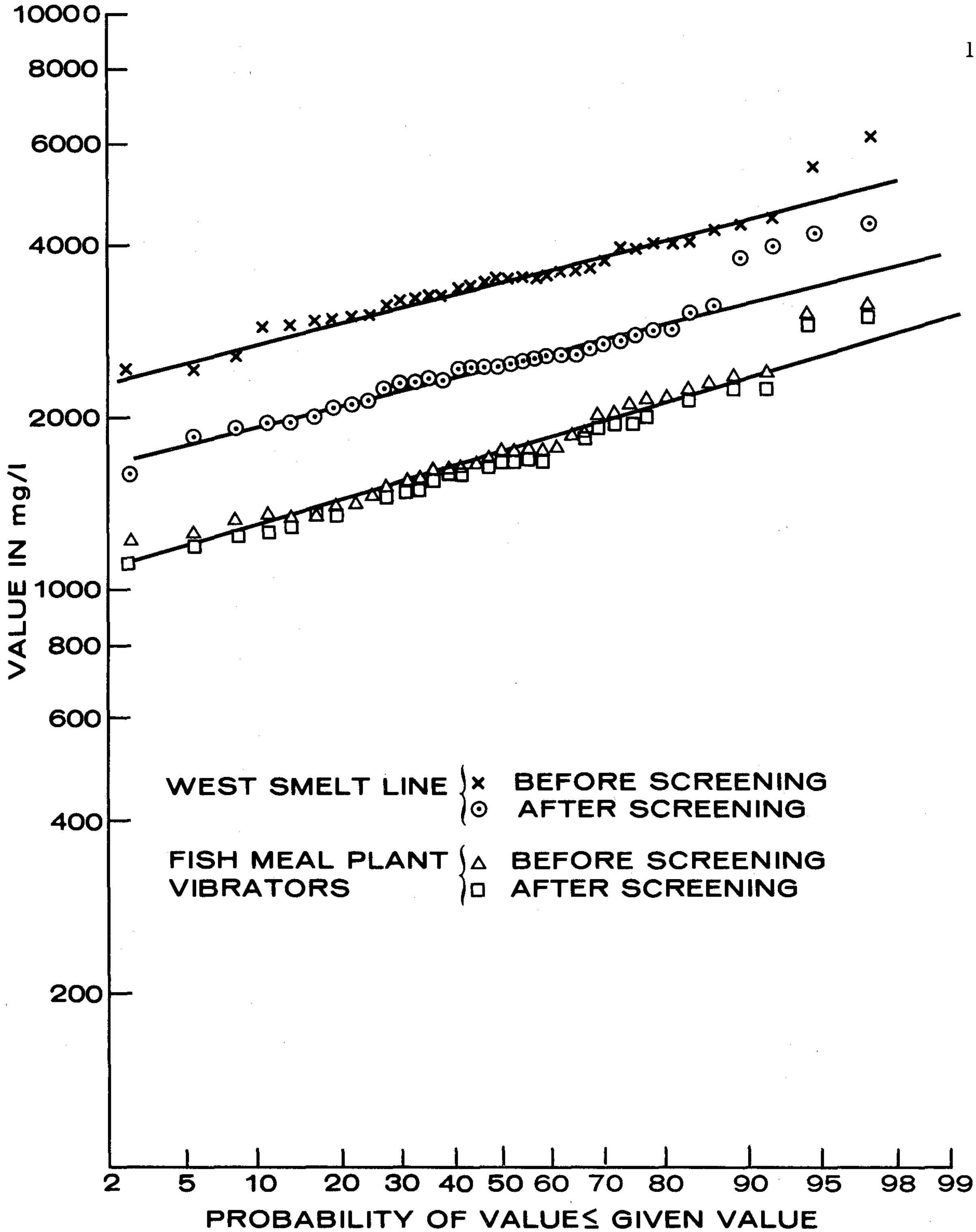


Figure 5.18 In-plant Suspended Solids Probability Plot

Table 5.18: Suspended Solids Removals by 20 Mesh Tangential Screening

Smelt Line	Before Screening (mg/l)	After Screening (mg/l)	Percent Removals
1.	2362 ± 380	1621 ± 261	31.4
2.	3434 ± 483	2473 ± 332	28.0
Perch Line	1107 ± 191	825 ± 156	25.5

Twenty mesh tangential screens will remove about 30 percent of suspended solids from smelt wastewater and about 25 percent from perch wastewater. The remaining suspended solids are made up of fine particles of protein (fish flesh), scales and oil.

The mean values of suspended solids for the two smelt lines indicates that number 2 line, west smelt line, produces a waste with considerably higher suspended solids than the number 1 line, east smelt line. The reason for this is not clear but could be due to the methods of handling the solid and liquid waste from each processing machine to the screens. These suspended solids values are also considerably higher than those found during our own waste characterization study. It should be borne in mind that our samples were taken directly under each machine whereas these samples were taken at the screens, some distance away.

Finally it should be noted from figure 5.18 that the vibrators in the fish meal plant do not remove any additional solids after the wastewater has passed over the tangential screens.

CHAPTER 6

CONCLUSIONS

The wastewater can be characterized as of medium strength with large day to day variations in the major parameters. The combined perch and smelt wastewater, with a BOD_5 of 3044 ± 1413 mg/l, is stronger than either the perch wastewater, with a BOD_5 of 1847 ± 1793 mg/l, or the smelt wastewater, with a BOD_5 of 1152 ± 631 mg/l, possibly due to prolonged contact.

In the case of all three wastewaters no significant statistical relationships could be found between unfiltered BOD_5 and COD. Further expressing the combined wastewater in units of pounds/1000 pounds of fish processed instead of in units of concentration did not account for the day to day variability in the strength of the wastewater.

The large flows and medium strength of the combined wastewater represent a load on the aerated lagoon similar in effect to a low flow of high strength stickliquor. With a BOD_5 of 156,068 ± 90,000 mg/l, the discharge of stickliquor from fish meal plants is not recommended. Stickliquor should be recovered by evaporation or trucked away from land disposal.

The characteristics of the wastes determined from this study are comparable to the characteristics of other fish processing wastewaters. Any variations can be accounted for by:

1) Type of fish processed,

2) Processing techniques,

3) Plant size, and

4) Water usage.

The organic strength and nutrient concentrations in the waste were such as to suggest that biological treatment might be practical Batch studies showed that within 10 days 90 percent of total BOD_5 had been removed, as had approximately 70 percent of the soluble organic carbon. The associated reaction rates were about 10 percent removed / day for BOD_5. The addition of 5 percent by volume of stickliquor to the batch biological systems had a two fold effect:

1) the residual BOD_5 and total organic carbon concentrations, after 20 days of degradation, increased, and
2) the reaction rates decreased for both BOD_5 and total soluble organic carbon.

The continuous reactors, with detention times from 7.5 hours to 15 days, and sludge ages from 3 days to 15 days indicated that maximum treatment of the combined wastewater could be obtained in a reactor with a detention time in excess of 5 days with no sludge recycle or a short detention time (7.5 hours) with sludge recycle. The maximum removal of total BOD_5 was 50 percent and of filtered total organic carbon was 80 percent. Nutrient removals in these reactors were typical of biological systems.

A preliminary analysis of physical treatment of combined wastewater indicated that flotation showed promise, giving a 40 percent removal in BOD_5. Sedimentation, however, only removed 10 percent of BOD_5 after 60 minutes of settling.

It was shown that the pollutional strength of perch and smelt wastewater increased with increased contact time between the solid waste material and the liquid waste. The addition of 20 mesh tangential screens effected a 25 to 30 percent removal of suspended solids in the perch and smelt wastewater. However removal of these solids from the water should be instituted at the earliest possible point after the processing machines.

Water usage in the plant is almost constant, at about 300,000 gallons per day. This observation has been found by other authors in other plants. The use of dry capture techniques for transporting the fish and offal and for fish processing should be encouraged, commensurate with meeting the necessary sanitary requirements.

REFERENCES

1) American Public Health Association, Standard Methods for the Examination of Water and Waste Water, 12 ed. New York, A.P.H.A. Inc., (1965).

2) Beall, D., "Losses in the Effluent of Pilchard Reduction Plants in British Columbia," The Biological Board of Canada, Ottawa, Bulletin No. 35, (1933).

3) Borchardt, J.A. and F. G. Pohland, "Anaerobic Treatment of Alewife Processing Wastes," Journal W.P.C.F., 42, 2060-2068, December, (1970).

4) Brodersen, K.T., "Characterization of Fish Processing Plant Effluents - A Study of the Waste Characteristics of Fish Processing Plants Located in the Maritime Region," Preliminary Report, Department of the Environment, Government of Canada, October, (1971).

5) Buczowska, Z and J. Dabaska, (Characteristics of the Wastes of the Fish Industry). Byul. Inst. Med. Morsk. Gdansk., 7, 204-212, (1956).

6) Busch, A.W., Aerobic Biological Treatment of Waste Waters, Principles and Practice, Oligodynamics Press, Houston, Texas, (1971).

7) Canadian Plant and Process Engineering Limited, "Fish Processing Wastes, A Study of Harbour Pollution Resulting from Fish Processing in Shippegan, Lameque, and Caraquet, New Brunswick," for the New Brunswick Water Authority, February, (1970).

8) Carpenter, G.A., "Submerged Evaporation and its application to Fish Stickwater Recovery," Chemical and Process Engineering, 39: 425-427, December, (1958).

9) Carrick, C.W., "Use of Industrial Wastes in Poultry Feeding," Proceedings 6th Industrial Waste Conference, Purdue University, 130-134, (1951).

10) Chun, M.J. et al., "A Characterization of Tuna Packing Waste," Proceedings 23rd Industrial Waste Conference, Purdue University, 786-805, (1968).

11) Claggett, F.G., "Clarification of Waste Water other than Stickwater from British Columbia Fishing Plants," Fisheries Research Board of Canada, Vancouver, British Columbia, Technical Report No. 14, (1968).

12) Claggett, F. G., and J. Wong, "Salmon Canning Waste-Water Clarification Part I Flotation by Total Flow Pressurization," Vancouver, Fisheries Research Board of Canada, British Columbia, Circular No. 38, January, (1968).

13) Claggett, F.G. and J. Wong, "Salmon Canning Waste-Water Clarification, Part II A Comparison of Various Arrangements for Flotation and some Observations concerning Sedimentation and Herring Pump-Water Clarification," Fisheries Research Board of Canada, Vancouver, British Columbia, Circular No. 42, February, (1969).

14) Claggett, F.G., " A Proposed Demonstration Plant for Treating Fish Processing Plant Wastewater," Fisheries Research Board of Canada, Vancouver, British Columbia, Technical Report, No. 197, (1970).

15) Davis,H.C., "Disposal fo Liquid Waste from Fish Canneries, from the Viewpoint of the Fish-Canning Industry," Sewage Works Journal, 16: 947-948, July, (1944).

16) Davis,R.H. and J. G. P. McKinney, "Herring Pumpwater Waste Reduction: A Fish Meal Factory Effluent," Halifax, Canada Department of Fisheries and Foresty, Inspection Branch, Technical Report No.4, June, (1970).

17) Delaney, J.A. and Associates, "Georgetown Seafoods Limited, Georgetown, Prince Edward Island, Study of Waste Treatment," for Department of Regional Economic Expansion, Ottawa, November, (1970).

18) Delaney, J.A. and Associates, "Georgetown Seafoods Limited, Georgetown, Prince Edward Island, Re-Study of Waste Treatment," for Department of Regional Economic Expansion, Ottawa, August, (1971).

19) Department of Fisheries and Foresty, "Annual Statistical Review of Canadian Fisheries," 2: 1954-1969, Economic Branch,Fisheries Service, Ottawa, (1970).

20) Dreosti, G.M., "Fish Solids from Factory Effluents: Whipping procedure for flotation," Fishing News International, 53-54, November, (1967).

21) Dreosti, G. M. and W. Wesemann, "Cleaning of Sea Water by Flocculation," Fishing Industry Research Institute, University of Cape Town, South Africa, Progress Report No. 40, December, (1958).

22) Dugal, L. C., "Proximate Composition of some Freshwater Fish," Fisheries Research Board of Canada, London, Ontario.

23) Eckenfelder, W.W., Water Quality Engineering For Practicing Engineers, Barnes and Noble, Inc., New York, (1970).

24) Eckenfelder, W.W. and D.L. Ford, Water Pollution Control, Experimental Procedures for Process Design. Jenkins Publishing Co., New York, (1970).

25) Eckenfelder, W.W. and D. J. O'Connor, Biological Waste Treatment, Pergamon Press, New York, (1961).

26) Food Industries, "Recovering by-products from fish waste" p.96, "There's good hard cash in stickwater", 22: 54, February, (1950).

27) Gallagher, F.S., "Fish Meal Fertilizer Wastes," Industrial Wastes, 4, September, (1959).

28) Hart, J. L. et al, "The Extent of the Pollution Caused by Pilchard Reduction Plants in British Columbia," The Biological Board of Canada, Ottawa, Bulletin No. 34.

29) Holas, F.W., "Pollution and the Fish and Seafood Industry, II Progress Report, Wastes," A Report to the National Pollution Control Council "Other Foods" Sub Council, October, (1970).

30) Hopkins, E.S. and J. Einarrsson, "Water Supply and Waste Disposal at a Food Processing Plant," Industrial Water and Wastes, 152-154, September-October, (1961)

31) Hunter, J.V. and H. Heukelekian, "The Composition of Domestic Sewage Fractions," Journal W.P.C.F. 37: 1142-1163, August, (1965).

32) Jensen, C.L., "Industrial Wastes from Seafood Plants in the State of Alaska," Proceeding 20th Indsutrial Waste Conference, Purdue University, 329-350, (1965).

33) Kato, K. and S. Ishikawa, "Recovery of Fish Oil and Protein from Fish Processing Effluent", Proceedings 24th Industrial Waste Conference, Purdue University, 610-619, (1969).

34) Kempe, L.L. et al, "Disposal of Fish Processing Wastes," Department of Chemical and Metallurgical Engineering, College of Engineering, University of Michigan, July, (1968).

35) Knowlton, W.T., "Effects of Industrial Wastes from Fish Canneries on Sewage Treatment Plants," Sewage Works Journal, 17: 514-515, January, (1945).

36) Levenspiel, O., Chemical Reaction Engineering, John Wiley and Sons, Inc., New York, (1967).

37) Limprich, H. (Problems Arising from Waste Waters from the Fish Industry). IWL Forum, 66: 36, (1966).

38) Loehr, R.C. and G.A. Rohlich, "A Wet Method for Grease Analysis, Proceedings 17th Industrial Waste Conference, Purdue University, 215-232, (1962).

39) MacLeod, R.A. et al, "Studies on the Conversion of Fish Stickwater to Solubles," Fisheries Research Board of Canada, Vancouver, British Columbia, January, (1955).

40) Matusky, F.E. et al, "Preliminary Process Design and Treatability Studies of Fish Processing Wastes," Proceedings 20th Industrial Waste Conference, Purdue University, 60-74, (1965).

41) Montreal Engineering Cannery Ltd., "Maritime Provinces Water Resources Study, Stage I, Appendix III Industrial Water

Demands." for Atlantic Development Board, January, (1969).

42) Nunnallee, D. and B. Mar, "A Quantitative Compilation of Industrial and Commercial Wastes in the State of Washington," Washington State Water Pollution Control Commission, Olympia, Washington, (1969).

43) Paessler, A. H. and R. V. Davis, "Waste Water from Menhaden Fish Oil and Meal Processing Plants," Proceedings 11th Industrial Waste Conference, Purdue University, 60-74, (1965).

44) Pigott, G.M. and C. Chung-Ling, "A New Method of Processing Fish Waste, Part I - Evolution of the Process," Paper presented at Pacific Northwest Pollution Control Association, Seattle, Washington, November, (1969).

45) Pigott, G.M.et al, "A New Method of Processing Fish Waste, Part II - Refinement of the Process," Paper presented at the Pacific Northwest Pollution Control Association, Victora, British Columbia, October, (1970).

46) Pigott, G.M., "Fish Waste for Profit - Not Pollution," Proceedings 26th Industrial Waste Conference, Purdue University, May, (1971).

47) Shaffner, J., "The Various Methods of Reducing the Waste Material being Discharged from the Fish Processing Plants in Lameque, Shippegan and Caraquet, New Brunswick," Report submitted to New Brunswick Water Authority, (1970).

48) Shawinigan Engineering Company Ltd. and James F. Maclaren Ltd., "Water Resources Study of the Province of Newfoundland and Labrador," for Atlantic Development Board, Appendices, 8, September, (1968).

49) Soderquist, M.R., "A Survey of Oregon's Food Processing Waste Problems," Paper presented at Pacific Northwest Pollution Control Association Annual Meeting, Seattle, Washington, (1969).

50) Soderquist, M.R. et al., "Seafoods Processing: Pollution Problems and Guidelines for Imporvement," Proceedings of the National Symposium on Food Processing Wastes, Portland, Oregon, 189-225, (1970).

51) Soderquist, M.R. et al., "Current Practice in Seafoods Processing Waste Treatment," Department of Food, Science and Technology, Oregon State University, Corvallis, Oregon. Report prepared for the Environmental Protection Agency, Water Quality Office, Washington, April, (1970).

52) Tonseth, E.I. and H.B. Berridge, "Removal of proteins from industrial waste waters," Effluent and Water Treatment Journal, 8, 124-128, March, (1968).

53) Ventz, D. and G. Zanger, (Contribution to Biological Purification of Effluents from Fish Processing Plants). Fisch Forschung. Wissen. Schriften. 4: 91-97, (1966).

54) Vrabik, E.R., "Fundamental Principles of Dissolved-Air Flotaion of Industrial Wastes," Proceedings 12th Industrial Waste Conference, Purdue University, 745-778, (1957).

APPENDIX I

WASTE CHARACTERIZATION - SMELT WASTEWATER

Date	BOD_5 (mg/1)	BOD_{20} (mg/1)	COD (mg/1)	Filtered TOC (mg/1)	Suspended Solids (mg/1)	Volatile Suspended Solids (mg/1)	Total Solids (mg/1)	Total Volatile Solids (mg/1)	pH	Temperature ^0C
22/7			1328							
30/7	889		1027		308					
3/8			3631		1132					
4/8			3542	450	2430				6.5	19.0
6/8			961	86	430	430			7.0	21.0
9/8	820		1229	44	390	350	1240		7.0	19.0
10/8	1360	1521	2415	128	1340	1210	1440		7.0	17.0
11/8	1170		2564	178	492		1229		7.1	14.5
13/8	725		1529	91	420		983		6.9	13.0
16/8	1404		1942	151	596		1531		7.2	19.5
17/8	1003		3160	222	488		1610		7.2	19.5
18/8	1170		2271	175	392	264	1156		7.2	19.0
20/8	492		737	157	616	364	640	260	7.1	16.0
23/8	397		1107	126	300	276	748	556	7.2	13.0

WASTE CHARACTERIZATION - SMELT WASTEWATER

Date	BOD_5 (mg/l)	BOD_{20} (mg/l)	COD (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)	Total Solids (mg/l)	Total Volatile Solids (mg/l)	pH	Temperature ^0C
24/8	704	1470	1705	252	328	296	1224		7.2	15.0
25/8	760		1270	217	420	416	872	656	7.1	18.0
26/8	2384	1930	4140	398	496	420	2572	1744		
27/8	441		1280	315	240	240	588	340		
30/8	1930		1865	242	620		1616	1332	6.7	18.0
31/8	1830	2030	3200	286	660		1712	1400	6.9	18.0
1/9	1395		4840	388	772	752	1920	1612	7.0	18.0
2/9	1345		2850	194	468		1400	1196	7.4	20.0
3/9	1010			334	756		1844	1156	7.1	22.0
7/9	1290		2282	398	768		1576	1316	7.3	22.0
8/9	867		3180	186	304		1044	824	7.4	22.0
9/9	2200		4250	408	1680	1635	2708	2312	6.9	22.0
10/9	544		620	200	208		928	752	7.4	21.0

WASTE CHARACTERIZATION - SMELT WASTEWATER

Date	BOD_5 (mg/l)	BOD_{20} (mg/l)	COD (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)	Total Solids (mg/l)	Total Volatile Solids (mg/l)	pH	Temperature ^0C
13/9	921		477	60	45		3488		7.4	20.0
14/9	1798		2443	384	453		1376	1016	7.2	21.5
15/9	363			209	345	205	616	428	7.5	21.0
16/9	2180		3120	195	1615		888		7.5	19.0
17/9	236		540	99	100		736	276	7.6	19.0
20/9	2715		2248	200	1120		2304	896	7.5	18.5
21/9	1590	130	1250	262	400	365	1228	884	7.6	19.5
22/9	1870		1600	158	552		852	664	7.4	19.0
23/9	1028	78	760	112	30		656	336	7.4	19.0
24/9	421		160	76	20		320	128	7.9	19.0
7/10	799		539	69	564	540	676	488	7.4	17.0
15/10	457		347	126	445	365	860	608	7.2	16.0
28/10			504		168	140	640	412	6.9	16.2
11/11			280		82	66	520	264	7.3	14.0

WASTE CHARACTERIZATION - PERCH WASTEWATER

Date	BOD_5 (mg/1)	BOD_{20} (mg/1)	COD (mg/1)	Filtered TOC (mg/1)	Suspended Solids (mg/1)	Volatile Suspended Solids (mg/1)	Total Solids (mg/1)	Total Volatile Solids (mg/1)	pH	Temperature ^0C
22/7			2990							
29/7	768								7.1	
3/8	372		3200		1048					
5/8			3100		720				6.8	19.0
6/8			3490	122	1040	980			6.8	20.5
9/8	562		739	114	400	210	1035		7.1	18.5
10/8	292	771	317	37	800	540	1285		7.3	19.0
11/8	1080		1777	85	508		790		7.3	15.0
12/8	1095		2376	130	584		1586		7.0	16.0
13/8	795		864	74	332	320	721		7.1	15.0
16/8	702		1516	258	448		855		7.3	20.0
17/8	1500		3760	228	944	904	1904		7.2	20.5
18/8	1120		3685	244	792	768	1316		7.2	21.0
19/8	1117		3332	290	932		2253		7.1	21.0

WASTE CHARACTERIZATION - PERCH WASTEWATER

Date	BOD_5 (mg/1)	BOD_{20} (mg/1)	COD (mg/1)	Filtered TOC (mg/1)	Suspended Solids (mg/1)	Volatile Suspended Solids (mg/1)	Total Solids (mg/1)	Total Volatile Solids (mg/1)	pH	Temperature ^0C
20/8	913		2187	252	624		1308	856	7.1	17.0
23/8	608		1713	175	544	544	1504	1280	7.3	14.0
24/8	1309	1540	2650	262	796		1668	1300	7.2	16.0
25/8	1922		6050	280	1064	1044	1956	1656		18.5
26/8	1150	1140	2335	316	848	696	1416	1028		18.0
27/8	4660		6600	286	2230		2800	2556		18.0
30/8	1147		8920	336	870		2152	1888	6.8	18.0
31/8	1009	1150	4160	330	510		1356	1132	7.0	19.0
1/9	1480		3530	270	310		1040	896	6.8	18.0
2/9	2640		7240	550	1720		3596	2800	7.1	20.0
3/9	1010			398	690		1384	1088	7.1	21.5
7/9	4820		2998	553	1620	1540	2712	2220	7.1	22.0
8/9	1100		2137	448	735	720	1628	1004	7.3	22.0

WASTE CHARACTERIZATION - PERCH WASTEWATER

Date	BOD_5 (mg/l)	BOD_{20} (mg/l)	COD (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)	Total Solids (mg/l)	Total Volatile Solids (mg/l)	pH	Temperature ^0C
9/9	1770		2075	298	640		1428	1096	7.0	21.0
10/9	855		2420	298	720		1522	1260	7.1	22.0
13/9	1760		2220	390	1320		1200	976	7.4	21.0
14/9	880		1300	136	363	260	884	596	7.0	21.0
15/9	783			367	535	305	1172	864	7.3	21.0
16/9	1950		14650	576	1280	1280	1412		6.6	20.0
17/9	936		1600	297	655	650	1800	1208	7.4	20.0
20/9	4920		2085	335	588		2368	1072	7.3	18.5
21/9	8900	336	11700	506	2940	2895	4156	3640	6.1	21.0
22/9	1590		1700	438	836	816	1840	1424	6.9	19.0
23/9	5040	245	3400	290	995		3120	2424	7.2	20.0
24/9	1075		799	186	390		1364	1124	7.7	19.0
7/10	4950		4111	156	4070	3960	4808	4396	6.9	17.0

WASTE CHARACTERIZATION - PERCH WASTEWATER

Date	BOD_5 (mg/l)	BOD_{20} (mg/l)	COD (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)	Total Solids (mg/l)	Total Volatile Solids (mg/l)	pH	Temperature ^0C
15/10	1588		1310	396	915	840	1808	1484	6.7	16.2
28/10			1048		460		936	824	7.3	15.4
11/11			600		300	250	808	544	7.1	14.0

WASTE CHARACTERIZATION - COMBINED WASTEWATER

Date	BOD_5 (mg/l)	BOD_{20} (mg/l)	COD (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)	Total Solids (mg/l)	Total Volatile Solids (mg/l)	pH	Temperature ^0C
22/7			2832							
28/7					1760	1160				
29/7		1302							6.9	
30/7					1688					
3/8	909		5450		1800	1148				
4/8	3159	3980	7970	486	2380				6.5	26.0
5/8	1566	1730	2660		780				7.0	25.0
6/8	7025		3892	194	1490	1460			7.0	25.0
9/8	2220		3779	390	2430	2190	6776		6.9	26.0
10/8	3860	5850	8620	520	2310	2180	4402		7.2	22.0
11/8	2340		4468	312	1428	1412	2250		7.2	18.0
12/8	1215		2313	189	700		1279		7.0	22.0
13/8	3740		5330	363	1276	1256	2444		7.2	19.0
16/8	2460		4895	316	2432	2084	4220		6.1	20.0
17/8	2930		7920	357	1740		3334		6.8	22.0

WASTE CHARACTERIZATION - COMBINED WASTEWATER

Date	BOD_5 (mg/l)	BOD_{20} (mg/l)	COD (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)	Total Solids (mg/l)	Total Volatile Solids (mg/l)	pH	Temperature ^0C
18/8	2574		3989	290	904	892	1772		7.0	28.0
19/8	795		1929	166	520	520	1143		7.2	28.0
20/8	1827		3412	270	636	620	1816	1368	6.9	18.0
23/8	3510			380	2220	2210	3408	3100	7.2	15.0
24/8	1667	7050	4251	270	1150		2040	1824	7.3	19.0
25/8	4220		5640	428	1070		2996	2892	6.9	32.0
26/8	2578	4340	4680	278			2248	1876	6.7	32.0
27/8	2530		3950	248			1652	1380		
30/8	3850		6860	462	880		3276	2916	6.8	32.0
31/8	3940	4260	5940	366	470		2832	2592	6.8	29.0
1/9	3050		5240	278	280		2532	2204	6.8	32.0
2/9	2840		6490	396	1250		3420	3052	7.1	32.0
3/9	2980			398	870		3106	2672	6.9	34.0

WASTE CHARACTERIZATION - COMBINED WASTEWATER

Date	BOD_5 (mg/l)	BOD_{20} (mg/l)	COD (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)	Total Solids (mg/l)	Total Volatile Solids (mg/l)	pH	Temperature ^0C
7/9	4600		5660	582	1280		3588	3056	6.9	28.0
8/9	3100		5310	418	2810	2710	3816	3344	6.9	29.0
9/9	4010		9050	477	2390	2300	3412	2988	7.2	25.0
10/9	2760		6790	360	1635	1560	3208	2544	7.1	24.0
13/9	2760		7500	290	1900		3568	2656	6.6	22.0
14/9	2750		6190	210	2370		3400	2692	6.6	22.5
15/9	5000			519	1850	1450	4580	3864	6.8	25.0
16/9	1570		2980	418	695	635	504	404	6.2	21.0
17/9	2840		6240	420	2010		2908	2328	6.9	23.0
20/9	7960		7250	648	2420	2228	14984	12388	6.4	19.0
21/9	3390	182	2690	427	195		1900	1532	5.7	18.5
22/9	3040		4720	496	510		1264	972	6.5	23.0
23/9	2690	227	2560	280	505		1244	728	7.0	22.0

WASTE CHARACTERIZATION - COMBINED WASTEWATER

Date	BOD_5 (mg/l)	BOD_{20} (mg/l)	COD (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)	Total Solids (mg/l)	Total Volatile Solids (mg/l)	pH	Temperature ^0C
24/9	3680		3196	279	1070		2264	1892	7.3	31.0
7/10	1880		1660	175	950	540	1088	708	6.8	19.0
15/10	1980		1040	226	840	790	1844	1432	7.0	20.0
28/10			3190		170		844	528	6.5	20.0
11/11			879		350	283	980	692	7.2	16.9

WASTE CHARACTERIZATION - STICKLIQUOR

Date	BOD_5 (mg/l)	BOD_{20} (mg/l)	COD (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)	Total Solids (mg/l)	Total Volatile Solids (mg/l)	pH	Temperature ^0C
3/8			98950						6.4	82.0
4/8			155900							
6/8	70200		85600	6350	42000				6.6	82.0
9/8			174050	6100	90800		107588		6.7	80.0
1/9	342000									
8/9	294000		332000	40400			112320	90872	6.8	72.0
10/9			126600	16500			67890	60000	6.9	67.0
14/9	175000		252000	42500			97600	83310	6.9	61.5
15/9	147000			18500			112080	100100	6.8	82.0
21/9	141000	243000	373000	17250			121820		6.2	79.0
22/9	118000		160000	17250			45280	40320	6.6	81.0
23/9	150500	99520	25600	14500			112230	101890	6.6	64.0
24/9	155200		192000	22000			124390	115360	7.2	68.0

WASTE CHARACTERIZATION - STICKLIQUOR

Date	BOD_5 (mg/l)	BOD_{20} (mg/l)	COD (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)	Total Solids (mg/l)	Total Volatile Solids (mg/l)	pH	Temperature ^0C
7/10	41100		70300	1500			10860	89120	8.3	68.0
15/10	82950		30800	4050			67330	61910	6.9	65.0
28/10			165600				98070	91350	6.7	74.5
11/11			99100				60700	58860	6.9	67.0

NUTRIENT CHARACTERISTICS

SMELT WASTEWATER

Date	Nitrite (mg/l)	Nitrate (mg/l)	Phosphate Unfiltered (mg/l)	Phosphate Filtered (mg/l)	Total Kjeldahl Nitrogen (mg/l)
4/8	0.015	0.314	33.5	29.5	151.2
10/8	0.009	0.260	23.7	21.8	110.6
17/8	0.006	0.395	19.9	16.9	115.0
24/8			21.0	17.9	190.0
26/8			21.0	18.4	115.0
31/8			25.1	17.5	
2/9			16.5	15.0	71.4
7/9			18.0	12.5	79.8
9/9			28.5	26.5	168.0
14/9			19.5	14.0	
21/9					74.2
24/9			9.0	11.0	
7/10		0.23	7.5	7.5	365.0
15/10		0.23	23.5	13.3	74.0

NUTRIENT CHARACTERISTICS

PERCH WASTEWATER

Date	Nitrite (mg/l)	Nitrate (mg/l)	Phosphate Unfiltered (mg/l)	Phosphate Filtered (mg/l)	Total Kjeldahl Nitrogen (mg/l)
29/7	0.040	0.840	21.5	18.7	
10/8	0.012	0.235	7.2	3.4	42.0
12/8	0.051	0.620	16.7	12.5	105.0
17/8	0.012	0.305	13.9	13.5	110.6
19/8			17.5	11.0	102.2
24/8			41.0	14.0	89.6
26/8			17.0	12.7	92.4
31/8			14.5	11.0	
2/9			25.5	22.0	245.0
7/9			37.5		224.0
9/9			18.0	13.5	108.0
14/9			11.5	8.5	65.8
21/9					162.4
24/9		0.120	41.5	8.0	
7/10		0.120	15.0	12.5	103.6
15/10		0.400	33.8	20.8	150.6

NUTRIENT CHARACTERISTICS

COMBINED WASTEWATER

Date	Nitrite (mg/l)	Nitrate (mg/l)	Phosphate Unfiltered (mg/l)	Phosphate Filtered (mg/l)	Total Kjeldahl Nitrogen (mg/l)
29/7	0.034	0.58	15.5	10.4	
4/8	0.025	0.508	32.0	26.0	
10/8	0.051	2.100	44.0	27.1	207.2
12/8			10.5	9.5	68.6
17/8	0.014	1.04	22.1	20.9	152.6
19/8			7.0	23.5	65.8
24/8			12.4	14.0	92.4
26/8			16.0		127.0
31/8			24.5	24.2	
2/9			19.5	22.5	173.0
7/9			29.5	20.5	186.0
8/9					171.0
9/9			23.0	12.5	
14/9			24.5	15.5	151.2
21/9					96.6
24/9			45.0	5.0	
7/10		0.19	9.0	4.0	89.6
15/10		0.19	25.0	14.9	121.0

NUTRIENT CHARACTERISTICS

STICKLIQUOR

Date	Nitrite (mg/l)	Nitrate (mg/l)	Phosphate Unfiltered (mg/l)	Phosphate Filtered (mg/l)	Total Kjeldahl Nitrogen (mg/l)
3/8			655		
4/8					7980
7/9		42.5	884		7740
14/9		7.5	893		5670
20/9		6.3	581		
7/10		2.5	217		929
15/10		3.8	544		5250

OIL AND GREASE CHARACTERISTICS

Date	Smelt (mg/l)	Perch (mg/l)	Combined (mg/l)	Stickliquor (mg/l)
18/10	40.0	30.0	70.0	
20/10	40.0	20.0	80.0	1500.0
25/10	30.0	40.0	70.0	
27/10			30.0	
3/11		20.0	20.0	
5/11			10.0	
10/11	40.0	10.0	40.0	920.0

APPENDIX 2

LINEAR REGRESSION

The correlation coefficient, r, is the most commonly used statistical parameter for measuring the degree of association of two linearly dependent variables. It is defined as:

$$r = \frac{\sum x_1 y_1 - N\bar{x}\bar{y}}{S_x S_y}$$

where S_x and S_y are the standard deviations of x_1 and y_1, and $\bar{x}$ and $\bar{y}$ are the mean values.

The coefficient of determination, r^2, is a measure of the degree to which the variance or square of the standard deviation, S_y^2 and S_x^2, is explained or accounted for by the linear regression. In other words, it is a measure of the difference between the variance of the observed (actual) values y_1 and the variance of the values determined for given values of x_1 by the use of the linear-regression line. The greater the value of r^2, the smaller is the difference.

The results obtained from linear regression are summarized in the table below. It should be noted that the values of the correlation coefficient, r, vary from 0.41 to 0.87. These values indicate that while there is not a strictly functional relationship between the x and y parameters (variables), there is a trend.

RESULTS OF LINEAR REGRESSION ANALYSIS

Waste	Number of Samples	Parameter (mg/l) y	Parameter (mg/l) x	Correlation Coefficient, r	Coefficient of Determination, r^2	Remark
Smelt	31	BOD_5	COD	0.63	0.40	No correlation
Smelt	33	Total Solids	Suspended Solids	0.73	0.53	No correlation
Smelt	9	Filtered TOC	Total Volatile Solids - Volatile Suspended Solids	0.72	0.52	No correlation
Perch	33	BOD_5	COD	0.49	0.24	No correlation
Perch	37	Total Solids	Suspended Solids	0.87	0.76	No correlation
Perch	12	Filtered TOC	Total Volatile Solids - Volatile Suspended Solids	0.32	0.10	No correlation
Combined	35	BOD_5	COD	0.41	0.17	No correlation
Combined	35	Total Solids	Suspended Solids	0.60	0.36	No correlation
Combined	9	Filtered TOC	Total Volatile Solids- Volatile Suspended Solids	o.74	0.55	No correlation

APPENDIX 3

ANALYSIS OF VARIANCE

A summary of the procedure is given below:

Source of Variance	Degree of Freedom	Sum of Squares	Mean Square
Among Groups	(k-1)	$S.S.B = \frac{1}{n}\sum_{i=1}^{k}\left[\sum_{j=1}^{n}X_{ij}\right]^2 - \frac{1}{kn}\left[\sum_{i=1}^{k}\sum_{j=1}^{n}X_{ij}\right]^2$	$A = \frac{S.S.B.}{(k-1)}$
Within Groups	k(n-1)	$S.S.E. = \sum_{i=1}^{k}\sum_{j=1}^{n}X_{ij}^2 - \frac{1}{n}\sum_{i=1}^{k}\left[\sum_{j=1}^{n}X_{ij}\right]^2$	$B = \frac{S.S.E.}{k(n-1)}$
Total	kn-1	S.S.T. = S.S.E. + S.S.B.	

$$F = A/B$$

Following determination of the statistic F, tables of values of F for given degrees of freedom are consulted. In all cases the value of F determined was well below the value given in the table, this indicates that there was statistically no difference between the two sets of observations tested.

The analysis of variance test was used to determine if there was any statistical difference between the perch and smelt wastewaters. Tests were made on the following parameters:

1) BOD_5
2) COD

3) Filtered total organic carbon

4) Suspended solids

5) Total solids

6) Total volatile solids

The results are given in the table below:

Parameter	Degrees of Freedom	Values of F
BOD_5	51	0.98
COD	59	0.92
Filtered Total organic Carbon	65	1.43
Suspended solids	51	0.67
Total solids	47	0.77
Total volatile solids	27	0.64

Because the values of the statistic F are below the values given in the table, for the degrees of freedom given, it can be concluded that there is no difference between the perch and smelt wastewaters as far as the parameter tested are concerned.

An analysis of variance was also performed on two sets of observations taken from BOD_5 values determined for the combined wastewater. Since two groups of technicians carried out the analysis it was decided to check to ensure that any inherent differences in analysis technique did not lead to errors in the result. The test was carried out to determine if both sets of values were drawn from the same parent population - a situation which would arise if no differences existed in the techniques used by each group of technicians. The value of the statistic F was 0.78 with 27 degrees of freedom. This indicates that all the BOD_5 values for the combined wastewater were drawn from the same parent population. Further the results obtained by each group of technicians are comparable.

STUDENT 'T' TEST

If it is desired to test the hypothesis that a sample whose mean value is $\bar{x}$ could have come from a population whose mean value is $\bar{X}$ and whose standard deviation is y, we calculate the ratio:

$$t = \frac{\text{Error in Mean}}{\text{Standard Error of Mean}} = \frac{(\bar{X} - \bar{x})}{\frac{y}{n^{1/2}}} = \frac{(\bar{X} - \bar{x})\, n^{1/2}}{y}$$

which is called Student's 't'.

In using this test we often assume that the sample variances are sufficiently alike to warrant assuming that they are independent estimates of the same population variance. This being the case, before carrying out the Student's 't' test to investigate the difference between the sample means we should do a prior test - the significance of the difference between sample variance is tested using Snedecor's F test.

An F test has already been completed, the results indicate no significant difference between the sample variances of perch and smelt wastewater. The results of the 't' tests between perch and smelt wastewater are given in the table below. The Null Hypothesis is that there is no difference between the sample means.

Parameter	Degrees of Freedom	Value of 't'	Remarks
BOD_5	72	2.17	2% level significant
COD	79	2.76	1% level significant
Filtered total organic carbon	60	1.99	5% level significant
Suspended solids	75	2.29	2% level significant

The values of 't' indicate that there is no significant difference between the two sample means.

APPENDIX 4

BATCH REACTOR - SMELT WASTEWATER

Date	Time	pH	Temperature °C	BOD_5 (mg/l) Filtered	BOD_5 (mg/l) Unfiltered	COD (mg/l) Filtered	COD (mg/l) Unfiltered	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
0	14.35	7.1	19.0	680	1920	840	5836	212	890	
1	10.00	7.1	16.5	218	1650	370	4190	117	1830	1650
2	10.00	7.2	19.5	168	2380	262	3639	116	1480	
3	13.40	7.3	24.0	187		236	3577	127	1520	1500
4	13.10	7.0	24.5	86.6		134	2925	85	1540	1090
7	13.30	7.3	19.0	91.0	550	348	1798	153	940	
8	13.30	7.5	24.0	39.8	505	401	1594	157	940	660
9	13.30	7.6	24.0	30.4	363	340	1295	82	1130	
10	13.30	7.8	22.0	70.0	386	325	1110	63	770	700
11	13.30		24.0	69.0	171	494	1055	70	680	670
14	13.30		21.0	68	194	400	1183	56	900	830
16	13.30	8.4	20.0	33	167	756	962	50	740	

BATCH REACTOR - SMELT WASTEWATER

Date	Time	pH	Temperature °C	BOD_5 Filtered (mg/l)	BOD_5 Unfiltered (mg/l)	COD Filtered (mg/l)	COD Unfiltered (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
17	9.00	8.1	21.0	17	123	146	991	62	730	
21	13.00	7.1	23.5		218	173	573	53	400	

15 Litres Smelt Wastewater and 2 Litres Lagoon Liquor (Seed)

Air Supply = 3,500 c.c./min.

Day	Phosphate Filtered (mg/l)	Phosphate Unfiltered (mg/l)	Total Kjeldahl Nitrogen (mg/l)
0	16.69	19.74	
16	39.05	47.85	
21			54.6

BATCH REACTOR - PERCH WASTEWATER

Date	Time	pH	Temperature °C	BOD_5 Filtered (mg/l)	BOD_5 Unfiltered (mg/l)	COD Filtered (mg/l)	COD Unfiltered (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
0	10:45	6.7	19.0	750	1965	839	2939	264	400	
1	10:00	6.9	16.5	492	1920	243	1975	69	760	700
4	14:00	7.3	25.5	66	504	271	1177	66	520	
5	11:30	7.8	20.0	25	374	135	1675	63	550	300
6	14:30	7.0	22.0	52	304	166	988	58	910	
7	10:30	8.0	14.5	26	246	188	911	50	320	
8	9:30	8.2	18.0	23	270	142	992	44	170	
11	10:20	8.0	17.0	27	131	233	722	41	1050	
12	14:30	8.0	21.0	13	75	520	800	70	790	740
13	13:10	8.1	20.0	18	206	1123	747	77	2360	2010
14	13:10	8.1	21.0	25.7	292	173	716	61	720	710

BATCH REACTOR - PERCH WASTEWATER

Date	Time	pH	Temperature °C	BOD_5 (mg/l) Filtered	BOD_5 (mg/l) Unfiltered	COD (mg/l) Filtered	COD (mg/l) Unfiltered	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
15	13:15	7.9	25.0	21.9	173	182	751	59	490	330
18	13:15	6.0	19.0	10.5	146	190	743	40	380	
19	13:30	6.0	23.5	8.6	162	228	779	45	670	
20	13:30	5.9	24.0	9.2	154	140.	848	41	850	760

15 Litres of Perch Wastewater and 2 Litres of Lagoon Liquor (Seed)

Air Supply = 3,500 c.c./min.

Day	Phosphate (mg/l) Filtered	Phosphate (mg/l) Unfiltered	Total Kjeldahl Nitrogen (mg/l)
0	18.5	24.0	214.2
20	17.00	22.3	68.6

BATCH REACTOR - COMBINED WASTEWATER

Date	Time	pH	Temperature °C	BOD_5 Filtered (mg/l)	BOD_5 Unfiltered (mg/l)	COD Filtered (mg/l)	COD Unfiltered (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
0	11:00	7.3	22.5	304	1360		2528	140	1660	1290
1	14:25	7.0	19.0	98	1030	157	1913	40		
2	9:30	7.3	18.0	114	1050	131	2156	37	890	
5	10:20	7.2	17.0	50	444	109	1311	39	1650	
6	14:30	6.8	21.0	24	374	405	1376	53	530	
7	13:10	7.3	19.5	13	351	159	1179	41	790	480
8	13:45	7.5	24.0	33.6	281	213	1375	68	520	470
9	13:10	7.7	24.0	8.8	141	237	790	43	740	410
12	13:30	8.1	19.0	6.4	91.8	198	830	39	770	
13	13:30	8.1	23.0	9.4	117.0	165	745	37	380	
14	13:00	8.2	24.0	6.9		164	734	35	760	650
15	13:00	8.0	22.0	6.9		151	632	41	450	190

BATCH REACTOR - COMBINED WASTEWATER

Date	Time	pH	Temperature °C	BOD_5 Filtered (mg/l)	BOD_5 Unfiltered (mg/l)	COD Filtered (mg/l)	COD Unfiltered (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
16	13:00	8.1	24.0	81	209	359	670	42	530	
19	13:00		21.0		212	280	866	41	530	
21	13:00	7.6	20.0	16.4	193	492	837	39	620	590

15 Litres of Combined Wastewater and 2 Litres of Lagoon Liquor (Seed)

Air Supply = 3,500 c.c./min.

Day	Phosphate Filtered (mg/l)	Phosphate Unfiltered (mg/l)	Total Kjeldahl Nitrogen (mg/l)
0	6.9	7.8	68.6
21	8.6	11.6	71.4

BATCH REACTOR - SMELT WASTEWATER AND STICKLIQUOR

Date	Time	pH	Temperature °C	BOD_5 Filtered (mg/l)	BOD_5 Unfiltered (mg/l)	COD Filtered (mg/l)	COD Unfiltered (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
0	16:25	6.9	21.0	1530	4730	2750	10,900	528		
1	9:30	7.2	21.0	885	5060	1705	8260	498		
2	9:00	6.9	21.0	1370	5050	1561	7730	544	2180	2100
6	13:00	6.9	24.0	1520	3930	635	3130	486	1750	1750
7	11:45	6.7	23.5	1160	3480	1720	6000	582	1850	1840
9	11:00	7.2	21.0	1350	2380	2025	5250	525	2110	
12	13:00	7.7	18.5	1070	2540	1935	6500	296	1700	
13	13:30	7.8	19.0	640	2130	1345	5650	216	1720	
15	14:45	7.7	17.0	325	2900	680	4080	275	2660	2000

BATCH REACTOR - SMELT WASTEWATER AND STICKLIQUOR

Date	Time	pH	Temperature °C	BOD_5 Filtered (mg/l)	BOD_5 Unfiltered (mg/l)	COD Filtered (mg/l)	COD Unfiltered (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
16	13:30	7.7	17.0	429	3010	867	8160	217	1240	
19	14:00	8.4	17.5	370	1090	625	2185	244	770	720

15 Litres Smelt Wastewater, 0.75 Litres of Stickliquor (5%), and 2 Litres of Lagoon Liquor (Seed)

Air Supply = 3,500 c.c./min.

Day	Phosphate Filtered (mg/l)	Phosphate Unfiltered (mg/l)	Total Kjeldahl Nitrogen (mg/l)
0			309
6	19.5	23.0	
19	14.5	17.5	280.0

BATCH REACTOR - PERCH WASTEWATER AND STICKLIQUOR

Date	Time	pH	Temperature °C	BOD_5 Filtered (mg/l)	BOD_5 Unfiltered (mg/l)	COD Filtered (mg/l)	COD Unfiltered (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
0	11:30	7.2	22.0	1080	5640	1210	5250	640	3960	
1	10:30	7.4	21.0	1368	4510	1950	6800	506	5060	4940
4	13:00	6.8	19.0	1770	3140	2600	10300	585	1860	
5	13:30	7.2	20.0	1015	4290	1975	9260	290	1860	
7	15:00	7.4	18.5	2730	5500	1720	6640	315	4163	3163
8	13:30	7.4	18.0	1300	4660	934	6560	360	2840	
11	14:00	7.9	18.0	901	2380	494	2575	438	1920	1640
12	15:00	8.2	17.0	622	1580	773	4650	342	4280	
15	14:00	8.8	15.0	299	2390	746		242	1600	1420
18	15:00	8.2	19.8	220	730	475	1710	242	1560	1300
19	10:00	8.5	20.2	389	579	504	1414	200	920	

BATCH REACTOR - PERCH WASTEWATER AND STICKLIQUOR

Date	Time	pH	Temperature °C	BOD_5 (mg/l) Filtered	BOD_5 (mg/l) Unfiltered	COD (mg/l) Filtered	COD (mg/l) Unfiltered	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
21	11:30	8.7	19.6				1308	127	410	340
22	13:20	8.5	20.9	103	480	389	1318	131	1650	980

15 Litres Perch Wastewater, 0.75 Litres of Stickliquor (5%) and 2 Litres of Lagoon Liquor (Seed)

Air Supply = 3,500 c.c./min.

Day	Phosphate (mg/l) Filtered	Phosphate (mg/l) Unfiltered	Total Kjeldahl Nitrogen (mg/l)
0		29.5	365.0
22			267.4

BATCH REACTOR - COMBINED WASTEWATER AND STICKLIQUOR

Date	Time	pH	Temperature °C	BOD_5 (mg/l) Filtered	BOD_5 (mg/l) Unfiltered	COD (mg/l) Filtered	COD (mg/l) Unfiltered	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
0	11:30		28.0	3860	5100	4360	14720	624		
1	9:05		21.0	2400	4420	3820	9050	653		
2	13:00	7.3	20.0	2050	5470	3255	10300	557		
3	13:00	7.3	21.0	1320	3550	3700	10950	630		
4	9:0	6.8	21.0	1690	4840	2083	8115	685	1360	
8	13:00	7.3	23.0	1340	5940	1145	6950	619	1120	
9	11:45	7.0	23.5	1580	4999	2350	8900	602	2040	1950
11	11:00	7.6	21.0	1462	4940	2700	9200	630	1970	
14	13:00	7.7	18.5	1432	4070	2230	11000	285	1940	
15	13:30	7.8	20.0	1160	4510	2050	8550	485	1560	

BATCH REACTOR - COMBINED WASTEWATER AND STICKLIQUOR

Date	Time	pH	Temperature °C	BOD_5 Filtered (mg/l)	BOD_5 Unfiltered (mg/l)	COD Filtered (mg/l)	COD Unfiltered (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
17	15:00	7.8	18.5	2840	5000	1925	8240	326	3880	2500
18	13:30	7.7	18.5	1720	6930	1680	10320	477	1900	
21	14:00	7.4	18.0	1498	3250	1587	6200	342	2700	2400

15 Litres of Combined Wastewater, 0.75 litres of Stickliquor (5%) and 2 Litres of Lagoon Liquor (Seed).

Air Supply = 3,500 c.c./min.

Day	Phosphate Filtered (mg/l)	Phosphate Unfiltered (mg/l)	Total Kjeldahl Nitrogen (mg/l)
0	49.8	50.6	
21	17.0	44.5	428.4

APPENDIX 5

BATCH STUDY - SMELT WASTEWATER

PERCENT REMAINING

Day	BOD_5 Filtered	BOD_5 Unfiltered	Filtered Total Organic Carbon
0	100	100	100
1	37.2	94.0	61.0
2	28.6		60.4
3	31.9		66.0
4	14.8		44.4
7	15.5	31.4	79.7
8	6.8	28.8	81.8
9	5.2	20.6	42.8
10	12.0	22.0	32.8
11	11.8	9.8	36.5
14	11.6	11.0	29.2
16	5.6	9.5	26.1
18	2.9	7.0	32.3
22		12.4	27.6

Average Suspended Solids = 1011.3 mg/l.

BATCH STUDY - PERCH WASTEWATER

PERCENT REMAINING

Day	BOD_5 Filtered	BOD_5 Unfiltered	Filtered Total Organic Carbon
0	100	100	100
1	63.3	95.0	30.4
4	8.5	25.0	29.0
5	3.2	18.4	27.6
6	6.6	15.0	25.4
7	3.3	12.2	22.0
11	3.5	6.5	18.0
12	1.7	3.7	30.8
13	2.3	10.2	33.7
14			26.7
15	2.8	8.5	26.0
18	1.4	7.2	17.6
19	1.1	8.0	19.8
20	1.2	7.6	18.0

Average Suspended Solids = 726.4 mg/1.

BATCH STUDY - COMBINED WASTEWATER

PERCENT REMAINING

Day	BOD_5 Filtered	BOD_5 Unfiltered	Filtered Total Organic Carbon
0	100	100	100
1	37.6	84.4	37.8
2	39.0		28.0
5	17.1	43.0	29.5
6	8.2	36.2	40.0
7	4.5	34.0	31.0
8	11.5	27.2	51.5
9	3.0	13.6	32.6
12	2.2	8.8	29.5
13	3.1	11.3	28.0
14	2.3		26.5
15	2.3		31.0
16		20.2	31.9
19		20.5	31.1
21	5.6	18.6	29.5

Average Suspended Solids = 739.4 mg/1.

BATCH STUDY - SMELT WASTEWATER AND STICKLIQUOR

PERCENT REMAINING

Day	BOD_5 Filtered	BOD_5 Unfiltered	Filtered Total Organic Carbon
0	100	100	100
1	81.0	73.1	91.0
2	89.5		99.0
6	99.0	83.0	88.2
7	75.8	73.5	
9	88.2	50.2	95.5
12	70.0	53.8	53.9
13	41.8	45.1	39.3
15	21.2	61.3	50.0
16	28.1		39.5
19	24.1	23.1	44.3

Average Suspended Solids = 1775.6 mg/1.

BATCH STUDY - SMELT WASTEWATER AND STICKLIQUOR

PERCENT REMAINING

(Following Time Lag Adjustment.)

Day	BOD_5 Filtered	BOD_5 Unfiltered	Filtered Total Organic Carbon
0	100	100	100
1	99.0	83.0	88.2
2	75.8	73.5	
4	88.2	50.2	95.5
7	70.0	53.8	53.9
8	41.8	45.1	39.3
10	21.2	61.3	50.0
11	28.1		39.5
14	24.1	23.1	44.3

A four day lag period is necessary for acclimatization of the micro-organisms following the addition of stickliquor.

BATCH STUDY - PERCH WASTEWATER AND STICKLIQUOR

PERCENT REMAINING

Day	BOD_5 Filtered	BOD_5 Unfiltered	Filtered Total Organic Carbon
0	100	100	100
1	94.2	79.5	79.5
4		55.6	86.5
5	71.8	75.8	42.9
7		97.0	46.5
8	92.0	82.2	53.2
11	64.0	42.1	64.6
12	43.9	28.0	50.8
15	21.2	42.4	36.4
18	15.5	13.9	36.4
19			29.5
20	26.0	10.6	

Average Suspended Solids = 2696.2 mg/1.

BATCH STUDY - PERCH WASTEWATER AND STICKLIQUOR

PERCENT REMAINING

(Following Time Lag Adjustment)

Day	BOD_5 Filtered	BOD_5 Unfiltered	Filtered Total Organic Carbon
0	100	100	100
1	92.0	82.2	85.0
4	64.0	42.1	
5	43.9	28.0	79.2
8	21.2	42.4	56.8
11	15.5	13.9	56.8
13	26.0	10.6	46.0

A seven day lag period is necessary for acclimatization of the micro-organisms following the addition of stickliquor.

BATCH STUDY - COMBINED WASTEWATER AND STICKLIQUOR

PERCENT REMAINING

Day	BOD_5 Filtered	BOD_5 Unfiltered	Filtered Total Organic Carbon
0	100	100	100
1	85.5	88.8	85.0
2	70.0		69.0
3	45.2	69.0	78.2
4	55.9	96.0	85.1
8	45.9		76.9
9	54.0	97.0	75.0
11	50.0	96.0	78.2
14	48.8	79.0	35.5
15	39.7	87.6	60.0
18	58.8		40.4
19			59.2
21	51.1	63.1	42.5

Average Suspended Solids = 2052.2 mg/1.

No period of acclimatization was necessary for the micro-organisms following the addition of stickliquor.

APPENDIX 6

CONTINUOUS COMBINED WASTEWATER REACTOR

Detention Time = 15 hours　Volume of Reactor = 15 litres　Air Supply = 8,000 c.c./min.

Feed Rate = 1 litre/hour　Sludge Age = 3 days　Seed: 2 litres of lagoon liquor

Date	Time	Parameter	pH	Temperature °C	BOD_5 Filtered (mg/l)	BOD_5 Unfiltered (mg/l)	COD Filtered (mg/l)	COD Unfiltered (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
21/9	15:45	Feed					400	6120		2900	2700
		Reactor	6.5	19.0			985	23,200		6360	6060
		Clarifier Sludge						66,000		17,900	15,180
22/9	15:00	Feed					373	3800		640	
		Reactor	6.7	20.0			773	22,720		1700	1360
		Clarifier Sludge					640	56,000		18,960	15,020
24/9	14:00	Reactor	7.8	17.5	496	3650	619	2080		1640	1100
		Clarifier Sludge					620	31,200		20,280	17,220
		Clarifier Effluent					425	1120		460	350
27/9	15:30	Feed					338	1146	271	410	310
		Reactor	7.4	21.0			63	1083	235	2250	1900
		Clarifier Sludge					233	17,200	440	30,000	26,900
		Clarifier Effluent					62	496		400	240

CONTINUOUS COMBINED WASTEWATER REACTOR

Detention Time = 15 Hours   Volume of Reactor = 15 Litres   Air Supply = 8,000 c.c./min.

Feed Rate = 1 Litre/ hour   Sludge Age = 3 Days   Seed: 2 litres of lagoon liquor

Date	Time	Parameter	pH	Temperature °C	BOD_5 (mg/l) Filtered	BOD_5 (mg/l) Unfiltered	COD (mg/l) Filtered	COD (mg/l) Unfiltered	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
28/9		Feed	7.3		282	1380	377	850		320	
		Reactor	7.5	25.5	282	1287	508	1419		1050	
		Clarifier Sludge			529	7000	299	27,800		13,880	12,560
		Clarifier Effluent			76	680	141	469		250	
29/9		Feed			98.2	744	463	1380	260	548	
		Reactor	7.6	25.0	778	418	47	716	79	1140	
		Clarifier Sludge						29,400	330	31,200	30,400
		Clarifier Effluent			24.5	240	161	710	75	320	
30/9	16:00	Feed	6.6		158	1560	504	1820	180	490	330
		Reactor	7.6	21.9	107	598	147	878	72	390	380
		Clarifier Sludge				6280		12,910	520	9,100	7,700
		Clarifier Effluent			14	351	177	346	63	20	

CONTINUOUS COMBINED WASTEWATER REACTOR

Detention Time =15 Hours   Volume of Reactor =15 Litres   Air Supply = 8,000 c.c./min.

Feed Rate =1 Litre/Hour   Sludge Age = 3 Days   Seed: 2 litres of lagoon liquor

Date	Time	Parameter	pH	Temperature °C	BOD_5 Filtered (mg/l)	BOD_5 Unfiltered (mg/l)	COD Filtered (mg/l)	COD Unfiltered (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
3/10	13:40	Feed				1375	452	1420	212	775	515
		Reactor	7.5	23.1		1675	157	1160	97	1940	1080
		Clarifier Sludge				6870		39,000	725	21,600	11,550
		Clarifier Effluent			73	445	86	360	116	705	365
5/10	9:30	Feed			118	1355	599	1800	175	650	
		Reactor	7.9	19.2	153	472	122	1005	50	1155	1100
		Clarifier Sludge				4690		14,050	580	9350	8500
		Clarifier Effluent			13		100	316	58	162	
7/10	15:30	Feed			565	825	316	2140	172	790	570
		Reactor	7.7	12.0		1680	84.5	1481	97	1420	
		Clarifier Sludge				7340		37,700	2700	17,050	16,500
		Clarifier Effluent			85	850	112	488	72	320	295

CONTINUOUS COMBINED WASTEWATER REACTOR

Detention Time = 15 Hours   Volume of Reactor = 15 Litres   Air Supply = 8,000 c.c./min.

Feed Rate = 1 Litre/Hour   Sludge Age = 3 Days   Seed: 2 litres of lagoon liquor

Date	Time	Parameter	pH	Temperature °C	BOD_5 Filtered (mg/l)	BOD_5 Unfiltered (mg/l)	COD Filtered (mg/l)	COD Unfiltered (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
8/10	9:30	Feed	7.1		367	1365	232	908	148	900	
		Reactor	7.8	14.1	300		465	1109	79	1170	1020
		Clarifier Sludge				7220		11,560	235	20,700	17,250
		Clarifier Effluent			325	616	74.1	258	50	380	188
13/10		Feed			539	1100	488	1332	325	475	350
		Reactor			68	514	106	1095	97	810	
		Clarifier Sludge				7800		12,720	1220	13,500	
		Clarifier Effluent			54	640	88	496	97	350	

CONTINUOUS COMBINED WASTEWATER REACTOR

Detention Time = 15 Hours   Volume of Reactor = 15 Litres   Air Supply ≈8,000 c.c./min.

Feed Rate = 1 Litre/hour   Sludge Age = 5 Days   Seed: 2 litres of lagoon liquor

Date	Time	Parameter	pH	Temperature °C	BOD_5 (mg/l) Filtered	BOD_5 (mg/l) Unfiltered	COD (mg/l) Filtered	COD (mg/l) Unfiltered	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
18/10	14:00	Feed	7.2		292	948	262	1220		785	645
		Reactor	7.5	18.8	28	666	102	1328		920	900
		Clarifier Sludge				11,350		19,300	1020	11,450	10,150
		Clarifier Effluent			25	135	78.3	345		540	420
19/10	13:30	Feed	7.0		263	778	263	1179	204	920	750
		Reactor	7.8	18.0	20.2	1323	104	1272	86	1,000	980
		Clarifier Sludge				6310		16,310	485	12,500	11,300
		Clarifier Effluent			17	131	98	310	43	305	275
20/10	13:30	Feed	7.9		132	600	174	1090	75	850	660
		Reactor	7.8	19.2	120	520	93.6	1530	122	1280	1150
		Clarifier Sludge				1850		20,650	520	13,950	13,250
		Clarifier Effluent			27	32	95.6	344	79	330	300

CONTINUOUS COMBINED WASTEWATER REACTOR

Detention Time = 15 Hours Volume of Reactor = 15 Litres Air Supply = 8,000 c.c./min.

Feed Rate = 1 Litre/hour Sludge Age = 5 Day Seed: 2 litres of lagoon liquor

Date	Time	Parameter	pH	Temperature °C	BOD_5 Filtered (mg/l)	BOD_5 Unfiltered (mg/l)	COD Filtered (mg/l)	COD Unfiltered (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
21/10	14:00	Feed	7.0		350	915	314	1318	250	605	570
		Reactor	7.5	20.5	27	1260	95.5	1905	79	1430	1300
		Clarifier Sludge				1200		19,700	660	16,850	14,850
		Clarifier Effluent			20		105	432	62	355	320
25/10	10:30	Feed	6.9		383	880	318	1240	220	1660	940
		Reactor	6.7	13.9	22.5	540	103	1421	91	1240	1200
		Clarifier Sludge				820		19,360	925	16,700	14,600
		Clarifier Effluent					107	406	143	260	
27/10	9:30	Feed	7.1		323	745	318	1140	310	710	630
		Reactor				463	66.8	1426	159	1210	1030
		Clarifier Sludge				11,000		23,200	1377	18,650	15,800
		Clarifier Effluent				810	82.5	659	105	590	

CONTINUOUS COMBINED WASTEWATER REACTOR

Detention Time =7.5 Hours **Volume of Reactor** = 15 Litres **Air Supply** = 8,000 c.c./min.

Feed Rate = 2 Litres/hour **Sludge Age** = 3 Days **Seed: 2 litres of lagoon liquor**

Date	Time	Parameter	pH	Temperature °C	BOD_5 (mg/l) Filtered	BOD_5 (mg/l) Unfiltered	COD (mg/l) Filtered	COD (mg/l) Unfiltered	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
29/10	10:00	Feed	6.9		340	900	422	1161		785	585
		Reactor	7.8		34	590	64.5	1262	153	1310	1100
		Clarifier Sludge				11,100		13,420	964	17,300	10,100
		Clarifier Effluent				200	60.9	453	86	730	
3/11	9:00	Feed	7.2		370	805	286	1212	297	605	
		Reactor	7.0	7.9	57.0	760	91.3	1048	151	1030	990
		Clarifier Sludge				9200		10,700	1490	13,450	8100
		Clarifier Effluent			30	210	85.4	491		570	540
5/11	10:00	Feed	7.7		330	550	156	589	317	320	320
		Reactor	7.8	8.1	87	551	118	966	221	570	
		Clarifier Sludge				1300		20,900	1490	17,000	16,100
		Clarifier Effluent			89	260	136	409	161	385	

CONTINUOUS COMBINED WASTEWATER REACTOR

Detention Time = 7.5 Hours **Volume of Reactor** = 15 Litres **Air Supply** = 8,000 c.c./min.

Feed Rate = 2 Litres/hour **Sludge Age** = 3 Days **Seed: 2 litres of lagoon liquor**

Date	Time	Parameter	pH	Temperature °C	BOD_5 (mg/l) Filtered	BOD_5 (mg/l) Unfiltered	COD (mg/l) Filtered	COD (mg/l) Unfiltered	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
8/ 11	9:30	Feed	6.9		115	480	120	532	163	450	415
		Reactor	7.7	4.0	102	667	720	770	119	600	580
		Clarifier Sludge				10,100		18,450	950	21,000	19,750
		Clarifier Effluent			70	200	120	249	168	305	300
10/ 11	10:30	Feed	6.6		160	536	198	809	224	540	500
		Reactor	7.0	14.1	63	640	67.9	825	142	675	615
		Clarifier Sludge				13,300		24,200	1524	25,600	23,100
		Clarifier Effluent			59	243	80	268	110	560	545
12/11	9:30	Feed	7.3		104	345	183	545		370	340
		Reactor	7.2	22.1	7	400	69.6	611		900	560
		Clarifier Sludge				11,500		15,990		16,300	14,100
		Clarifier Effluent			9.4	189	76.5	399		500	435

<u>CONTINUOUS COMBINED WASTEWATER REACTOR</u>

Detention Time = 7.5 Hours **Volume of Reactor** = 15 Litres **Air Supply** = 8,000 c.c./min.

Feed Rate = 2 Litres/Hour **Sludge Age** = 3 Days **Seed: 2 litres of lagoon liquor**

Date	Time	Parameter	pH	Temperature °C	BOD_5 (mg/l) Filtered	BOD_5 (mg/l) Unfiltered	COD (mg/l) Filtered	COD (mg/l) Unfiltered	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
15/11	10:30	Feed	7.0		157	445	183	734		355	350
		Reactor	7.4	22.1	28	365	93.4	755		560	520
		Clarifier Sludge				9360		11,050		13,350	11,700
		Clarifier Effluent			14	140	96.4	410		240	240
17/11	11:00	Feed	7.3		216	596	227	828		545	490
		Reactor	7.4	22.0		485	126	742		830	750
		Clarifier Sludge				6050		11,830		16,550	
		Clarifier Effluent			17	264				500	
19/11	11:15	Feed	7.0				241	690		565	550
		Reactor	7.3	18.8			108	681		810	810
		Clarifier Sludge						19,800		22,650	20,000
		Clarifier Effluent					114	438		485	470

CONTINUOUS COMBINED WASTEWATER REACTOR

DETENTION TIME = 5 Days VOLUME OF REACTOR = 15 Litres START = September 13, 1971 AIR SUPPLY = 3500 c.c./min.

FEED RATE = 1.8 ml/min. NO SLUDGE RECYCLE SEED = 2 Litres of Lagoon Liquor

Date	Time	pH	Temperature °C	BOD_5 (mg/l)		COD (mg/l)		Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
				Filtered	Unfiltered	Filtered	Unfiltered			
15/9							2160			
21/9	15:00	7.2	18.5	475	2960	575	4000	448	1520	
22/9	16:00	6.9	20.5	123	1550	425	3720	544	1000	900
24/9	14:00	7.4	17.0	180	3660	588	1120		1630	1410
27/9	15:30	7.2	21.1		855	314	1780	194	1020	
28/9	11:00	7.3	22.6		632	412	1843	206	810	
29/9	11:30	7.7	24.1	72.0	1335	244	835	166	980	
30/9	14:30	8.0	22.0	45	749	148	865	75	100	70
3/10	13:30	8.1	22.9	52	1131	117	887	62	1310	820
5/10	11:15	8.2	16.5			110	1070	69	830	

CONTINUOUS COMBINED WASTEWATER REACTOR

Date	Time	pH	Temperature °C	BOD_5 Filtered (mg/l)	BOD_5 Unfiltered (mg/l)	COD Filtered (mg/l)	COD Unfiltered (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
7/10	15:15	8.2	11.5	56.4	500	96	886	50	3800	690
8/10	16:00	8.2	14.5	190	1335	62	881	53	1090	1080
13/10				68	457	77.5		53	940	900

Date	Phosphate Filtered (mg/l)	Phosphate Unfiltered (mg/l)	Total Kjeldahl Nitrogen (mg/l)
24/9	1.0	11.5	126.0
15/10	9.6	30.7	145.0

CONTINUOUS COMBINED WASTEWATER REACTOR

DETENTION TIME = 10 Days **VOLUME OF REACTOR** = 15 Litres **START** = September 10, 1971 **AIR SUPPLY** = 3500 c.c./min.

FEED RATE = 0.9 ml/min. **NO SLUDGE RECYCLE** **SEED** = 2 Litres of Lagoon Liquor

Date	Time	pH	Temperature °C	BOD_5 Filtered (mg/l)	BOD_5 Unfiltered (mg/l)	COD Filtered (mg/l)	COD Unfiltered (mg/l)	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
15/9							2390			
27/9	15:30	7.8	20.0	472	762	171	2195	135	600	
29/9	11:30	7.9	24.0		507	244	867	46	800	
3/10	13:15	7.9	22.1		1240	177	770	50	1450	680
5/10	14:45	6.7	19.0		473	142	971	50	720	
7/10	15:00	6.5	12.2		583	138	754		800	610
8/10	15:30	6.7	14.5	87.5	2305	85.4	511	164	880	750
13/10				49	305	136	775	53	450	

Date	Phosphate Filtered (mg/l)	Phosphate Unfiltered (mg/l)	Total Kjeldahl Nitrogen (mg/l)
27/9	2.0	13.0	115.0
14/10	17.0	28.3	85.0

CONTINUOUS COMBINED WASTEWATER REACTOR

DETENTION TIME = 15 Day VOLUME OF REACTOR = 15 Litres START =September 10, 1971 AIR SUPPLY= 3500 c.c./min.

FEED RATE = 0.6 ml/min. NO SLUDGE RECYCLE SEED = 2 Litres of Lagoon Liquor

Date	Time	pH	Temperature °C	BOD_5 (mg/l) Filtered	Unfiltered	COD (mg/l) Filtered	Unfiltered	Filtered TOC (mg/l)	Suspended Solids (mg/l)	Volatile Suspended Solids (mg/l)
15/9							1060			
27/9	15:30	7.9	20.0		622	199	1255	180	760	
29/9	11:30	7.9	24.0	11.7	480	138	913	72	820	
3/10	13:00	8.0	22.0	17.5	643	206	723	72	1100	350
5/10	15:00	8.3	18.9	48		58	833	53	610	
7/10	14:30	8.2	12.1			192	736	43	650	550
8/10	15:30	8.0	14.4	100	440	96.9	775	46	770	670
13/10				11.7	767	96	630	115	610	

Date	Phosphate (mg/l) Filtered	Unfiltered	Total Kjeldahl Nitrogen (mg/l)
27/9	1.0	11.5	113.4
14/10	6.8	27.0	97.0

APPENDIX 7

CONTINUOUS COMBINED WASTEWATER REACTOR

DETENTION TIME = 7.5 Hours SLUDGE AGE = 3 Days

PERCENT REMOVALS

Date	BOD_5 Filtered	BOD_5 Unfiltered	COD Filtered	COD Unfiltered
15/11	82.2	18.0	49.0	
17/11		18.6	44.6	10.4
Mean $\bar{x}$	82.2	18.3	46.8	10.4
Std. Dev.		± 0.3	± 2.2	

Suspended Solids $\bar{x}$ = 695 mg/l.

Std. Dev. = ± 135 mg/l.

No. of detention times to equilibrium = 6

CONTINUOUS COMBINED WASTEWATER REACTOR

DETENTION TIME = 15 Hours SLUDGE AGE = 3 Days

PERCENT REMOVALS

Date	BOD_5 Filtered	BOD_5 Unfiltered	COD Filtered	COD Unfiltered	Filtered TOC
29/9		43.6	89.8	48.1	69.5
30/9		61.8	70.8	51.8	60.0
3/10			65.3	18.3	54.2
5/10		65.2	79.6	44.2	71.5
7/10			73.3	30.8	43.6
13/10	87.2	53.2	78.3	17.8	70.0
Mean $\bar{x}$	87.2	55.95	76.2	35.2	61.47
Std. Dev.		$\pm$9.66	$\pm$8.5	$\pm$15.0	$\pm$11.07

Suspended Solids $\bar{x}$ = 1090 mg/l.

Std. Dev. = $\pm$535 mg/l.

No. of detention times to equilibrium = 22.5

CONTINUOUS COMBINED WASTEWATER REACTOR

DETENTION TIME = 15 Hours SLUDGE AGE = 5 Days

PERCENT REMOVALS

Day	BOD_5 Filtered	BOD_5 Unfiltered	COD Filtered	COD Unfiltered	Filtered TOC
25/10	94.0	38.6	67.8		58.7
27/10		38.0	79.0		
29/10	90.0	34.5	85.0		
Mean $\bar{x}$	92.0	37.0	77.2		58.7
Std. Dev.	± 2.0	± 1.81	± 7.14		

Suspended Solids $\bar{x}$ = 1253.3 mg/l.

Std. Dev. = ± 41.9 mg/l.

No. of detention times to equilibrium = 17.16

CONTINUOUS COMBINED WASTEWATER REACTOR

DETENTION TIME = 5 Day SLUDGE AGE = 5 Days

PERCENT REMOVALS

Date	BOD_5 Filtered	BOD_5 Unfiltered	COD Filtered	COD Unfiltered	Filtered TOC
30/9	71.5	52.0	70.0	52.5	58.2
3/10		17.8	74.0	37.6	69.0
5/10			81.8	40.6	60.7
7/10	89.8	39.5	69.5	58.5	71.0
8/10	51.0		73.2		64.2
13/10	87.0	58.5	84.0		83.8
Mean $\bar{x}$	74.83	41.95	75.42	47.30	67.82
Std. Dev.	±17.81	±17.93	±6.09	±9.86	±9.2

Suspended Solids $\bar{x}$ = 1420.0 mg/1.

Std. Dev. = ±1176.2 mg/1.

BOD_5: N.P. = 100:10:1 (Initial)

17: 5:1 (Final)

No. of detention times to equilibrium = 3.2

CONTINUOUS COMBINED WASTEWATER REACTOR

DETENTION TIME = 10 Day SLUDGE AGE = 10 Days

PERCENT REMOVAL

Date	BOD_5 Filtered	BOD_5 Unfiltered	COD Filtered	COD Unfiltered	Filtered TOC
29/9		31.9	47.4	37.2	82.1
3/10			60.8	45.8	76.5
5/10		65.2	76.1	46.0	71.5
7/10		29.4	56.2	65.0	
8/10	76.2		63.0	59.2	
13/10	91.0	72.2	72.0	41.8	83.8
Mean $\bar{x}$	83.60	49.68	62.58	49.17	78.48
Std. Dev.	±10.47	±22.18	±10.45	±10.68	±5.60

Suspended Solids $\bar{x}$ = 1115.7 mg/l

Std. Dev.= ±655.0 mg/l.

BOD_5: N:P = 65:10:1 (Initial)

10: 3:1 (Final)

No. of detention times to equilibrium = 1.9

CONTINUOUS COMBINED WASTEWATER REACTOR

DETENTION TIME = 15 Day SLUDGE AGE = 15 Days

PERCENT REMOVALS

Date	BOD_5 Filtered	BOD_5 Unfiltered	COD Filtered	COD Unfiltered	Filtered TOC
29/9	87.0	36.4	70.2	33.8	72.1
3/10		53.3	55.0	49.0	66.0
5/10	59.2		90.0	53.5	69.8
7/10			39.2	65.5	75.0
8/10	73.0	67.7	58.0	38.2	69.0
13/10	97.0	30.3	80.5	52.8	64.8
Mean $\bar{x}$	79.05	46.93	65.48	48.80	69.45
Std.Dev.	$\pm$16.49	$\pm$16.93	$\pm$18.47	$\pm$11.44	$\pm$ 3.79

Suspended Solids $\bar{x}$ = 1018.6 mg/l.

Std. Dev. = $\pm$646.6 mg/l.

BOD_5:N:P = 60:11:1 (Initial)

20: 4:1 (Final)

No. of detention times to equilibrium = 1.1

APPENDIX 8

CONTACT TIME

SMELT WASTEWATER

Time (Minutes)	BOD_5 (mg/l)	COD (mg/l)	Suspended Solids (mg/l)
0	973	634	1,025
15	1,250	1,028	1,495
30	1,330	1,305	1,405
60	1,360	1,562	2,020
120	1,450	1,728	1,590

Values below expressed as percent increase of initial value.

Time (Minutes)	BOD_5 (mg/l)	COD (mg/l)	Suspended Solids (mg/l)
0	0	0	0
15	28.5	61.8	45.7
30	37.1	106.0	37.0
60	39.8	146.0	97.0
120	49.0	172.5	55.0

CONTACT TIME

PERCH WASTEWATER

Time (Minutes)	BOD_5 (mg/l)	COD (mg/l)	Suspended Solids (mg/l)
0	285	329	218
15	305	455	215
30	296	408	225
60	287	376	243
120	411	423	243

Values below expressed as percent increase of initial value.

Time (Minutes)	BOD_5 (mg/l)	COD (mg/l)	Suspended Solids (mg/l)
0	0	0	0
15	7.0	38.3	0
30	3.9	24.0	3.2
60	1.0	14.3	11.4
120	44.0	28.6	11.4

FLOTATION TESTS

PERCENT REMOVALS

Run #1: Total flow (850 mls.) pressurized to 30 p.s.i. Air/Solids ratio = 3.28.

Time (Minutes)	BOD_5	COD	Suspended Solids
0	0	0	0
5	40.5	7.7	14.4
15	41.1	12.1	13.0

Run #2: Total flow (850 mls.) pressurized to 20 p.s.i. Air/Solids ratio = 1.92.

Time (Minutes)	BOD_5	COD	Suspended Solids
0	0	0	0
5	41.5	19.7	25.9
15	39.5	19.7	28.8

Run #3: 250 mls. subnatant pressurized to 40 p.s.i., 750 mls. in graduate - 1/3 recycle system. Air/Solids ratio = 1.10.

Time (Minutes)	BOD_5	COD	Suspended Solids
0	0	0	0
5	29.0	20.4	24.0
15	29.0	20.4	26.7

Run #4: 250 mls. subnatant pressurized to 30 p.s.i., 750 mls. in graduate - 1/3 recycle system. Air/Solids ratio = 0.81.

Time (Minutes)	BOD_5	COD	Suspended Solids
0	0	0	
5	35.0	13.5	
15	41.7	9.2	

RESPIRATION RATES

(for continuous combined wastewater reactors)

Time (Minutes)	DETENTION TIME 5 Days	10 Days	15 Days
	Dissolved Oxygen p.p.m.		
0	5.07	7.49	8.06
1	4.78	7.29	7.96
2	4.49	7.19	7.85
3	4.21	7.09	7.75
4	3.92	6.89	7.65
5	3.63	6.79	7.55
10	2.39	5.99	6.83
14	1.43		
15		5.29	6.22
18	0.57		
20	0.19	4.59	5.62
25		3.89	5.10
30		3.29	4.49