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An Effluent Study of a Fresh Water Fish Processing Plant

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AN EFFLUENT STUDY OF A FRESH WATER FISH PROCESSING PLANT

by

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Current methods of processing fish require 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, the resulting fish meal was sold as animal feed, but the remaining waste water still has been discharged to receiving waters.

The characterization of wastes from various types of fish plants has been the subject of a number of studies. These have been reviewed by Riddle (1972) but almost all the plants handled seafood as opposed to freshwater fish. Further the information on treatment was 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 Canadian Department of the Environment with the cooperation of the Department of Chemical Engineering, McMaster University agreed to undertake a study to:

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

Omstead Fisheries, 1961, Limited of Wheatley, Ontario was chosen for this study. Omstead Fisheries processed some 34 million pounds of perch and smelt in 1969. The plant is situated about one mile south of the village of Wheatley, Ontario, and some twenty miles south east of Windsor, on the Lake Erie shoreline.

The various steps for processing perch and smelt are shown on Figure 1. Perch are normally filleted whereas smelt are eviserated. As the processing operations are carried out by machine the company attempts to keep a steady flow of fish through the processing machines. If the supply of perch is low, hand filleting is employed, while smelt processing is discontinued until the supply is replenished. Following processing the fish are placed on trays in large boxes for freezing and eventually packaged in small boxes for the consumer market.

The offal from the fish processing plant is transported by auger to the fish meal plant (figure 1), where it is processed into animal feed and high grade fish oil. Only washdown water is discharged from the fish meal plant. As many fish meal plants

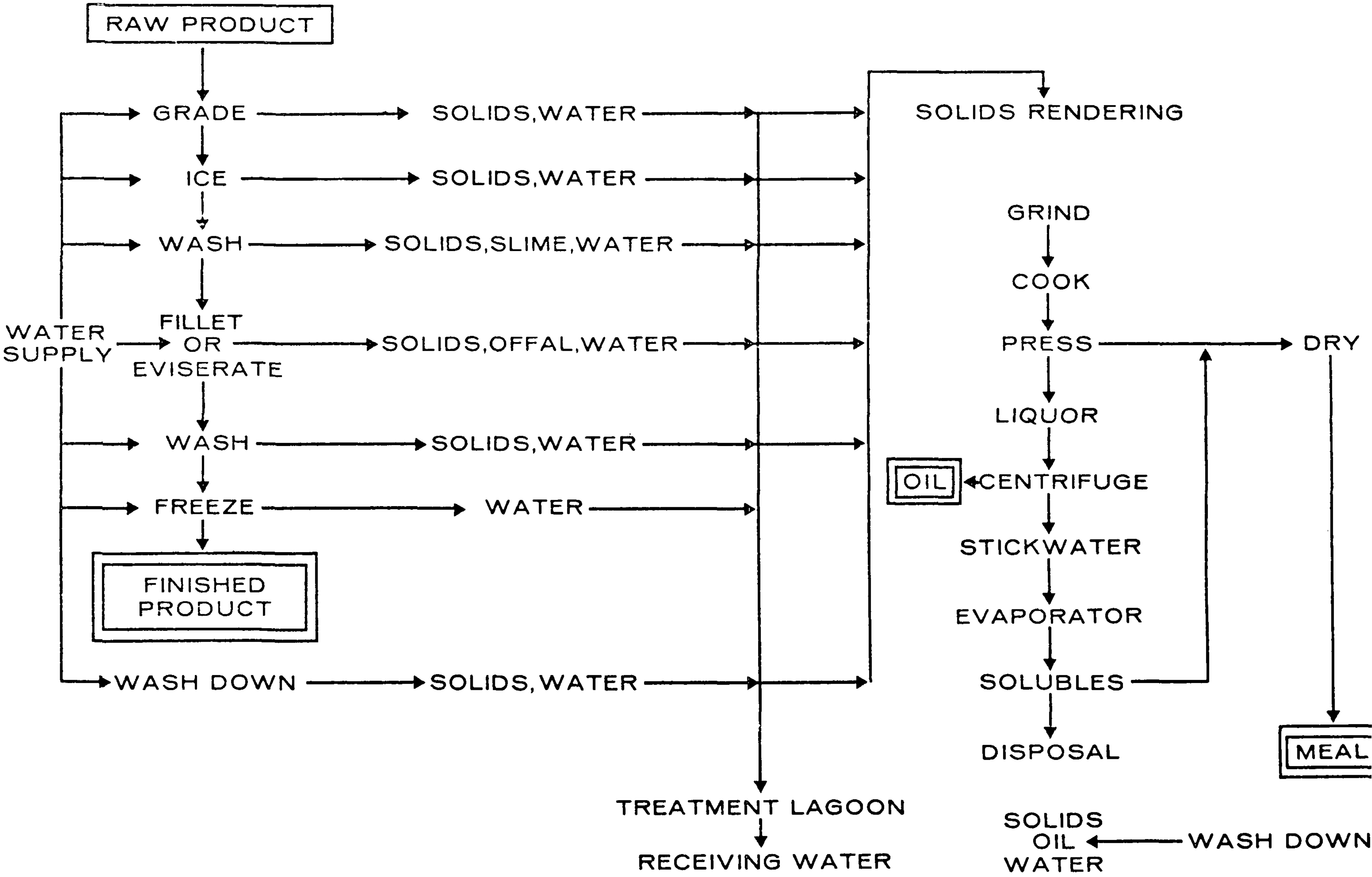

Figure 1. Fish Processing And Fish Meal Plant Operation

do not recover stickliquor but discharge it as a waste product it was decided to study the characteristics and treatability of stickliquor in conjunction with the waste water from the fish processing plant.

Since Omstead Fisheries process two species of fish, perch and smelt, the waste from each process area was sampled separately together with the combined waste. Two litre grab samples of the perch wastewater, smelt wastewater, combined wastewater and stick-liquor were taken once per day. This procedure provided sufficient data during the course of the study,in excess of 35 daily values, to allow for a statistical analysis of the major parameters.

The following analyses were performed on each waste on a regular basis:

1) 5 day biochemical oxygen demand, (BOD_5)
2) chemical oxygen demand, (COD)
3) total soluble organic carbon, (TOC)
4) temperature,
5) pH,
6) total (TS) and total volatile solids, (TVS), and,
7) suspended (SS) and volatile suspended solids (VSS).

In addition twice every 5 day work week, the following analyses were made on each waste:

1) 20 day biochemical oxygen demand, BOD_{20},
2) total Kjeldahl nitrogen,
3) nitrate,
4) nitrite, and
5) unfiltered and filtered total phosphate.

The characteristics of the smelt waste water are shown in table 1. The high values of the coefficient of variation defined as the standard deviation expressed as a percentage of the mean reflect the large variability of the waste on a day to day basis. This is presented graphically in figure 2. It should be noted that the coefficient of variation for BOD_5, COD, filtered TOC and total solids (TS) are of the same order of magnitude, between 54 and 62 percent, however the coefficient of variation of the suspended solids (SS) is in excess of 80 percent. This indicates a possible larger variability in day to day suspended solids values than in other parameters. The concentration of nutrients 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 is present in the filtered samples. The levels of both nitrate and nitrite are low while the total Kjeldahl nitrogen values obtained were predictably high (120 mg/l) as fish flesh is a protein.

The characteristics of the perch wastewater are shown in table 2. 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 (figure 3). Filtered TOC, suspended solids (SS), volatile suspended solids (VSS), total (TS) and total volatile solids (TVS) all have larger mean values than the smelt wastewater, but their coefficients of variations for each parameter are approximately the same.

Table 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	19	0.010	0.323	119	37
Standard Deviation	±6	±5	±0.004	±0.068	±42	±5
Coefficient of Variation	25.2%	28.4%	40.0%	21.2%	35.5%	13.4%
Number of Samples	10	10	3	3	9	4

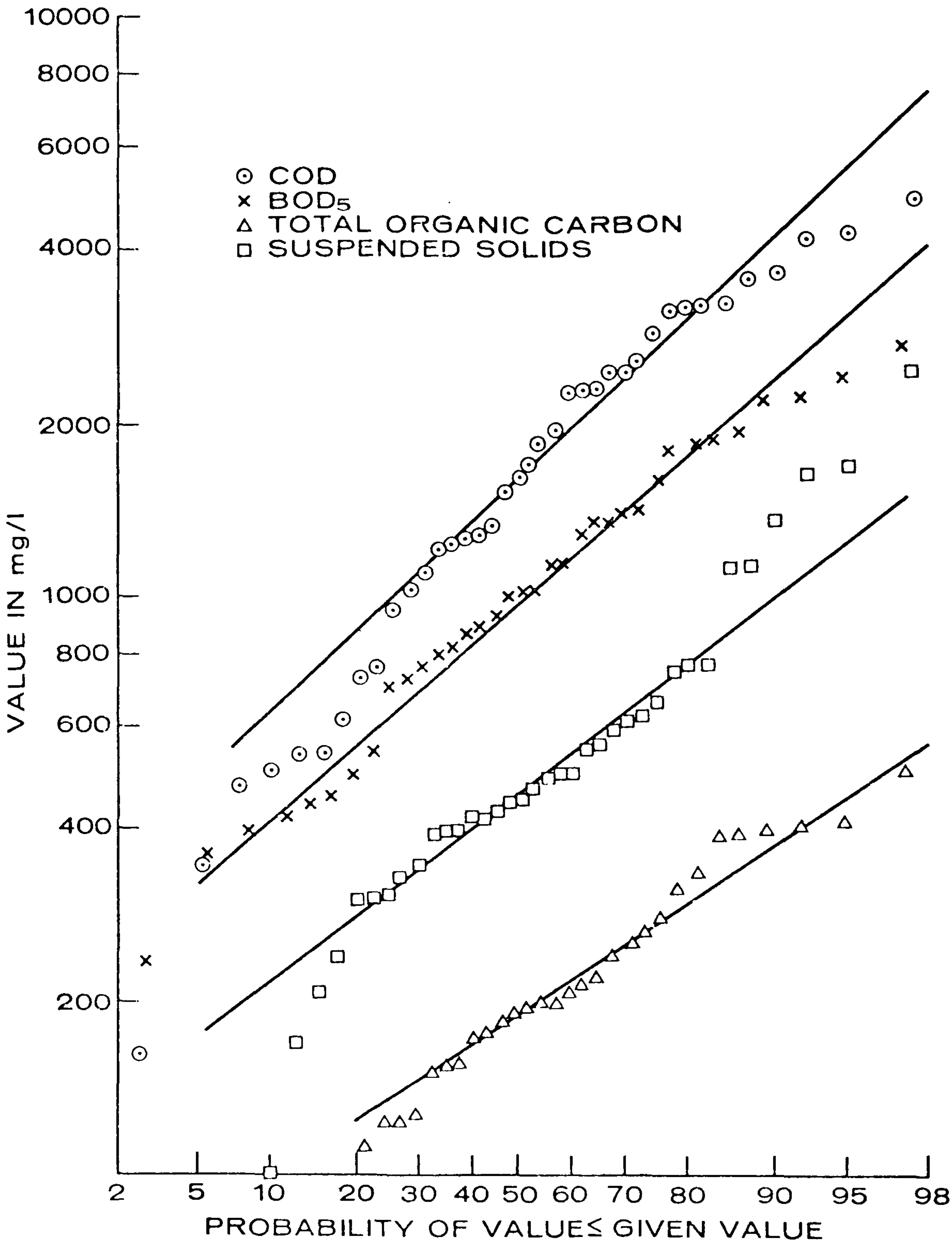

Figure 2. Smelt Wastewater Probability Plot

Table 2: Perch 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	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

	Phosphate (mg/l)		Nitrite (mg/l)	Nitrate (mg/l)	Total Kjedahl Nitrogen (mg/l)	Oil and Grease (mg/l)
	Unfiltered	Filtered				
Mean	18	15	0.0288	0.500	122	24
Standard Deviation	±8	±9	±0.0200	±0.282	±63	±12
Coefficient of Variation	43.0%	62.3%	69.1%	56.2%	51.4%	50.0%
Number of Samples	12	12	4	4	11	5

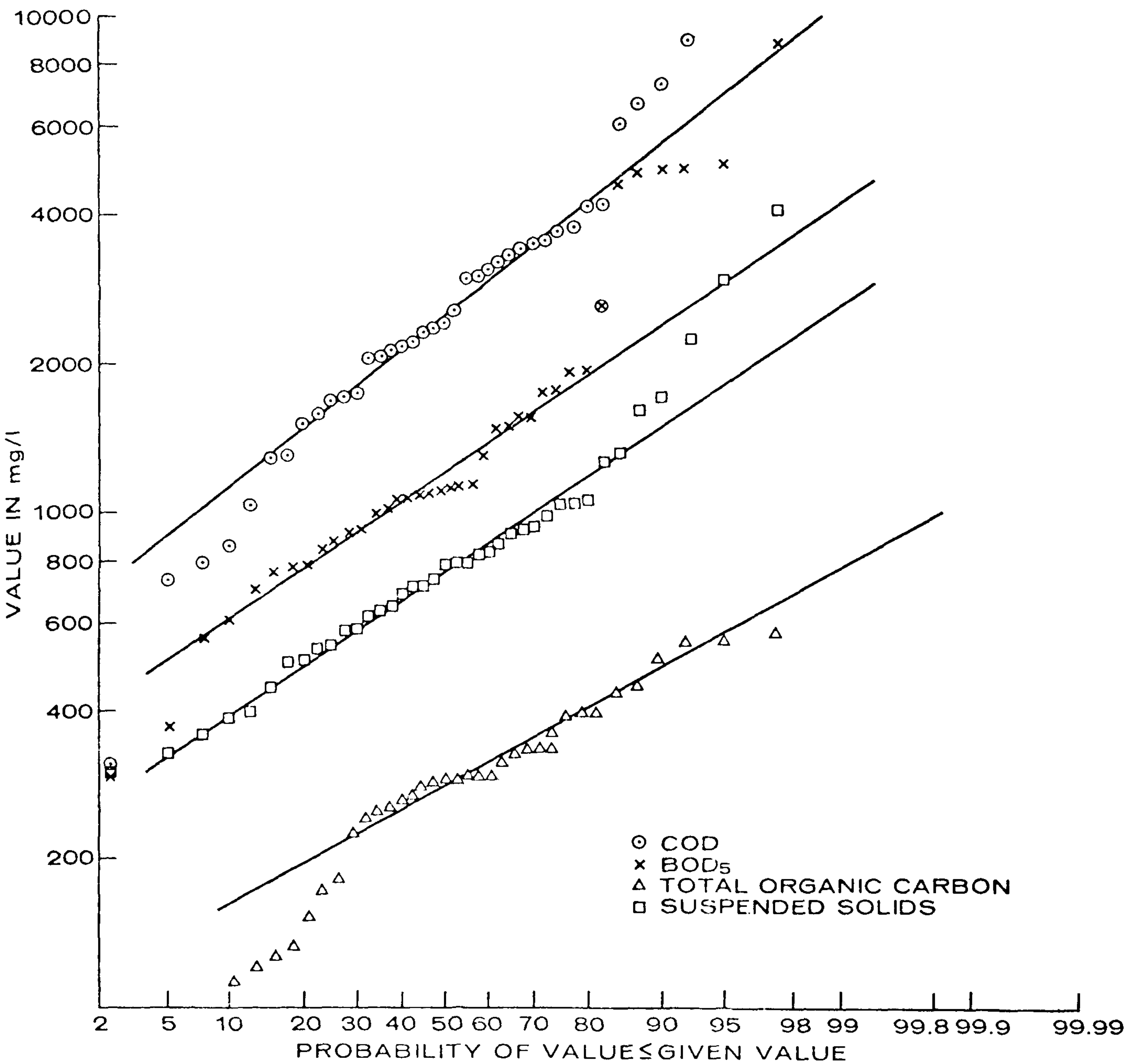

Figure 3. Perch Wastewater Probability Plot

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 Kjeldahl nitrogen values are high with a mean value of 122 mg/l, this compares to about 30 mg/l in domestic wastes (Hunter and Heukelekian, 1965).

A statistical analysis was undertaken to determine if significant differences existed between either variance or mean of the perch and smelt wastewater. The results indicated no significant difference could be established for the BOD_5, COD, filtered TOC, SS, or TS. Similarly the nutrient values appeared comparable.

The characteristics of the combined waste are shown on table 3. 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 is shown in figure 4. These results indicate the dampening effect of mixing the component flows as the combined wastewater is stronger, but less variable on a day to day basis, than its component parts.

During the study water use in the plant was examined and was found to be relatively constant at about 295,000 gallons per day, irrespective of the volume of fish processed (figure 5). This would tend to indicate that adjusting the data on the basis of production would not reduce the observed variability. Table 4 gives values for BOD_5, COD, filtered TOC, SS, and TS in terms of pounds per 1000 pounds of fish landed. Comparing the values of

Table 3: 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%
Coefficient of Variation	46.4%	90.5%	30.9%	51.8%	14.7%	77.6%	10.8%
Number of sample	40	39	36	40	19	36	28

	Phosphate Unfiltered (mg/l)	Phosphate Filtered (mg/l)	Nitrite (mg/l)	Nitrate (mg/l)	Total Kjeldahl Nitrogen (mg/l)	Oil and Grease
Mean	22	19	0.031	1.057	136	46
Standard Deviation	±9	±6	±0.016	±0.734	±49	±28
Coefficient of Variation	43.7%	32.8%	51.6%	69.4%	38.9%	61.1%
Number of Samples	13	13	4	4	11	7

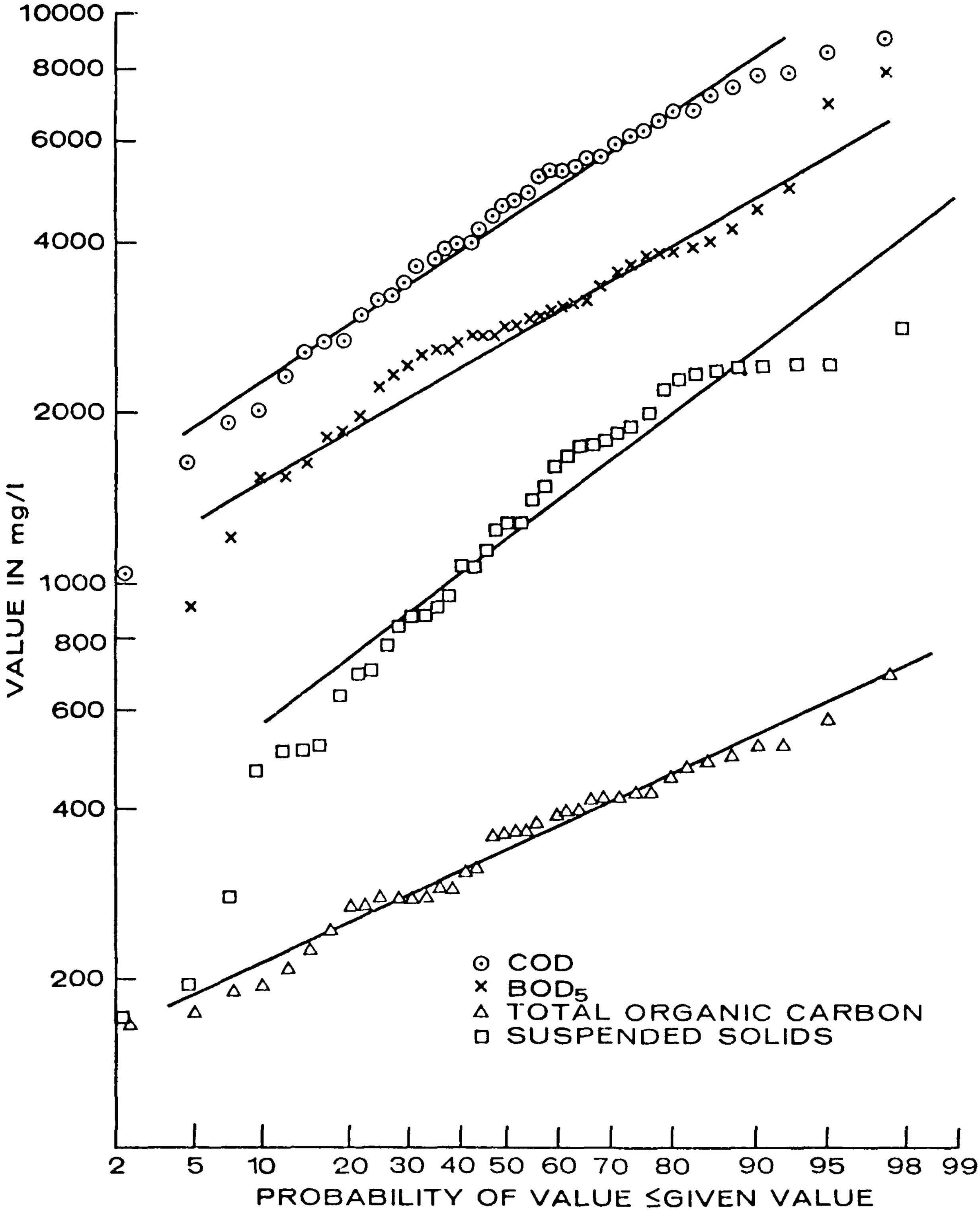

Figure 4. Combined Wastewater Probability Plot

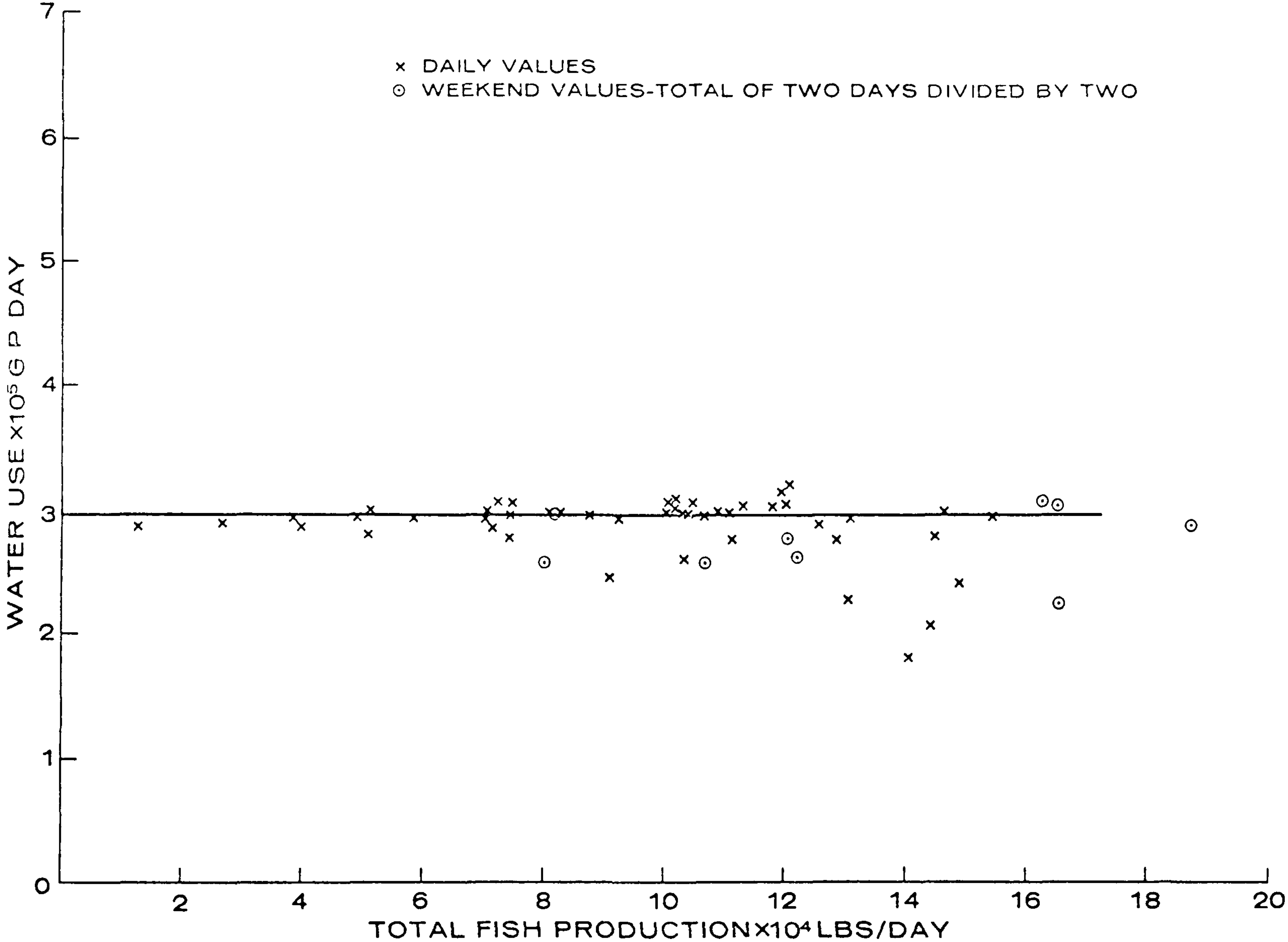

Figure 5. Water Use Against Total Fish Processed Per Day

Table 4: Combined Perch and Smelt Wastewater Characteristics

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

	BOD_5	COD	Filtered TOC	S.S.
Mean	4.5	8.0	0.57	2.3
Standard Deviation	±2.0	±3.6	±0.22	±1.3
Coefficient of Variation	45.4%	44.7%	38.0%	58.7%
Number of Samples	29	27	26	29

coefficient of variation on tables 3 and 4 it can be seen that there is little or no change. The exception is the COD in which the coefficient of variation was reduced from 90.5% to 44.7%.

The mean BOD_5:N:P ratio of the combined waste is approximately 150:7:1, this compared to 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 mg/l. Nitrite and nitrate values are again low, and were not determined following initial characterization. The similarity between the nutrient concentrations of the perch, smelt and combined waste and the marked increase in BOD_5 and COD in the combined waste suggests that increased contact time between the fish and the carrier water, as experienced by the combined waste, leads to further solubilization of the fish flesh.

To examine whether prolonged contact between offal and the carriage water could account for the increased strength of the combined waste, waste from the perch and smelt processing machines were collected and samples withdrawn after varying contact periods. Figure 6 is a plot of the percent increase of BOD_5, COD, and suspended solids with contact 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

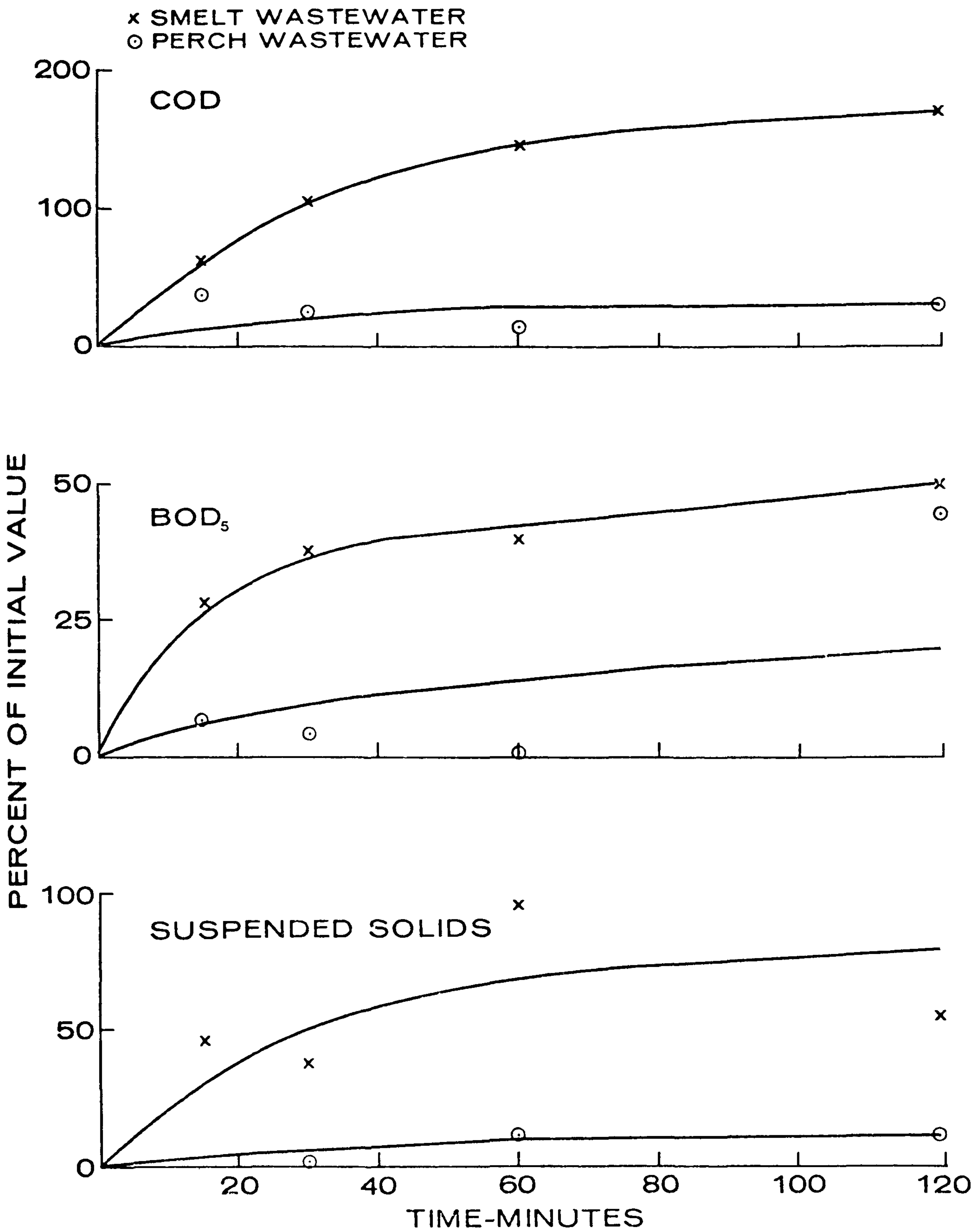

Figure 6. Contact Time-Perch And Smelt Wastewater

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.

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 stickliquor and it was deemed desirable to characterize this liquid especially in the light of its high strength.

Table 5 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 for the perch, smelt and combined wastewaters. The BOD_5/COD ratio of 0.98 may be compared to a BOD_5/COD ratio of 0.5 for domestic waste (Hunter and Heukelekian, 1965), and indicates the high degree of degradability of the stickliquor. 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.

Table 5: 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	633	5.0	5513	1210
Standard Deviation	±236	±2.3	±2835	±410
Coefficient of Variation	37.3%	45.6%	51.4%	38.8%
Number of Samples	7	4	5	2

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.

Comparison of Waste Characteristics

A comprehensive review of the existing literature (Riddle 1972) indicated that no characterization of perch, smelt or combined perch and smelt wastewater had been carried out. However, of the studies reviewed 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 6 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 such as species of fish processed, processing techniques and water usage.

Treatability Studies

Biological Treatment

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. The batch reactors used were filled with 15 liters of fish waste and 2 liters of liquor from the aerated lagoon. It was assumed this lagoon liquor would provide the source of acclimatized micro-organisms

Table 6: Review of Data from the Literature

Author (Fish Processed)	BOD_5 (mg/l)	Suspended Solids (mg/l)	Total Solids (mg/l)
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	-
Riddle (1972)			
(Perch)	1847	935	1810
(Smelt)	1152	599	1311
(Combined)	3044	1397	3070

necessary for each batch test. Air was supplied to the reactor at a rate of 3,500 c.c. per minute.

Figures 7 and 8 indicate the percentage of unfiltered and filtered 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 were considered to be "zero-order" with respect to the degradation of filtered and unfiltered BOD_5.

Stickliquor was added to the three reactors to monitor its effect on the biological degradation of the waste material. The addition of stickliquor did not appear to alter the "order" of the various reactions monitored.

The batch studies of perch, smelt and combined wastewater indicated removal of 90 percent of BOD_5 and in excess of 65 percent of soluble organic carbon during 10 days of aeration. Further aeration time would not substantially increase the removal efficiency. The addition of stickliquor markedly affected the biological system causing a drop in treatment efficiency. It was concluded that the batch reactor did not reach a steady state in the 20 days following stickliquor addition.

Following batch studies continuous reactors having detention times of 7.5 and 15 hours, 5, 10, and 15 days were employed. The 5, 10 and 15 days detention time reactors had no sludge recycle and the sludge age equaled the detention time. The 7.5 and 15 hour detention time reactors initially had a 3 day sludge age which was subsequently increased to 5 days by varying the amount of sludge recycled from the clarifier to the reactors.

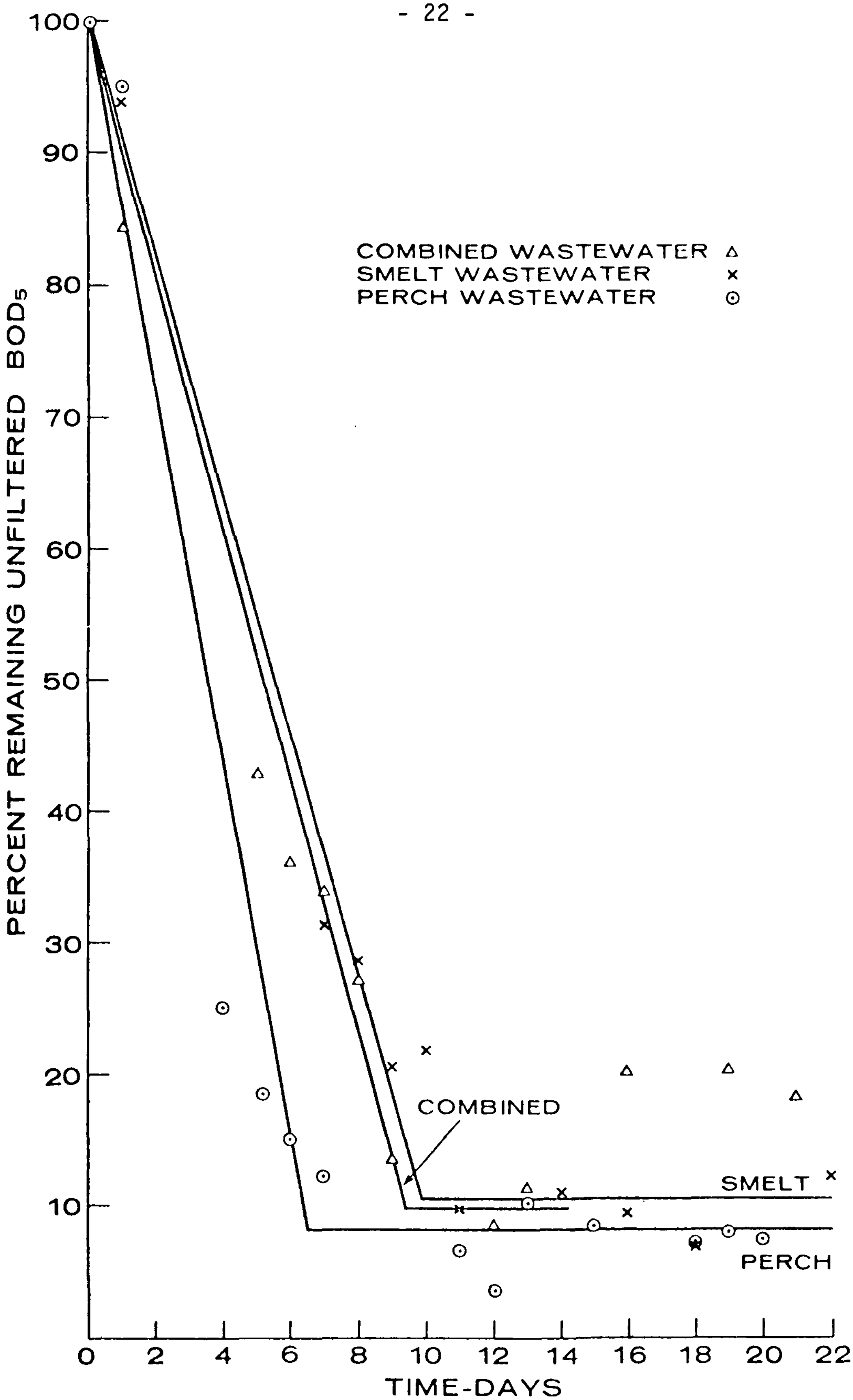

Figure 7. Batch Reactor Studies-Unfiltered BOD_5

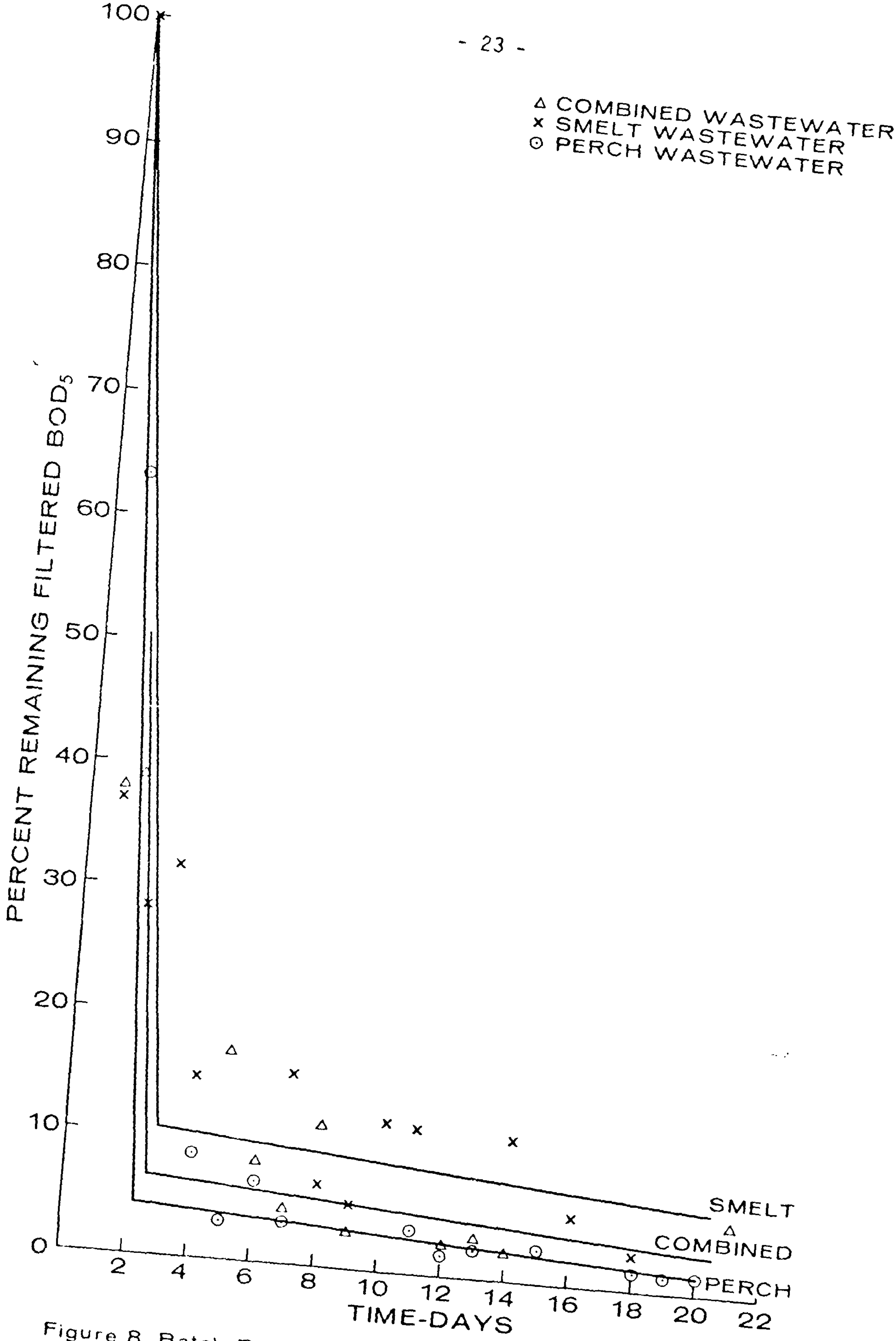

Figure 8. Batch Reactor Studies-Filtered BOD_5

Figure 9 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 9 indicates that a sludge age in excess of 3 days is required for maximum percentage removal of BOD_5, both filtered and unfiltered.

Figure 9 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 9 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.

Table 7 gives the residuals and percentage removals of BOD_5 for a batch reactor operated for 20 days. The percent removals of unfiltered and filtered BOD_5 in the batch reactor are 89 and 98 percent respectively for combined wastewater. This compares with 40 to 45 percent and 80 to 90 percent removals for unfiltered and filtered BOD_5 respectively in the continuous reactors.

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 nitrogen and 30 mg/l for unfiltered phosphate. Increasing the

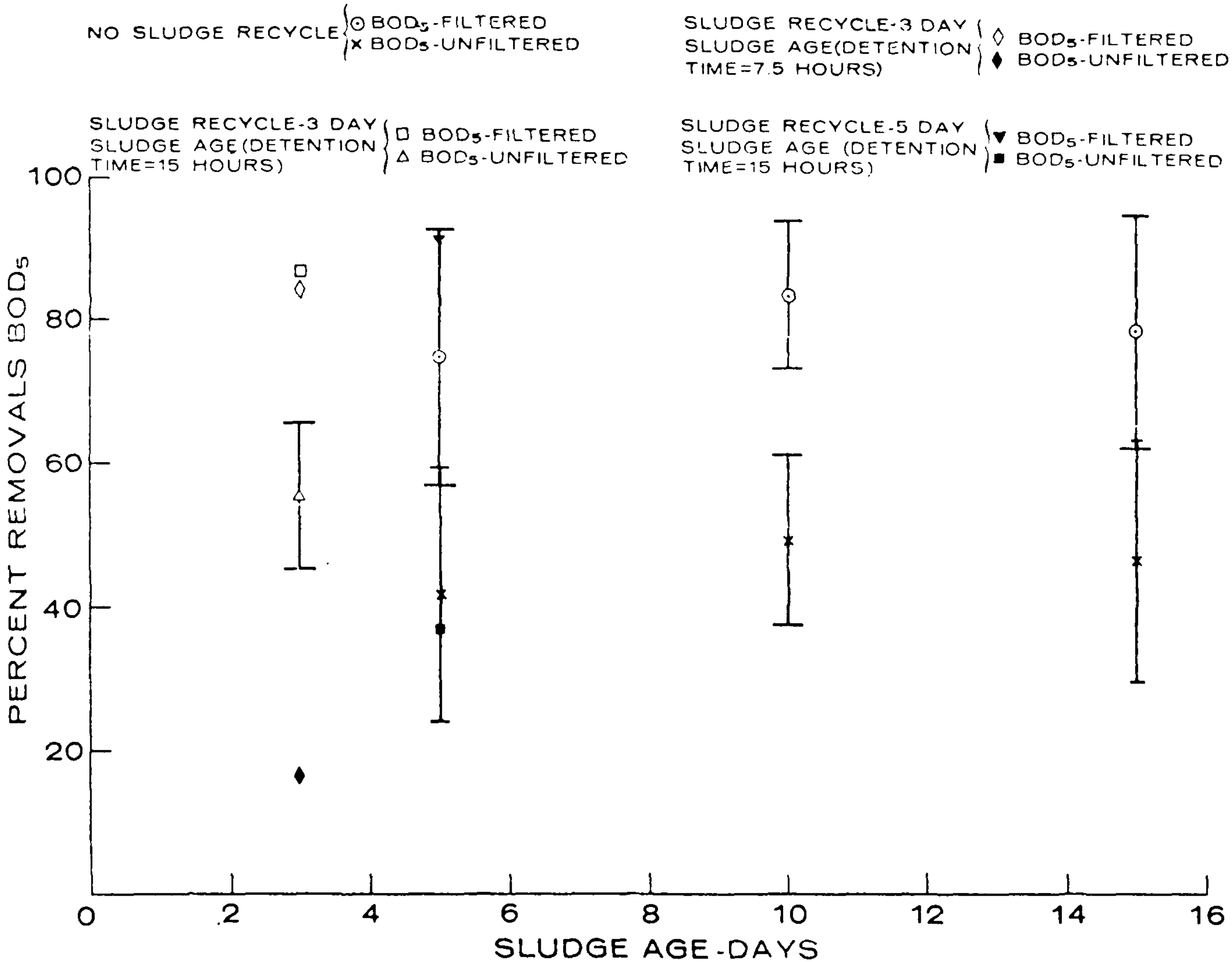

Figure 9. Continuous Reactor Studies-BOD_5 (Combined Wastewater)

Table 7: Residuals followed Biological Treatment and Percent Removal of BOD_5

Biological Treatment: Batch Reactors operated for 20 days (Combined Wastewater)

	BOD_5		Percent Removal of BOD_5	
	Filtered (mg/l)	Unfiltered (mg/l)	Filtered	Unfiltered
Perch Wastewater	10	150	97	92
Smelt Wastewater	40	150	94	88
Combined Wastewater	9	190	98	89

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.

Physical Pretreatment

Work by Claggett and Wong (1969) indicated significant reductions in BOD_5 and suspended solids in fish processing wastewater by the use of flotation, an advantage of this method being the recovery of flotable solids for fish meal production. Sedimentation and flotation tests were carried out in a preliminary study of the physical treatability of the wastes. Table 8 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 approximately 35 percent with a suspended 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.

Table 8: 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

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.

The results of sedimentation tests, on combined wastewater, shown in table 8, 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.

Conclusions

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

1) Type of fish processed,
2) Processing techniques,
3) Plant size, and
4) Water usage.

The wastewater from a fresh water fish processing plant 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 $\pm$ 1413 mg/l, is stronger than either the perch wastewater, with a BOD_5 of 1847 $\pm$ 1793 mg/l, or the smelt wastewater, with a BOD_5 of 1152 $\pm$ 631 mg/l, possibly due to prolonged contact.

The discharge of the high strength stickliquor to a biological treatment system would equal the loading from the processing plant. With a BOD_5 of 156,068 $\pm$ 90,000 mg/l, the discharge of stickliquor from fish meal plants is not recommended. Stickliquor should be recovered by evaporation or trucked away for land disposal.

The pollutional strength of perch and smelt wastewater increased with increased contact time between the solid waste material and the liquid waste. 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 has been found by other investigators 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.

The organic strength and nutrient concentrations in the waste suggest that biological treatment is 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 BOD_5 reaction rates were about 10 percent removed / day. The addition of 5 percent by volume of stickliquor to the batch biological systems decreased the reaction rates for both BOD_5 and total soluble organic carbon. Increased residual BOD_5 and total organic carbon concentrations, were observed even after 20 days of degradation.

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 but because of high nutrient concentrations relatively high levels of nitrogen and phosphorus may be expected in the effluent.

A preliminary analysis of physical treatment of combined wastewater indicated that flotation showed sufficient promise to warrant further study, giving a 40 percent removal in BOD_5. Sedimentation, however, only removed 19 percent of BOD_5 after 60 minutes of settling.

Acknowledgements

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