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Activated Sludge Treatment of a High Strength NSSC Mill Effluent

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ACTIVATED SLUDGE TREATMENT OF A HIGH STRENGTH NSSC MILL EFFLUENT

by

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ABSTRACT

Bench scale studies were carried out to investigate the feasibility of treating high strength Neutral Sulphite Semi-Chemical (NSSC) mill effluents using an activated sludge process.

Wastewater from Domtar Packaging Limited, Trenton, Ontario, was treated in a two-stage activated sludge system under different loading conditions. For comparison purposes, studies were conducted in a single-stage reactor operated as an extended aeration activated sludge system.

Experimental results indicated that the activated sludge process was not suitable for the treatment of this wastewater. Sludge bulking, foaming and poor oxygen transfer were the major problems encountered. The high concentration of dissolved solids contributed significant error to the determination of suspended solids; however, a procedure was developed for adjusting values which were in error. Bioassay tests showed that the untreated wastewater was toxic and activated sludge treatment did not significantly reduce the toxicity.

RÉSUMÉ

Des essais réduits ont permis d'étudier la possibilité de traiter par les boues activées les effluents très concentrés des usines de pâtes au sulfite neutre de sodium.

Des eaux usées de l'usine de la Domtar Packaging Limited de Trenton (Ontario) ont subi le traitement aux boues activées dans un système "biphasique" et dans des conditions de charges variables. A des fins de comparaison, des essais ont également eu lieu dans un réacteur "monophasique" fonctionnant comme un processus à boues activées en aération prolongée.

Les résultats de l'expérience indiquent que les boues activées ne conviennent pas au traitement de ces effluents. Les principaux problèmes ont été l'agrégation des boues, le moussage et un mauvais transfert de l'oxygène. La concentration élévee des substances solides en solution a faussé de façon notable le taux de matières en suspension; toutefois, on a mis au point une méthode pour compenser les valeurs erronées. Des essais biologiques ont démontré que les eaux brutes étaient toxiques et que le traitement aux boues activées n'en reduisait pas notablement la toxicité.

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CONCLUSIONS

1 Although the activated sludge process is capable of reducing the BOD_5 of high strength NSSC mill effluent, the overall operation and performance of the two-stage and the single-stage systems employed in this study, were unsatisfactory. Excessive foaming, oxygen deficiency and bulking sludge problems were encountered. This rendered the activated sludge processes unsuitable for the treatment of this particular wastewater.

2 Foaming restricted the rate of air addition and consequently an oxygen deficiency was encountered in the reactors. The use of an antifoaming agent for foam control in the two-stage activated sludge system was not considered to be economically feasible. In addition, the antifoaming emulsion caused solid-liquid separation problems.

3 Bulking sludge conditions, attributed to either filamentous organisms or a non-filamentous non-settling sludge, resulted in solid-liquid separation problems. In the latter case, it was apparent that the problem was related to the high total dissolved solids concentration.

4 By using pure oxygen, the concentration of dissolved oxygen in the single-stage activated sludge system was increased. Although better treatment efficiency was achieved, there was no improvement in the sludge settling characteristics.

5 The poor filterability of the wastewater, together with the high concentration of total dissolved solids, introduced significant error in the measurement of non-filterable solids by the conventional method of paper filtration.

Dilution of samples prior to filtration or centrifugation plus washing was found to be an acceptable procedure for the measurement of suspended solids in samples containing high concentrations of total dissolved solids.

6 The high strength NSSC mill effluent was toxic to rainbow trout. The median survival time (MST) was approximately four hours. Activated sludge treatment did not significantly reduce the toxicity, as the MST of the treated effluent varied from six to twelve hours.

7 Preliminary results of physical-chemical treatment using air stripping, coagulation, carbon adsorption and ozonation indicated that these methods were ineffective in removing the dissolved organic matter from the high strength NSSC mill effluent.

8 Although the activated sludge studies and physical-chemical treatment processes did not provide effective treatment of the concentrated NSSC mill effluent, it should be noted that, as reported in the literature, biological treatment of combined municipal and NSSC mill effluent have met with varying degrees of success.

1 INTRODUCTION

The semi-chemical pulping process was initially developed to utilize low-cost abundant hardwoods to produce pulps having outstanding physical properties for the manufacture of corrugating board and other products. Pulp is produced by a two-stage process. The wood chips are treated with a mild chemical in a digester followed by mechanical treatment in a refiner. In the digestion stage, the intracellular bondings are weakened by partial removal of hemicellulose and lignin while in the mechanical stage the individual fibres are physically separated. Pulp yields range from 60 to 80% depending on the end products desired and the extent of chemical treatment. The cooking time for semi-chemical pulping is less than that required for other pulping processes. Therefore, in contrast to fully cooked pulps which contain only minor amounts of lignin and hemicellulose, semi-chemical pulps contain 10 to 18% lignin, and 18 to 20% hemicellulose (1).

The Neutral Sulphite Semi-Chemical (NSSC) pulping process has been employed by Domtar Packaging Limited, Trenton, Ontario, since 1959. At the time of the experimental program, the mill was processing a mixture of hardwood, (poplar, maple, elm and birch) at a production capacity of approximately 170 tons per day of corrugated medium. The cooking liquor for the NSSC pulping process was prepared from sodium carbonate which was partially converted to sodium sulphite by the addition of sulphur dioxide. There was no chemical recovery in the mill, and the spent cooking liquor was discharged at approximately 110 m^3/day (24,000 IGPD) into two storage lagoons that had a combined total capacity of 38,000 m^3 (8.3 million Imperial Gallons). The stored spent liquor was used as road binder during the summer months. A continuous effort has been made to control and eliminate pollution at its source by in-plant methods. The installation of a new pressafiner in February, 1973, and the modification of mill operating procedures, reduced the mill effluent from more than 1,100 l/min (250 IGPM) to less than 380 l/min (83 IGPM). During the initial phase of studies which covered the period from June to October 1973, the average monthly effluent was 240 l/min (52 IGPM). The installation of additional facilities to regulate the flow rate and to increase white water storage further reduced the mill effluent to an average of 87 l/min (19 IGPM) after November, 1973.

Gehm (2), in a state-of-the-art review of pulp and paper waste treatment, reported that the volume of effluent from NSSC mills can be reduced by the practice of water recirculation. It was stated that the resulting effluent would have a BOD_5 concentration ranging from 1,500 to 5,000 mg/l and a suspended solids concentration of 400 to 600 mg/l. The BOD_5 concentration of the mill effluent at Domtar Packaging Limited, Trenton, was originally 4,000 mg/l, but it increased to 12,100 mg/l as the flow was reduced from 1,100 l/min (250 IGPM) to 87 l/min (19 IGPM).

A literature search failed to reveal whether it was feasible to treat the high strength NSSC effluent in a biological system. As a result, pilot scale aerated stabilization basin, pilot scale facultative stabilization basin and bench scale rotating biological contactor studies were carried out by Domtar Packaging Limited, at Trenton. At the same time, bench scale studies were carried out at the Wastewater Technology Centre (WTC), Burlington, to determine whether a two-stage or single-stage activated sludge process could be used to treat the high strength NSSC effluent.

The objectives of the project carried out at the WTC were as follows:

1. Investigate the feasibility of using either a single-stage or a two-stage activated sludge system for the treatment of high strength NSSC mill effluents.
2. Identify the operational problems and, if possible, provide solutions.
3. Conduct bioassays to measure the acute toxicity of the untreated and biologically treated wastewater.

In addition to the activated sludge studies, preliminary bench scale studies were carried out to evaluate the amenability of the high strength NSSC mill effluent to physical-chemical treatment methods. Results of this part of the study are presented in Appendix A.

2 LITERATURE REVIEW

Full scale activated sludge treatment of combined wastewater from an integrated kraft and NSSC mill has been reported by Perman and Burns (3). The main mill effluent containing wastewater from the NSSC pulping process had a BOD_5 and suspended solids concentration of 210 and 800 mg/l, respectively. After primary clarification, this effluent was combined with unsettled bleaching wastes. BOD_5 and suspended solids concentrations of this combined wastewater averaged 180 and 110 mg/l, respectively. Following three hours of activated sludge treatment and two hours of secondary clarification, 70% BOD_5 and 22% suspended solids reductions were achieved.

In pilot plant studies, Farrell et al (4) evaluated the treatability of combined wastewater from domestic sources and an integrated NSSC pulp and paper mill. The BOD_5 of the domestic wastes averaged 133 mg/l and that of the mill effluent, 1,850 mg/l. The most efficient process for the treatment of this wastewater was a combined trickling filter and extended aeration system. The former, operated as a roughing filter, was loaded at 3.7 to 4.5 kg $BOD_5/m^3 \cdot day$ (230 to 280 lb $BOD_5/1{,}000\ ft^3 \cdot day$). The latter was the major treatment unit operated at 0.09 to 0.64 kg $BOD_5/kg \cdot MLSS \cdot day$. The BOD_5 removal efficiency of the trickling filter ranged from 9 to 18% and that of the extended aeration unit from 74 to 94%. For design purposes, a loading of less than 0.2 kg $BOD_5/kg\ MLSS \cdot day$ was suggested. For the blended effluent having a large portion of BOD_5 contributed by the NSSC mill effluent, the efficiency of the treatment system was reduced, i.e., when the percentage of BOD_5 contributed by the NSSC mill effluent was increased from 40 to 90%, the effluent BOD_5 of the treatment system increased from 30 to 120 mg/l. Accordingly, it was recommended (4) that for the treatment of combined wastewater, the BOD_5 contributed by the NSSC mill effluent should not be greater than 90%.

Voelkel et al (5) reported that a combination of dilute pulping effluents from calcium base sulphite, ammonia base sulphite, de-inking and the NSSC pulping processes could be treated successfully with municipal wastewater in an activated sludge system. The blended wastewater had a BOD_5 and suspended solids concentration of 510 and 175 mg/l, respectively. In a contact stabilization pilot plant operated at a F/M ratio of approximately 0.3, 91% of the BOD_5 and 78% of the suspended solids were removed. Filamentous sulphur bacteria were observed in the treatment system; however, these could successfully be controlled by the addition of 5 to 10 mg/l of chlorine to the return sludge.

In activated sludge studies evaluating combined treatment of domestic sewage and weak NSSC pulping wastes (6), it was demonstrated in pilot plant operation that NSSC mill effluent could be treated successfully with domestic sewage. The mill effluent consisted of 88% process water from pulp washing and bleaching and 12% wastewater from paper mill operation. BOD_5 and suspended solids concentrations of this waste stream averaged 567 and 486 mg/l, respectively. After being combined with municipal sewage having a BOD_5 concentration of 107 mg/l and a suspended solids concentration of 138 mg/l at a volume to volume ratio of 1:1, the resulting waste mixture used for the pilot plant study had a BOD_5 and suspended solids concentration of 337 and 312 mg/l, respectively. Primary clarification removed 76% of the suspended solids and 25 to 30% of the BOD_5. Subsequent treatment in the activated sludge plant which was operated either as a conventional or contact stabilization unit, removed an additional 56 to 85% of the BOD_5. In some cases, the suspended solids concentration was higher in the process effluent than in the influent. Bulking sludge, that appeared to be caused by filamentous organisms, was the only problem noticed in treating the mixed wastes.

In addition to the pilot scale studies, it has been reported (6) that a bench scale reactor treating 100% mill effluent was operated at a loading of approximately 0.4 kg BOD_5/kg MLSS•day for three months. With the detention time in the aeration cell being approximately two hours, the BOD_5 was reduced by 76 to 95% while the suspended solids reduction was 60 to 91%. Although there was a gradual increase in SVI from 115 to 324 ml/g and a gradual decrease in MLSS from 5,000 to 2,980 mg/l during the experimental period, no deterioration in effluent quality was reported.

The literature review revealed that biological treatment of dilute NSSC mill effluents had been studied. However, no relevant information was available on activated sludge treatment of high strength NSSC wastewater and, therefore, this study was developed.

3 EXPERIMENTAL PROGRAM

3.1 Schedule of Experiments

The experimental schedule is outlined in Table 1. Both the two-stage and the single-stage operation commenced on July 24, 1973. Studies were conducted at three feed rates in each system over an experimental period of six months. The changes in operating conditions were considered necessary in order to upgrade the experimental program following an assessment of previous experimental results.

3.2 Reactors for Experiment

The single-stage reactor used in the study is shown in Figure 1. It consisted of a 150-litre aeration tank and an 8.5-litre clarifier. Air was introduced into the aeration tank through a circular perforated PVC diffuser ring located on the base of the tank. Feed and return sludge rates were controlled by variable speed peristaltic pumps.

The equipment for the two-stage experiment consisted of two identical single-stage reactors operated in series as shown in Figure 2. The aeration tank and the clarifier had a capacity of 51 and 8.5 litres, respectively. Variable speed peristaltic pumps were employed for the feed and sludge recycling. Each stage had its own sludge recycling. PVC diffuser rings were also used to introduce air into the aeration tanks.

3.3 Characteristics of Wastewater

The NSSC mill effluent was shipped from Domtar Packaging Limited, Trenton, to the Wastewater Technology Centre, Burlington, in polyethylene lined 200-litre (45 gallon) barrels. Upon arrival, the barrels were stored at 4°C. Wastewater characteristics were established by analyzing grab samples collected from the barrels following mixing of the contents.

As mentioned previously, there was a significant reduction in the volume of mill effluent after November, 1973, resulting in a remarkable increase in the strength of the wastewater. For comparison,

TABLE 1. EXPERIMENTAL SCHEDULE

Date From	 To	Feed Rate (1/day)	Aeration Tank Detention Time (days)	Days in Operation	Remarks
A: Two-Stage Treatment System					
July 24/73	Aug. 28/73	51	1	35	From Aug. 7 to Aug. 27/73, antifoam DB-110 was used.
Aug. 28/73	Oct. 31/73	26	2	64	
Oct. 31/73	Jan. 22/74	13	4	82	From Dec. 12/73 to Jan. 7/74, antifoam Eff-101 was used.
B: Single-Stage System					
July 24/73	Oct. 15/73	7.5	20	83	
Oct. 15/73	Dec. 7/73	15	10	53	From Nov. 21/73 to Dec. 7/73, pure oxygen was used.
Dec. 7/73	Jan. 22/74	7.5	20	46	

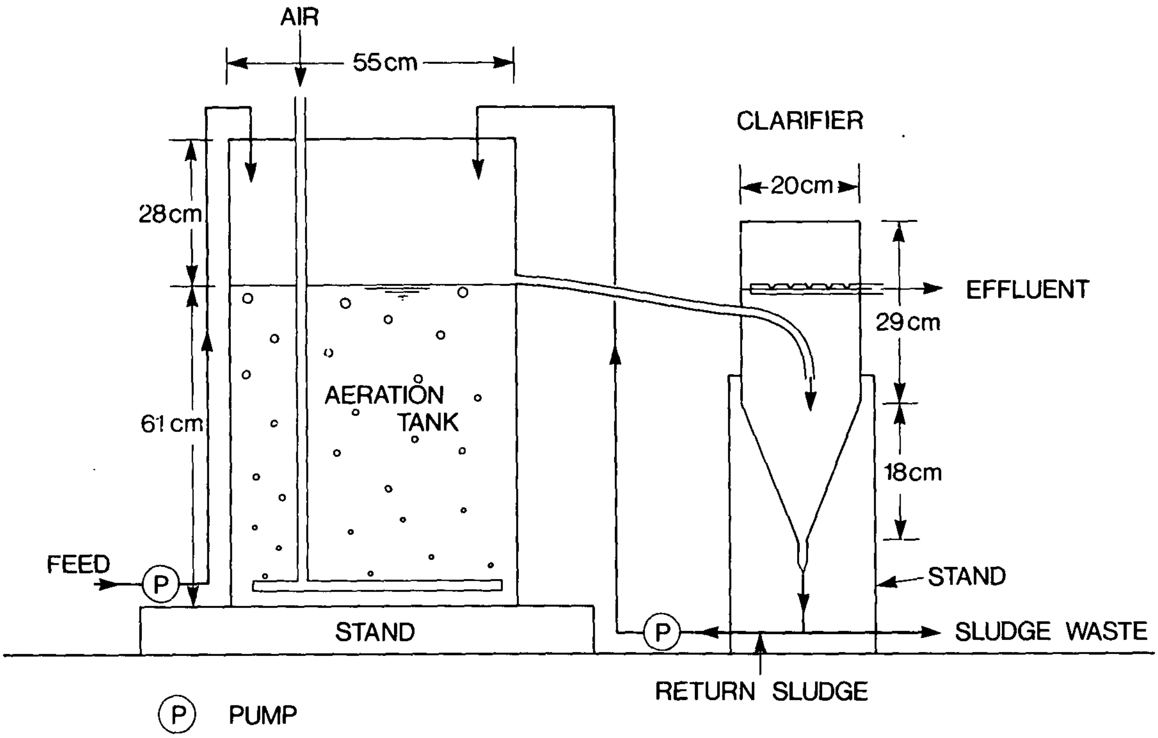

FIG. 1 SINGLE - STAGE REACTOR

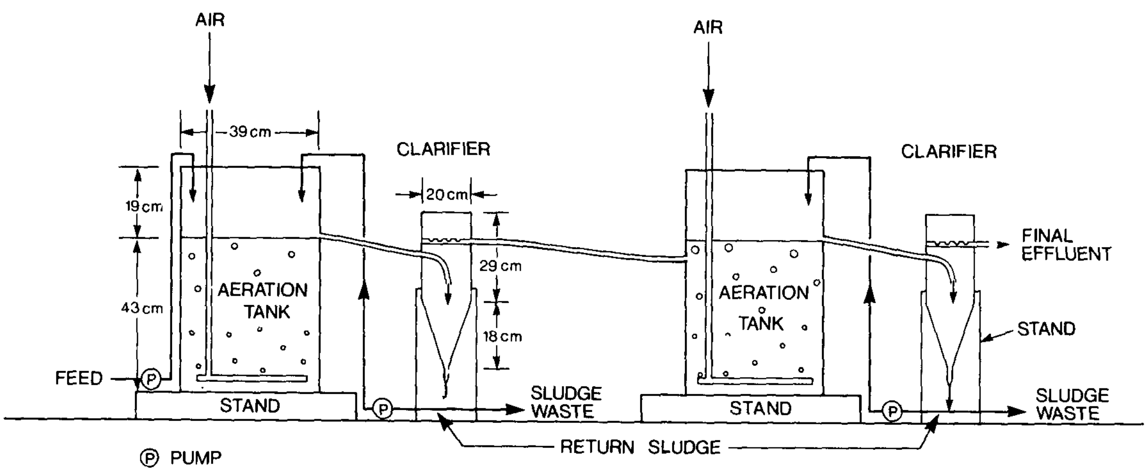

FIG. 2 TWO - STAGE REACTOR

the characteristics of the wastewater used before and after November, 1973, are presented separately in Table 2. As can be seen from the table, there was an increase of 89% in the BOD_5 and 115% in the total dissolved solids.

TABLE 2. CHARACTERISTICS OF WASTEWATER*

A. From July 24, to Oct. 31, 1973 (26 samples)			
	Range	Average	Standard Deviation
pH	7.0 - 9.0	7.8**	-
BOD_5 (mg/l)	2,000 - 10,600	6,400	3,100
TOC (mg/l)	720 - 13,400	7,400	3,900
COD (mg/l)	2,800 - 32,700	21,800	8,600
TDS (mg/l)	5,500 - 38,900	22,700	15,200
TKN (mg/l)	56 - 620	270	111
TP (mg/l)	10 - 132	60	36
H_2S (mg/l)	trace - 25	6	9
SS (mg/l)	95 - 3,650	1,400	1,100

B. From Nov. 1, 1973 to Jan. 22, 1974 (18 samples)			
	Range	Average	Standard Deviation
pH	6.9 - 7.7	7.2**	-
BOD_5 (mg/l)	10,200 - 15,300	12,100	3,600
TOC (mg/l)	13,100 - 15,900	14,300	780
COD (mg/l)	47,700 - 54,100	48,200	4,800
TDS (mg/l)	45,200 - 54,000	48,700	4,600
TKN (mg/l)	170 - 230	200	20
TP (mg/l)	21 - 57	31	11
H_2S (mg/l)	trace - 13	4	6
SS (mg/l)	1,400 - 4,100	2,300	790

BOD_5 - Five-day Biochemical Oxygen Demand (unfiltered)
TOC - Total Organic Carbon
COD - Chemical Oxygen Demand (unfiltered)
TDS - Total Dissolved Solids
TKN - Total Kjeldahl Nitrogen
TP - Total Phosphorus
SS - Suspended Solids
* - Unless specified otherwise samples were filtered
** - Median value

The concentration of BOD_5 ranged from 2,000 to 15,300 mg/l and total dissolved solids from 5,500 to 54,000 mg/l. Although significant amounts of nitrogen and phosphorus were present in the wastewater, the concentrations were not adequate to maintain an optimum growth condition for microorganisms in the activated sludge system. Therefore, additional nutrient was added to this high strength NSSC mill effluent.

The pH of the wastewater varied between 6.9 and 9.0 with the median value being 7.6. No adjustment was necessary because the pH values were within the acceptable range for biological treatment.

The wastewater had a high foaming tendency. During the operation of treatment systems, excessive foaming was observed in the reactors. Foaming restricted the rate of air supply, resulting in an oxygen deficiency in the reactor.

An evaluation of oxygen transfer characteristics of the wastewater is presented in Appendix B. As shown in Table B-1, the oxygen transfer coefficient (α) ranged from 0.30 to 0.41, indicating that the efficiency of oxygen transfer to the wastewater was very low in comparison to the values presented in Table B-2. This could be attributed to the presence of high concentrations of total dissolved solids and foaming substances (surface active agents) which restrict molecular diffusion of oxygen at the gas-liquid interface.

3.4 Change in Characteristics of Wastewater During Storage

An investigation was conducted to determine the change in wastewater characteristics due to storage. Several 1-litre samples were taken from the storage barrel after the contents were mixed. One sample was analyzed immediately and the rest were divided into two groups. One group was stored in a cold room at 4°C and the other was kept in a laboratory at room temperature (approximately 22°C).

After specific time intervals, one sample was taken from each group for chemical analyses. The analytical results shown in Table 3 indicate that the wastewater could be stored up to four weeks at 4°C without microbial degradation. The variations in BOD_5, TOC, COD, TDS, TKN and TP over the 28 days storage period at 4°C were within the limits of experimental error in the analytical determinations. Only a slight change in wastewater characteristics occurred within one week of storage at room temperature. Based on these results, it was concluded that the storage of NSSC mill effluent in the 4°C temperature controlled room for a period up to four weeks did not significantly affect the waste characteristics.

TABLE 3. CHANGE IN WASTEWATER CHARACTERISTICS DURING STORAGE

Storage Period (week)	Storage Temp. (°C)	pH	TOC (mg/l)	BOD_5 (mg/l)	COD (mg/l)	TDS (mg/l)	TKN (mg/l)	TP (mg/l)
Original Sample		7.7	7,700	7,000	27,100	25,100	95	18
1	4	7.7	-	7,300	27,500	25,000	89	13
	22	6.6	-	7,600	26,700	25,100	93	13
2	4	7.6	7,500	6,000	25,800	25,000	82	13
	22	6.2	7,100	5,700	25,400	23,200	89	14
3	4	7.4	7,900	6,700	26,000	24,600	73	-
	22	6.0	7,000	5,200	24,900	22,900	77	-
4	4	7.4	8,200	-	27,000	-	81	9

3.5 Experimental Procedures

Activated sludge from the Burlington Skyway Sewage Treatment Plant was used as a source of microorganisms to seed the reactors. The sludge was screened to remove large particulate matter which might interfere with the operation of the treatment systems. Ammonium chloride (NH_4Cl) and di-ammonium hydrogen phosphate [$(NH_4)_2HPO_4$] were added to the wastewater to provide a BOD:N:P ratio of 100:5:1. Unless specified otherwise, compressed air was used to supply dissolved oxygen and to provide mixing in the aeration tank.

For routine monitoring, feed rate, return sludge rate, dissolved oxygen, pH and concentration of mixed liquor suspended solids were measured daily, and if necessary, adjusted to the values specified by the experimental design. The analyses of process influent and effluents included BOD_5, TOC, total dissolved solids, suspended solids, total Kjeldahl nitrogen and total phosphorus. Excess sludge was wasted manually to maintain the desired solids concentration in the reactors.

3.6 Analytical Procedures

BOD_5 and COD analyses were performed according to Standard Methods (7). TOC's were determined using a Beckman Infrared Carbon Analyzer. TKN and phosphorus were analyzed by wet chemical colourimetric techniques according to methods specified by Technicon Instruments Corporation. H_2S determination was carried out using a Hach colourimeter.

3.6.1 Problems associated with the determination of suspended solids

One of the problems encountered in the study was associated with the analytical method used for measuring the suspended solids. The determination of influent, effluent, and mixed liquor suspended solids was carried out using 47 mm diameter glass fibre papers (Gelman Type A). Because of the poor filterability of samples (measurement of the filterability of sludges is illustrated in Appendix C), difficulty was encountered in filtering samples of large volume. Although 20 ml or less of sample volume was used for suspended solids determination, the filtration time for these samples ranged from one to four hours depending on sample size and solids concentration. This resulted in an estimated evaporation of 10 to 30% of the liquid from the sample. Because of the high concentration of total dissolved solids, the evaporation left a significant amount of dissolved solids residue on the filter paper, resulting in suspended solids concentrations much greater than the actual values.

Measures undertaken to correct the problem are illustrated in the two methods described below. Initially, these methods were developed to determine the amount of error introduced by the high concentration of total dissolved solids. Later, they were used to determine correction factors for the questionable suspended solids results obtained in the study. Since both methods gave reliable results, it is suggested that either one be used for the determination of suspended solids from samples containing high total dissolved solids.

3.6.1.1 Centrifuging-washing method. Five, 200 ml samples taken from the aeration tank were centrifuged simultaneously at 10,000 rpm for 10 minutes. The liquid portion of the samples was then decanted, leaving only the sludge in the centrifuge tubes. The sludge in one of the tubes was removed and placed in an evaporation dish for solids determination. For the four remaining tubes, distilled water was added to wash out dissolved solids in the sludge. Following mixing and centrifuging, the supernatant was decanted and the sludge in one of the tubes was scraped into an evaporation dish for solids determination. The procedure was repeated on the remaining samples until the fifth, 200 ml sample had received a total of four washings.

The suspended solids results obtained from centrifuging and washing on two sets of samples are presented in Figure 3. For comparison, the suspended solids concentrations determined by the conventional paper filtration method are also presented. As indicated, the paper filtration method gave erroneous results which were four to five times higher than the actual suspended solids concentration. The figure also shows that, after the second washing, the dissolved solids had a minimal effect on the determination of suspended solids. Additional results on suspended solids determined by this method are presented in Section 3.6.1.3.

3.6.1.2 Dilution method. Dilution of samples with distilled water prior to paper filtration was used to reduce the filtration time by decreasing the solids concentration. The dilution factor employed was defined as the ratio of the volume of sample plus dilution water, to the volume of sample used. After mixing, the diluted samples were

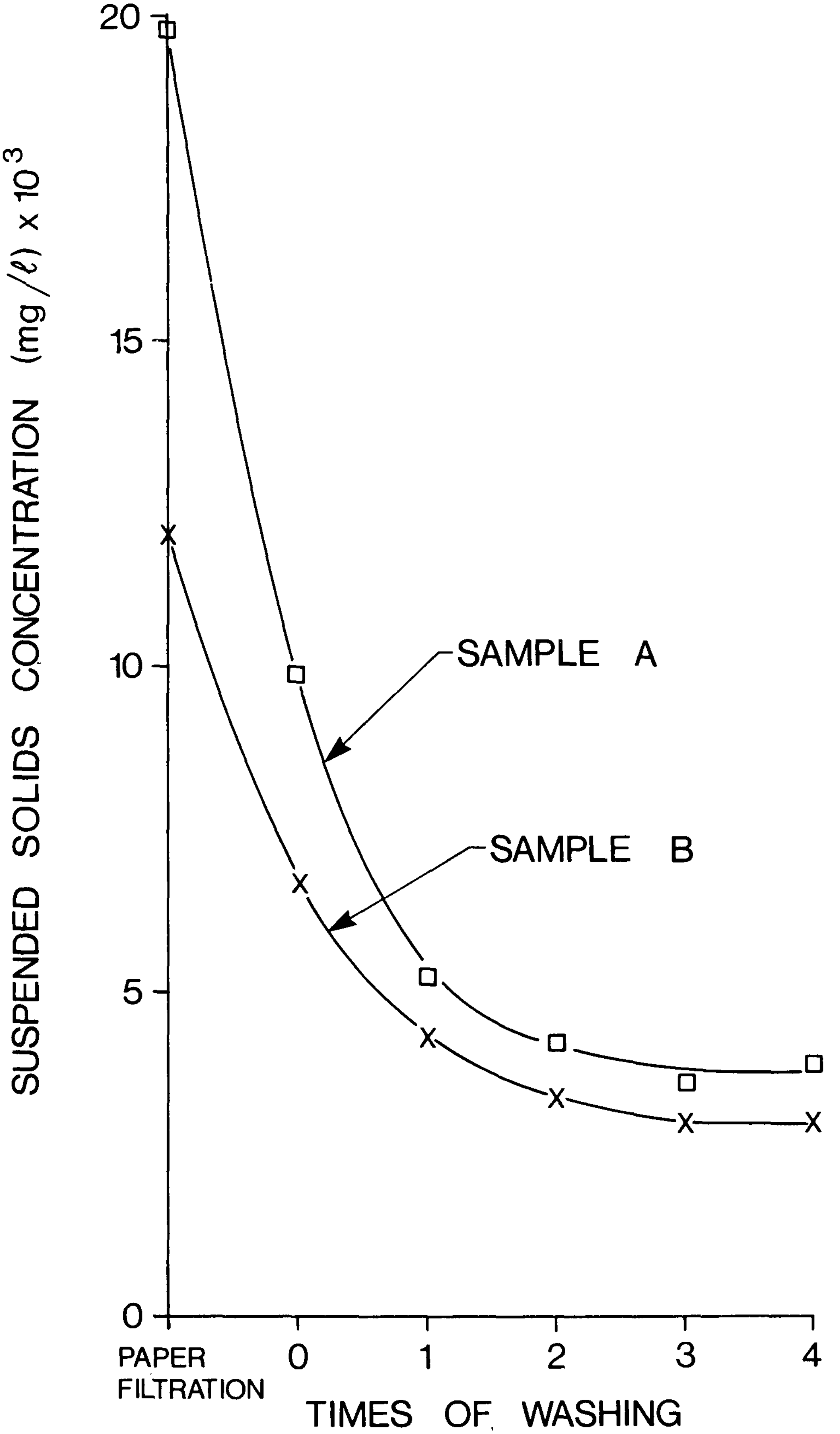

FIG. 3 RESULTS OF SUSPENDED SOLIDS DETERMINATION BY CONVENTIONAL PAPER FILTRATION AND CENTRIFUGING-WASHING METHODS

filtered through glass fibre papers for suspended solids determination. To determine the original suspended solids concentration, results obtained were corrected according to the dilution factor.

Figure 4 shows the results of dilution tests on five sets of samples taken from the single-stage reactor, indicating that the effect of dissolved solids on the determination of sludge concentration was negligible after samples were diluted 20 times or more. Samples without dilution exhibited erroneous results which were approximately five times higher than the anticipated values.

3.6.1.3 Establishment of correction factors. The problem associated with the determination of suspended solids was not identified until the middle of January, 1974, when the study was almost completed. All suspended solids had been determined by the conventional paper filtration method and, thus, all results obtained were in error. Consequently, a correction factor was established by developing a relationship between the results of paper filtration and the centrifuging-washing technique. The correction factors for influent, effluent and mixed liquor suspended solids are presented in Tables D-1, D-2 and D-3 of Appendix D. A comparison of the two methods gave correction factors of 1.7, 4.2 and 4.4 for influent, mixed liquor and effluent samples, respectively. The difference in the correction factors could be attributed to different concentrations and characteristics of the influent, effluent and mixed liquor suspended solids. All suspended solids values presented in the report have been corrected by dividing the results obtained from the paper filtration method by the corresponding correction factors.

3.7 Bioassay Procedures

Bioassays were performed on the raw wastewater and effluents from activated sludge systems to evaluate the process toxicity reduction capabilities. Juvenile rainbow trout (Salmo gairdneri) were used as test organisms in the study. Due to the limited volume of sample available for testing, only static bioassays were carried out. Median

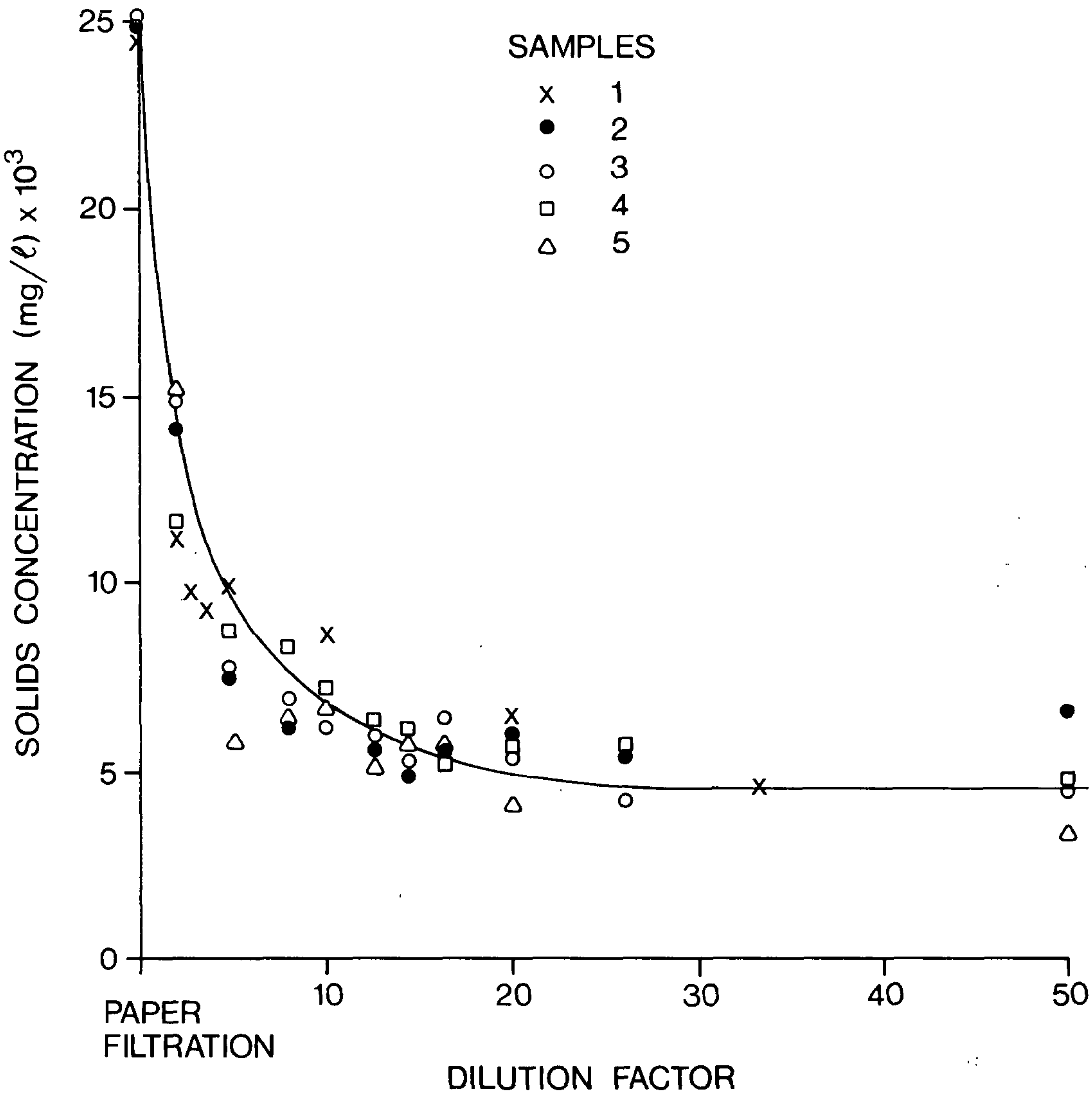

FIG.4 RESULTS OF SUSPENDED SOLIDS DETERMINATION BY CONVENTIONAL PAPER FILTRATION AND DILUTION METHODS.

survival time (MST) was used as the parameter to measure toxicity reduction. All bioassays were carried out on 65% test solutions (8) in a bioassay laboratory having the temperature controlled at 15±1°C. Compressed air was supplied at 50 cc/min to maintain the dissolved oxygen at greater than 6 mg/l in the test containers.

To qualitatively determine the toxicity level in the untreated and treated effluents, the first set of bioassays was carried out in 1-litre beakers containing three rainbow trout. This preliminary bioassay test procedure would have been replaced by the standard test specified in the guidelines for effluent regulations (8) if the results indicated that the regulatory standard (9) could have been met. Unfortunately, this was never achieved in the study and the preliminary test procedure was adopted for subsequent testing.

Fish weight during bioassays ranged from 0.5 to 1.5 grams providing a loading density of 0.6 to 0.2 l/g/day in the 1-litre test containers. Compared to the recommended minimum loading density of 2 l/g/day as specified in the guidelines (8), this lower volume-to-weight ratio could affect results in such a way that less toxicity would be detected (10). Therefore, the MST values presented in the report would be lower, had the standard test procedure been followed.

Since the pH of the untreated wastewater was within the acceptable range for bioassay testing, no adjustment was required. The pH of the biologically treated effluent ranged from 7.0 to 9.2. For samples with a pH of greater than 8.5, neutralization was carried out prior to bioassay testing. During the bioassay, an increase in pH was observed in the treated effluents requiring further additions of acid to maintain a constant pH level throughout the test. The effect of this continuous pH adjustment on bioassay results was also investigated in the study.

Attempts were made to reduce the toxicity by physical-chemical methods such as foam fractionation, carbon adsorption and ferric chloride addition. Results of bioassays carried out on wastewaters subjected to these treatment methods are presented in Appendix A.

4 EXPERIMENTAL RESULTS AND DISCUSSIONS

As mentioned previously, three loading conditions were studied for both the two-stage and single-stage activated sludge systems (Table 1). The operating conditions and experimental results of each loading are presented and discussed below. Daily operating data such as BOD_5, COD, TOC, SS, MLSS, TDS, DO, pH, TKN and TP for both treatment systems are presented in Appendix E.

4.1 Two-Stage Operation

By operating the activated sludge system at higher loading rates, the two-stage system, compared to the single-stage, offers the advantage of using smaller reactors. It is less subject to upsets by shock loads and provides a more stable operation. It is particularly suitable for the treatment of high strength wastewaters because the first reactor can be highly loaded, operated as a roughing stage with the second reactor serving as a polishing stage.

An attempt was made, therefore, in this study, to operate the two-stage system at high organic loadings. Although a relatively long detention time in the reactor was used in all three phases of the operation, the organic loading applied to the reactors was still in the range of a high rate activated sludge process due to the high BOD_5 concentration of the wastewater.

4.1.1 Phase 1

This phase of the two-stage operation was conducted over a period of 35 days with the treatment system being fed at 51 l/day. The detention time in the reactors of both stages was one day and that in the clarifiers was approximately five hours. In order to avoid denitrification which might occur in the clarifier due to a long detention time, a high return sludge rate (200% of feed rate) was used to facilitate a rapid recycle of the settled sludge to the reactors. According to Guo (11), this high sludge return rate should also favour a high protozoa population which is recognized as an important factor in obtaining a better effluent quality.

The organic loadings of the first and the second stages were 2.7 and 1.3 kg BOD_5/kg MLSS•day, respectively. The average concentration of MLSS was 3,300 mg/l in the first stage and 2,200 mg/l in the second stage reactor.

Two weeks were allowed for acclimation of the activated sludge. Experimental results for the operational period from day 15 to day 35 are presented in Table 4. Data collected from day 17 to day 24, when exceptionally low strength wastewater was used, are not included.

TABLE 4. AVERAGE OPERATING RESULTS IN PHASE 1 OF THE TWO-STAGE OPERATION

Parameters	Influent	Effluent				
		1st Stage	% Red.	2nd Stage	% Red.	Total % Red.
pH	7.4	8.3	--	8.6	--	--
BOD_5 (mg/l)	8,800	2,900	68	750	74	92
SS (mg/l)	1,600	550	65	420	23	73
TOC (mg/l)	10,000	5,400	47	3,700	31	63
COD (mg/l)	26,400	17,400	34	11,100	37	58
TDS (mg/l)	29,000	22,200	23	6,700	70	77
TKN (mg/l)	395	231	42	111	52	71
TP (mg/l)	100	59	41	37	37	63

As indicated in the table, a 92% BOD_5 reduction was obtained in the treatment system with the majority removed in the first stage reactor. Significant reduction in suspended solids and total dissolved solids was also observed.

The influent and effluent BOD_5 concentrations versus days of operation are presented in Figure 5. The day-to-day fluctuation in the BOD_5 of process effluents after two weeks of operation were within a small range indicating that the system was operating at a steady state condition.

Although significant BOD_5 reduction was obtained, difficulty was encountered in maintaining an adequate dissolved oxygen concentration

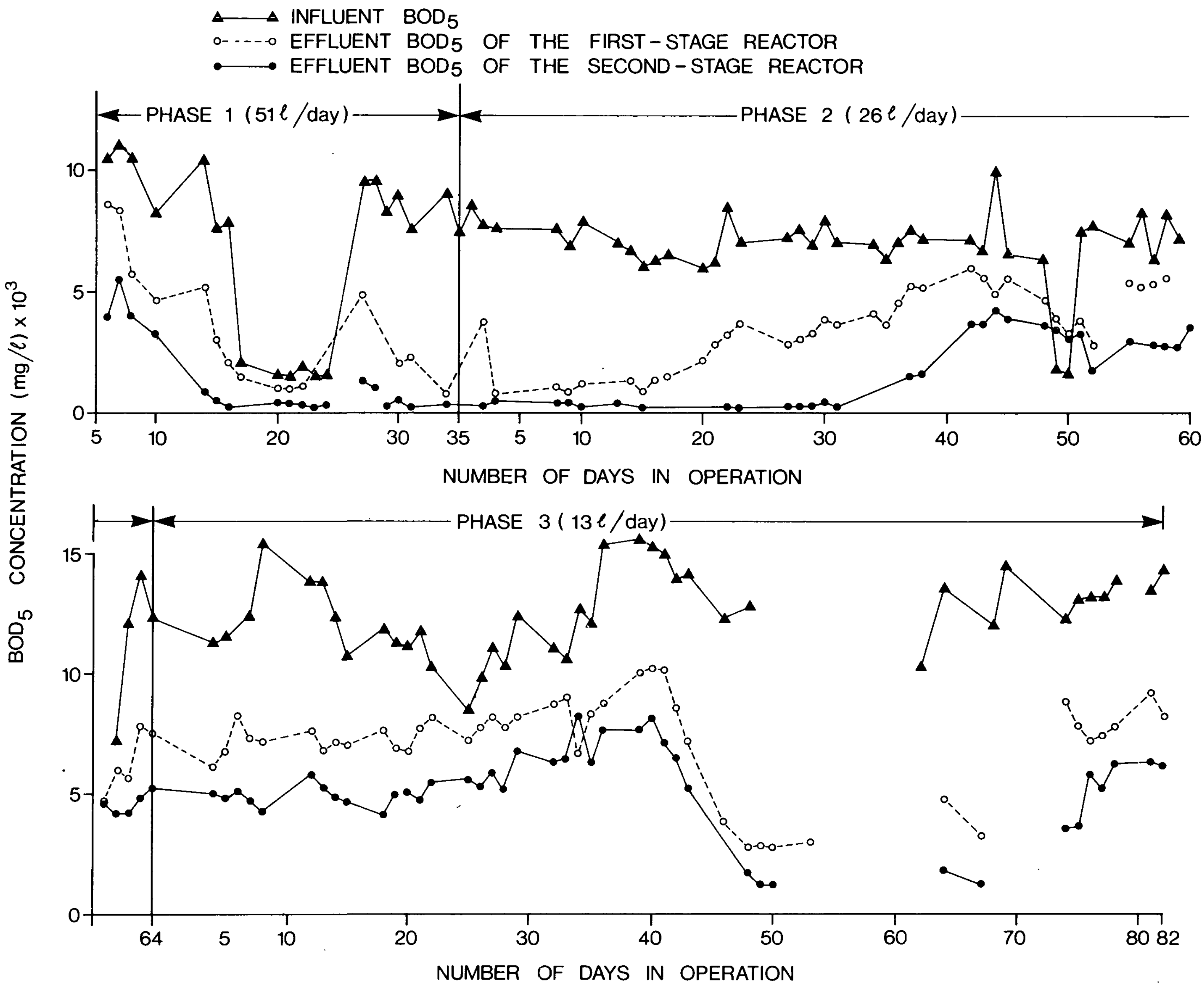

FIG. 5 BOD_5 CONCENTRATION FOR THE TWO-STAGE SYSTEM.

in the aeration tank. As indicated in Appendix E, only minimal dissolved oxygen ($\leq$0.5 mg/l) was measured in the aeration tanks of both stages. This could be attributed to the high organic loading employed and the poor oxygen transfer characteristics of the wastewater. Efforts to increase the rate of compressed air addition produced excess foam which resulted in a loss of sludge from the reactor. Modification of the reactor by increasing the free board did not improve the situation. As a result, Dow Corning DB-110 antifoam emulsion was selected for foaming control. The antifoam emulsion was diluted 100 times with tap water and pumped into the aeration tanks of both stages at 5 ml/min. This was the minimum dosage providing an effective control of foaming at the aeration rate necessary to maintain the oxygen level at greater than 0.5 mg/l. The diluted DB-110 antifoam emulsion had BOD_5, TOC, COD, TKN and TP concentrations of 123, 383, 1,010, 0.6 and 0.1 mg/l, respectively. Compared to the corresponding values of the high strength wastewater used, the organic load imparted to reactors by the antifoam was negligible. The addition of antifoam enabled more air to be introduced into the reactor and, as shown in Appendix E, a significant increase in dissolved oxygen was measured in the aeration cells of both stages.

A layer of scum approximately 10 cm in depth developed on the surface of the first stage clarifier after two weeks of antifoam addition. The same phenomenon occurred in the second stage clarifier a week later. Analytical results revealed that nitrate and nitrite were not detectable in effluent samples, indicating that the scum formation was not due to denitrification in the clarifier. No filamentous microorganisms were observed in sludge flocs. Although experiments were not carried out to determine the cause of scum formation, it was suspected that this was due to the addition of the antifoam emulsion.

Sludge flocs from both stages consisted of normally developed bacterial flocs. Opercularia were abundant in reactors of both stages, but more species of protozoa were present in the second stage. Photomicrographs of sludge flocs taken from reactors of both stages following four weeks of operation are presented in Figures 6 and 7.

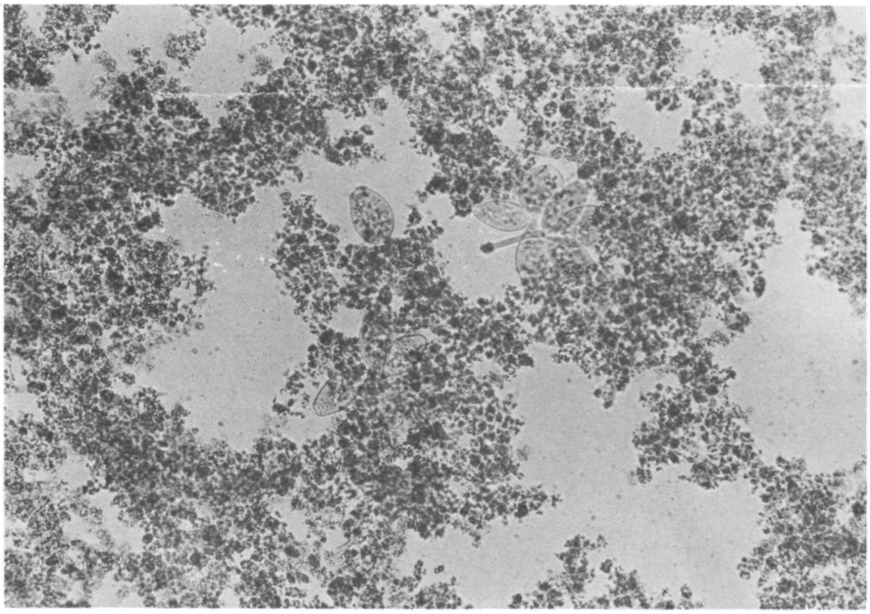

FIG. 6 TYPICAL SLUDGE FLOCS FROM THE FIRST STAGE REACTOR IN PHASE 1 OF THE TWO-STAGE OPERATION x 100

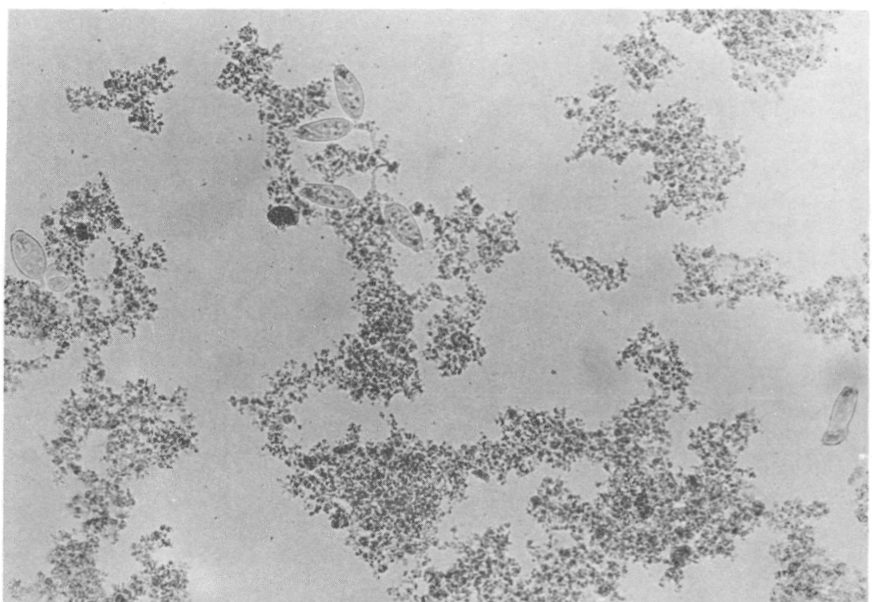

FIG. 7 TYPICAL SLUDGE FLOCS FROM THE SECOND STAGE REACTOR IN PHASE 1 OF THE TWO-STAGE OPERATION x 100

4.1.2 Phase 2

Although results of the first phase operation indicated that satisfactory BOD_5 reduction was obtained, preliminary estimates indicated that the cost of an antifoaming agent would be excessively high. It was decided to reduce the oxygen requirement of the system by decreasing the organic loading. Antifoam addition was discontinued and the feed rate was reduced to 26 l/day. The reduction of feed resulted in a corresponding increase in detention time from one to two days in the aeration tanks of both stages.

The average MLSS in the first and the second stage reactor was 3,000 and 2,200 mg/l, respectively. The organic loading of the first stage remained fairly constant at 1.2 kg BOD_5/kg MLSS•day. However, the organic loading of the second stage increased from 0.2 kg BOD_5/kg MLSS•day during the first four weeks of operation to 0.8 kg BOD_5/kg MLSS•day toward the end of the operation. This was caused by an increase in the effluent BOD_5 concentration of the first stage.

Although the organic loading was reduced by one-half, the problem of oxygen deficiency occurred again in the first stage reactor. No difficulty was encountered in maintaining the dissolved oxygen at greater than 2 mg/l in the second stage reactor until four weeks later when there was a substantial increase in organic loading caused by the higher effluent BOD_5 concentration of the first stage. Subsequently, a dissolved oxygen concentration consistently less than 0.5 mg/l was observed both in the first and the second stage reactors. Efforts to increase the dissolved oxygen concentration by introducing more air into the reactors were unsuccessful because the increased agitation caused serious foaming in the aeration tanks. Suspended solids were trapped in the foam phase and carried out of the reactor, resulting in a loss of sludge from the treatment system.

Effluent BOD_5 concentrations during the period of operation are presented in Figure 5. During the first two weeks of operation, with an average influent BOD_5 concentration of approximately 7,000 mg/l, an overall BOD_5 reduction of more than 90% was obtained. However, effluent quality of the first stage reactor deteriorated gradually thereafter.

Although the cause of deterioration was not investigated, it might have been due to the oxygen deficiency in the reactor. The increase in BOD_5 concentration of the first stage effluents resulted in a higher organic loading; therefore, a higher oxygen uptake rate in the second stage reactor. The first indication of oxygen deficiency in the second stage reactor appeared on day 28. Three days later a remarkable increase in BOD_5 concentration was observed in the second stage effluent. The performance of both stages deteriorated over the next four weeks of operation with the effluent BOD_5 concentration being higher than 4,000 mg/l toward the end of the experiment. For comparison, the operating results are divided into three groups as shown in Table 5.

Sludge flocs of the first stage reactor exhibited a physical structure similar to those in the previous phase of the operation; however, no protozoa were observed after the change in operating conditions. Since protozoa favour a high oxygen environment, their disappearance could be attributed to the low dissolved oxygen concentration in the reactor. Typical sludge flocs from the first stage reactor are shown in Figure 8.

Filamentous microorganisms were first observed in the second stage reactor after one month of operation and were continuously present over the entire experimental program. The protozoa population in the reactor was still abundant. The photomicrograph shown in Figure 9 was taken after four weeks of operation.

4.1.3 Phase 3

After the failure of several attempts to increase the dissolved oxygen level by introducing more compressed air into the reactors, and because of the poor treatment efficiency of the system, the feed rate was reduced from 26 to 13 l/day, giving a corresponding increase in detention time from two to four days in reactors of both stages. This phase of the operation was divided into two parts with the first part dealing with the operation without antifoam addition. The second part covered the rest of the operating period with antifoam addition.

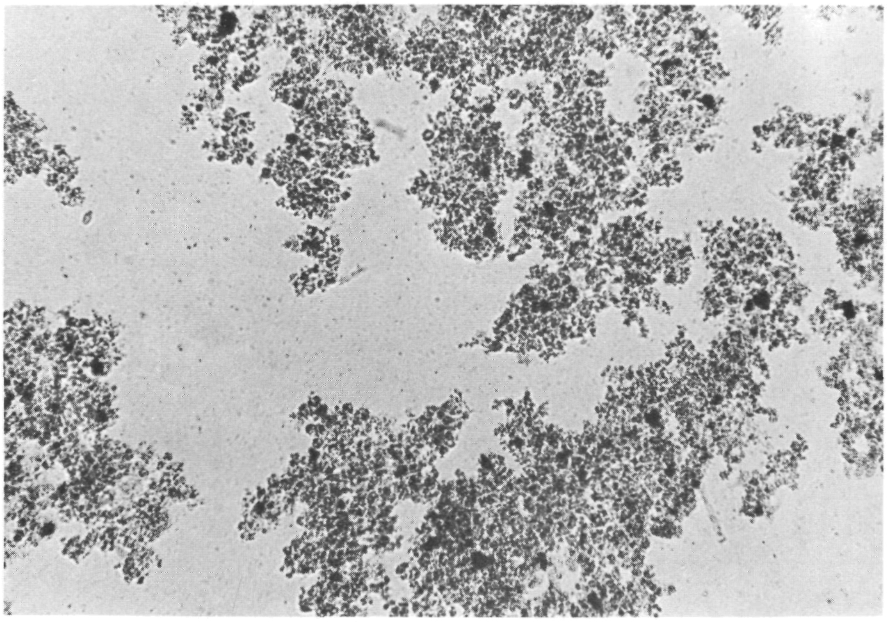

FIG. 8 TYPICAL SLUDGE FLOCS FROM THE FIRST STAGE REACTOR IN PHASE 2 OF THE TWO-STAGE OPERATION x 100

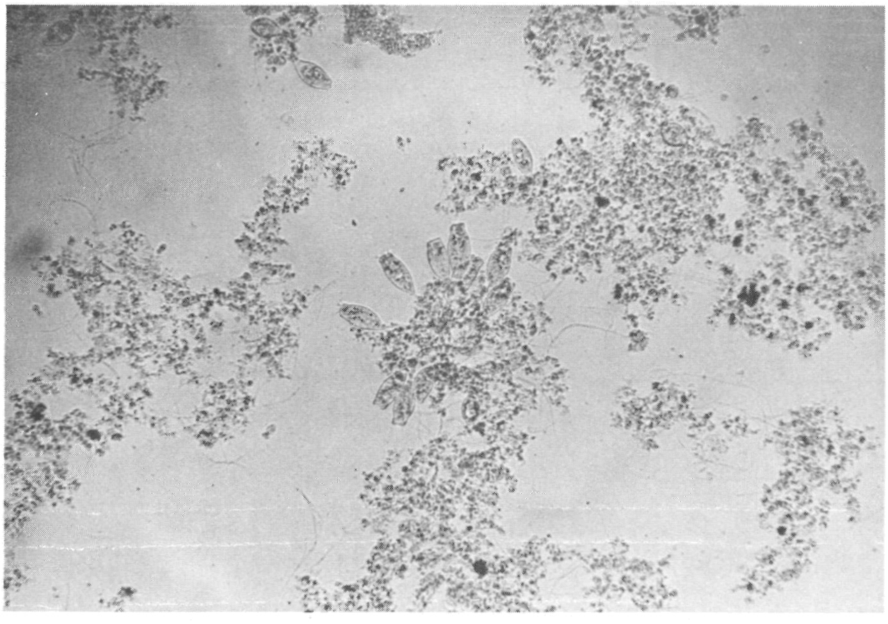

FIG. 9 TYPICAL SLUDGE FLOCS FROM THE SECOND STAGE REACTOR IN PHASE 2 OF THE TWO-STAGE OPERATION x 100

TABLE 5. AVERAGE OPERATING RESULTS IN PHASE 2 OF THE TWO-STAGE OPERATION

Parameters	Influent	Effluent 1st Stage	% Red.	Effluent 2nd Stage	% Red.	Total % Red.
I (Operating period from day 1 to day 15)						
pH	7.2	8.2		8.4		
BOD_5 (mg/l)	7,300	1,400	81	360	74	95
SS (mg/l)	900	540	39	360	34	60
TOC (mg/l)	8,000	3,800	53	3,200	17	60
COD (mg/l)	25,200	11,800	53	9,400	20	63
TDS (mg/l)	27,600	20,000	27	19,000	5	31
TKN (mg/l)	250	98	60	97	1	61
TP (mg/l)	49	21	57	24	-	51
II (Operating period from day 16 to day 31)						
pH	6.6	8.5		8.9		
BOD_5 (mg/l)	7,000	3,000	58	160	94	98
SS (mg/l)	1,900	320	83	190	39	90
TOC (mg/l)	8,200	5,100	38	2,500	52	70
COD (mg/l)	27,100	14,800	45	9,300	37	66
TDS (mg/l)	25,100	19,700	21	16,500	16	34
TKN (mg/l)	216	117	45	56	52	74
TP (mg/l)	38	22	42	14	36	63
III (Operating period from day 32 to day 64)						
pH	6.7	8.0		8.5		
BOD_5 (mg/l)	7,300	4,900	33	3,900	21	47
SS (mg/l)	790	330	59	200	38	75
TOC (mg/l)	8,300	6,800	18	5,500	19	34
COD (mg/l)	28,400	21,300	25	18,100	15	36
TDS (mg/l)	29,200	23,600	19	22,300	6	24
TKN (mg/l)	140	92	34	94	-	33
TP (mg/l)	22	9	59	9	0	59

4.1.3.1 Operation without antifoam addition. Although the feed rate was reduced by one-half to lower the oxygen requirement in the reactors, this was partly offset by a significant increase in the strength of wastewater. As indicated in Table 2 of Section 3.3, water conservation measures resulted in significantly higher BOD_5 and TDS concentrations in the mill effluent after November, 1973.

The organic loadings in the first and the second stages were 0.8 and 0.7 kg BOD_5/kg MLSS•day, respectively. The average MLSS concentration in the first stage reactor was 3,700 mg/l and that in the second stage was 2,800 mg/l. Although the organic loading was reduced by one-third from 1.2 kg BOD_5/kg MLSS•day in the previous phase of the operation, the oxygen deficiency problem still existed in reactors of both stages. Attempts to increase the dissolved oxygen level by introducing more air into the reactors resulted again in a severe foaming problem. The installation of a foam breaker consisting of a stirrer and large impellers located above the liquid level in the aeration tank resulted in a slight improvement in the situation. However, at the aeration rate necessary to maintain the dissolved oxygen level at greater than 0.5 mg/l in the reactor, this device was unsuccessful in preventing loss of foam, and thus, suspended solids from the reactor.

The average operating results are presented in Table 6 and the BOD_5 concentration versus days of operation is plotted in Figure 5. As can be seen, there was no improvement in treatment efficiency after the reduction in feed rate. The overall BOD_5 reduction was only 54%. Effluent quality was poor with the average BOD_5 being 7,800 and 5,700 mg/l for the first and second stages, respectively. Effluent suspended solids of the second stage reactor appeared to be slightly higher than that in the first stage. Compared to the previous phase of operation, a substantial increase in total dissolved solids was also observed in effluents of both stages.

No significant change was observed in the structure of sludge flocs from the first stage reactor. Microscopical examination revealed that there was an increase in numbers of filamentous microorganisms in sludge flocs of the second stage which could have been partially responsible for the increase in effluent suspended solids. The large population of small Amoeba present initially had disappeared and a small population of ciliated protozoa were observed. A photomicrograph of the filamentous growth in the second stage reactor is shown in Figure 10.

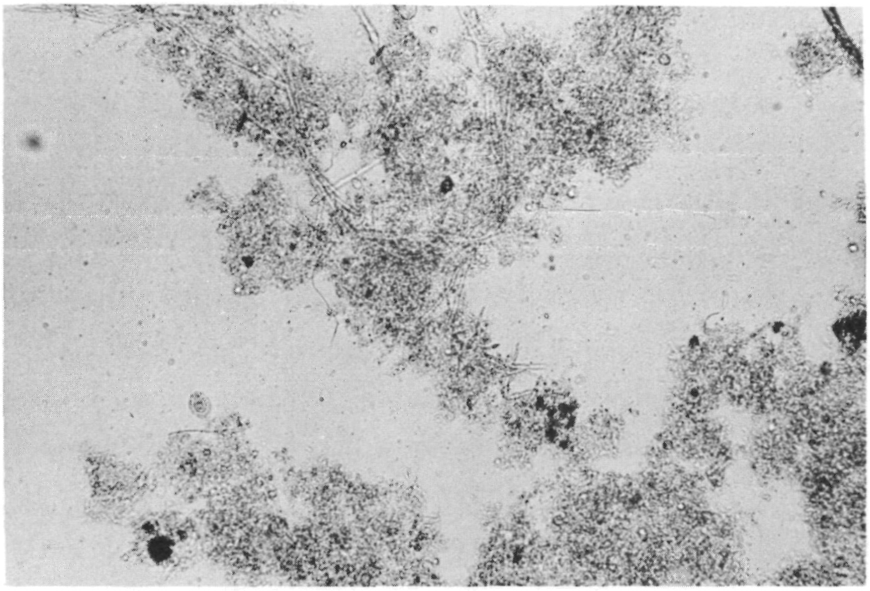

FIG. 10 FILAMENTOUS GROWTH IN THE SECOND STAGE REACTOR IN PHASE 3 OF THE TWO-STAGE OPERATION (WITHOUT ANTIFOAM ADDITION) x 100

TABLE 6. AVERAGE OPERATING RESULTS IN PHASE 3 OF THE TWO-STAGE OPERATION (WITHOUT ANTIFOAM ADDITION)

Parameters	Influent	Effluent				
		1st Stage	% Red.	2nd Stage	% Red.	Total % Red.
pH	6.5	8.2	--	8.5	--	--
BOD_5 (mg/l)	12,300	7,800	37	5,700	27	54
SS (mg/l)	1,200	470	61	540	--	55
TOC (mg/l)	12,300	10,900	11	9,800	10	20
COD (mg/l)	48,700	34,000	30	29,700	13	39
TDS (mg/l)	41,800	38,500	8	37,200	3	11
TKN (mg/l)	233	167	28	156	7	33
TP (mg/l)	36	19	37	19	--	37

4.1.3.2 Operation with antifoam addition. The continuing oxygen deficiency and poor treatment efficiency led again to considering the use of an antifoaming agent. Since addition of antifoam had originally resulted in conditions which provided an adequate oxygen supply, it was considered that additional studies were warranted. An alternate source of antifoaming agent, Hercules Defoamer Eff-101, was selected and addition initiated on day 42 of operation. The defoamer was diluted 250 times with tap water before being pumped to reactors of both stages. A dosage of 5 ml/min was sufficient to control foaming in the treatment system. The diluted defoamer had BOD_5, TOC, COD and TKN concentrations of 570, 880, 4,100 and 2.0 mg/l, respectively. No phosphorus was detected.

In comparison with the feed rate of wastewater at 18 l/day, the rate of defoamer addition was 7.2 l/day. With the addition of defoamer, the organic concentration (TOC) of raw wastewater was reduced approximately 30% as a result of dilution. However, the organic loading of the reactors was not significantly affected by this decrease because the addition of defoamer led to a corresponding decrease in the detention time.

Dissolved oxygen in the first stage reactor fluctuated between 0.4 and 5.8 mg/l, while in the second stage, the value was consistently greater than 1.0 mg/l. As shown in Figure 5, following addition of the antifoaming agent, a remarkable decrease in effluent BOD_5 was observed in both stages. BOD_5 concentration in the final effluent dropped to 1,150 mg/l and the overall treatment efficiency increased to 91% after the 10th day of the antifoam addition.

Unfortunately, a problem of poorly settling sludge was encountered in the second stage clarifier after the 14th day of operation. The sludge blanket reached the water surface, resulting in a continuous loss of sludge. Two weeks later, a similar problem occurred in the first stage clarifier. No filamentous microorganisms were observed in sludge flocs of this stage indicating that the sludge bulking problem was not due to filamentous growth.

Similar problems had been encountered in Phase 1 of the operation when antifoam emulsion DB-110 was used and thus, it was considered that the settling problems were closely related to the use of the antifoaming agent. Consequently, the addition of defoamer was discontinued, resulting in an oxygen deficiency in reactors of both stages. Treatment efficiency deteriorated and effluent BOD_5 concentration increased to the previous level. Since no improvement in sludge settling was achieved during the remaining period of operation, the entire operation was discontinued on January 22, 1974.

4.1.4 Summary

During the six-month operation of the two-stage activated sludge system, foaming, oxygen deficiency and sludge bulking were encountered in the treatment of high strength NSSC mill effluents. The addition of the antifoaming agent resulted in an efficient control of foaming and enabled an adequate dissolved oxygen level to be maintained in the reactor. However, sludge bulking problems accompanied this corrective measure and rendered it impractical. Although the wastewater was readily biodegradable, as indicated by the high BOD_5 removal efficiency, the two-stage activated sludge system should not be used for the treatment of this particular wastewater until these problems can be solved to ensure trouble-free operation.

Results of the last phase of operation indicated that even at a total detention time of eight days, overall operation was still not satisfactory. A longer detention time in this system was not considered because a parallel study was being carried out in a single-stage activated sludge system operating at a detention time of 10 and 20 days.

4.2 Single-Stage Operation

Treatment of the high strength NSSC mill effluent was also carried out in a single-stage activated sludge system to compare its performance with the two-stage system. While the two-stage reactors were being operated as a high rate activated sludge system, the single-stage reactor was operated as an extended aeration system at relatively low organic loadings. The experimental program was divided into three phases according to the feed rate used. The operating conditions and experimental results of each phase are presented and discussed in the following sections.

4.2.1 Phase 1

For 83 days, the single stage reactor was fed at 7.5 l/day with a detention time of 20 days in the aeration tank. During the same period, the two-stage system was operated at a total detention time of two and four days. A high return sludge rate (500% of feed rate) was used in the single-stage system to reduce sludge storage time in the clarifier. The reactor was operated at an average MLSS concentration of 2,900 mg/l with the organic loading being 0.1 kg BOD_5/kg MLSS•day.

The oxygen deficiency problem which was encountered in the two-stage operation did not occur in the single-stage system. With the exception of six measurements, dissolved oxygen levels in the reactor were always greater than 1.0 mg/l during the 83 days of operation. At the aeration rate necessary to maintain an adequate dissolved oxygen level, a depth of approximately 15 cm of foam was observed in the aeration tank which caused some inconvenience in sampling. No other operational problems associated with foaming were encountered.

Operational data are presented in Table 7. The average values are based on results of the last eight weeks of operation. Because of the long detention time in the reactor and the exceptionally low strength wastewater encountered during the third week of operation, data collected during the first four weeks of operation were not included.

As indicated in the table, at the average influent BOD_5 concentration of 7,400 mg/l, a 99% reduction was achieved in the treatment system leaving an average effluent BOD_5 concentration of only 80 mg/l. A significant reduction in suspended solids and total dissolved solids was also achieved.

The influent and effluent BOD_5 concentrations during the period of operation are plotted in Figure 11. As shown in the figure,

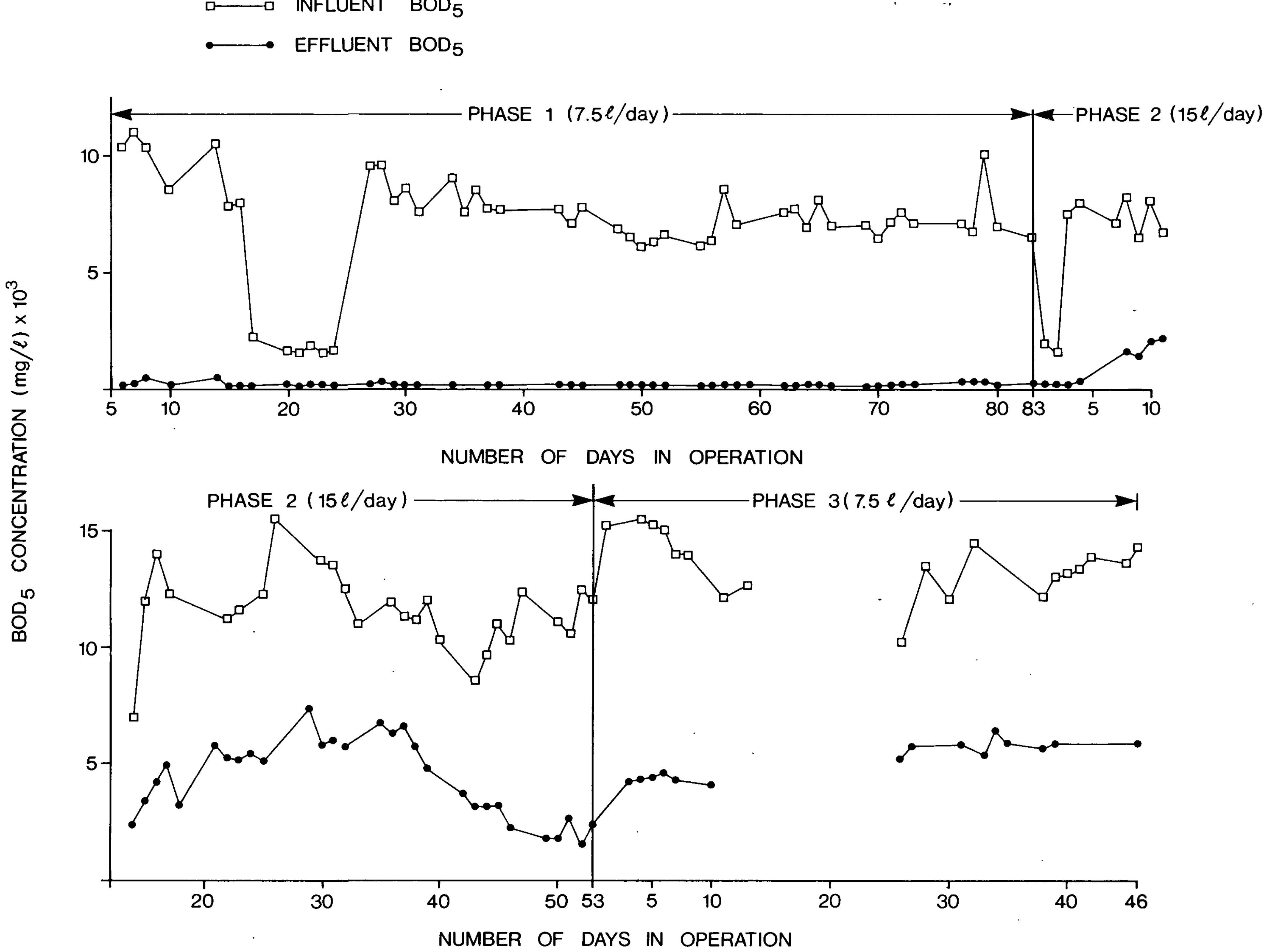

FIG. 11 BOD_5 CONCENTRATION FOR THE SINGLE-STAGE SYSTEM.

effluent BOD_5 concentrations remained constant throughout this phase of operation despite the wide variation in the influent BOD_5 concentration.

Compact sludge flocs abundant with stalked ciliates were observed under the microscope. Although a small population of filamentous microorganisms appeared after two months of operation, their effect on sludge settling characteristics was insignificant as no operational problems were encountered in the clarifier. A photomicrograph of sludge flocs taken after two months of operation is presented in Figure 12.

TABLE 7. AVERAGE OPERATING RESULTS IN PHASE 1 OF THE SINGLE-STAGE OPERATION

Parameters	Influent	Effluent	% Red.
pH	6.8	8.0	--
BOD_5 (mg/l)	7,400	80	99
SS (mg/l)	1,300	280	79
TOC (mg/l)	7,800	2,100	74
COD (mg/l)	26,600	6,600	75
TDS (mg/l)	27,300	15,800	42
TKN (mg/l)	224	87	61
TP (mg/l)	42	35	17

4.2.2 Phase 2

As consistently good results were obtained during the first phase of the operation at 0.1 kg BOD_5/kg MLSS•day, the experimental program was extended to evaluate the performance of the single-stage reactor at a higher organic loading. The feed rate was doubled to 15 l/day and the detention time in the aeration tank reduced to 10 days accordingly. Following the increase in feed rate, an oxygen deficiency was encountered in the aeration tank. Excessive foaming restricted the rate of air supply. As indicated previously, the use of an antifoaming agent for foam control was costly and resulted in operational problems; therefore, consideration was given to the use of pure oxygen.

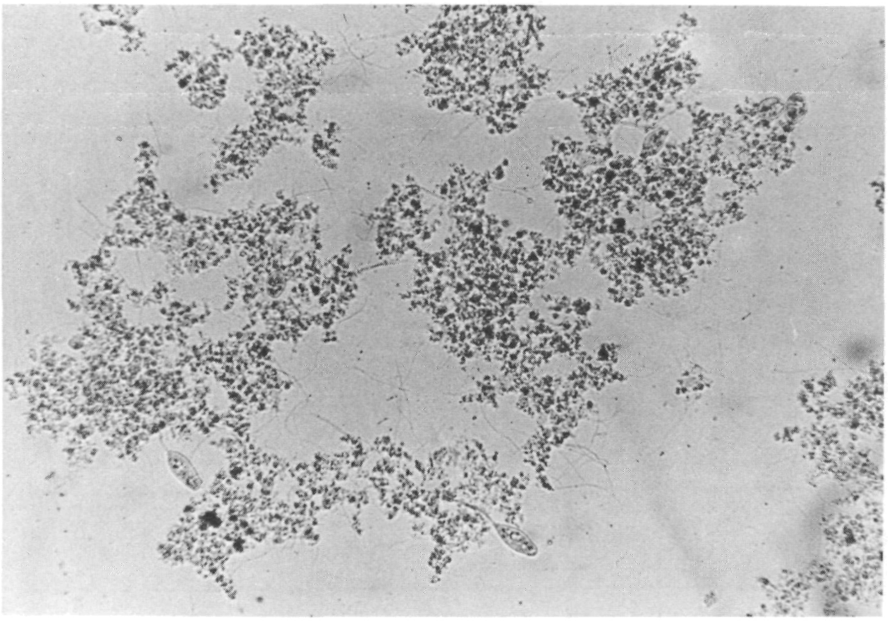

FIG. 12 TYPICAL SLUDGE FLOCS FROM THE REACTOR IN THE SINGLE-STAGE OPERATION x 100

Results of the operation have been divided into two parts according to the dissolved oxygen level in the reactor. The first part deals with the operation of the reactor with compressed air, during which the dissolved oxygen level was always less than 0.5 mg/l. In the second part, the system was operated with pure oxygen addition and the dissolved oxygen level was always greater than 0.5 mg/l.

4.2.2.1 Operation with compressed air. The increase in feed rate from 7.5 to 15 l/day resulted in an increase in the organic loading from 0.1 to 0.2 kg BOD_5/kg MLSS•day. After two weeks of operation, the increase in the strength of wastewater due to the modification in mill operation resulted in a further loading increase to 0.4 kg BOD_5/kg MLSS•day. However, MLSS concentrations in the reactor were maintained nearly constant at 3,100 mg/l throughout this part of the operation.

The BOD_5 concentrations during the period of operation are plotted in Figure 11, indicating that four days after the change in loading condition, effluent BOD_5 levels started to increase. As this occurred before the substantial increase in the strength of wastewater, the deterioration of treatment efficiency was considered to be mainly due to the oxygen deficiency in the reactor caused by the increase in organic loading. After day 15, the reduced performance of the reactor was compounded by the substantial increase in influent BOD_5 concentration, resulting in a further deterioration of effluent quality. Average results for the operating period from day 15 to 35 are presented in Table 8, indicating that only a 57% BOD_5 reduction was obtained. The concentration of effluent suspended solids and total dissolved solids was significantly higher than that in the previous phase of operation.

TABLE 8. AVERAGE OPERATING RESULTS IN PHASE 2 OF THE SINGLE-STAGE OPERATION (WITH COMPRESSED AIR)

Parameters	Influent	Effluent	% Red.
pH	6.4	8.3	--
BOD_5 (mg/l)	11,900	5,100	57
SS (mg/l)	1,130	550	52
TOC (mg/l)	13,100	8,200	37
COD (mg/l)	46,800	25,200	46
TDS (mg/l)	40,800	29,900	27
TKN (mg/l)	214	136	36
TP (mg/l)	33	32	3

The increase in organic loading also resulted in a change in species of filamentous microorganisms in the reactor. The predominant species during the previous operation was non-segmented filaments with a diameter of approximately 1 to 4 μ. After the feed was increased to 15 l/day, a species of larger (8 to 12 μ in diameter) segmented filaments was observed. The segmented filaments progressively increased in number and became the predominent species after one month of operation. A higher power magnification of the segmented filaments is presented in Figure 13.

4.2.2.2 Operation with pure oxygen addition. Before the pure oxygen addition was initiated, modifications to the reactor were made to enable a more efficient use of the pure oxygen. A PVC ring diffuser with approximately 0.5 mm diameter perforations was placed on the bottom of the aeration tank to introduce pure oxygen into the reactor. To retard diffusion of oxygen into the air, the reactor was covered with a plastic lid leaving only a small opening for exhaust gases. Pure oxygen was applied continuously at approximately 10 l/min.

After the pure oxygen addition, the dissolved oxygen level in the reactor was always greater than 0.5 mg/l. The effluent BOD_5 concentration dropped gradually from 7,000 to 2,000 mg/l in nine days and was followed by a levelling off at approximately 2,000 mg/l in the last week of operation (Figure 11). The higher BOD_5 reduction resulted in greater cell production which, in turn, led to an increase of MLSS in the reactor, as noted in the daily operational data presented in Appendix E.

The addition of pure oxygen also resulted in an increased protozoa population in sludge flocs. Carchesium, Opercularia and Vorticella were present in abundance. Figure 14 is a photomicrograph of typical sludge flocs during the period of pure oxygen addition. A significant increase in the population of segmented filaments was also observed.

Although BOD_5 removal efficiency improved significantly, uncontrollable rising sludge blankets occurred in the clarifier after one week of pure oxygen addition. Effluent suspended solids steadily increased from 390 to 930 mg/l over the 17-day operational period.

The poor settling characteristics of the sludge could be partially attributed to the presence of filaments as shown in Figure 14. On the other hand, the high concentration of total dissolved solids in the wastewater could also be responsible for the poor performance of the clarifier. Burnett (12), in the treatment of a

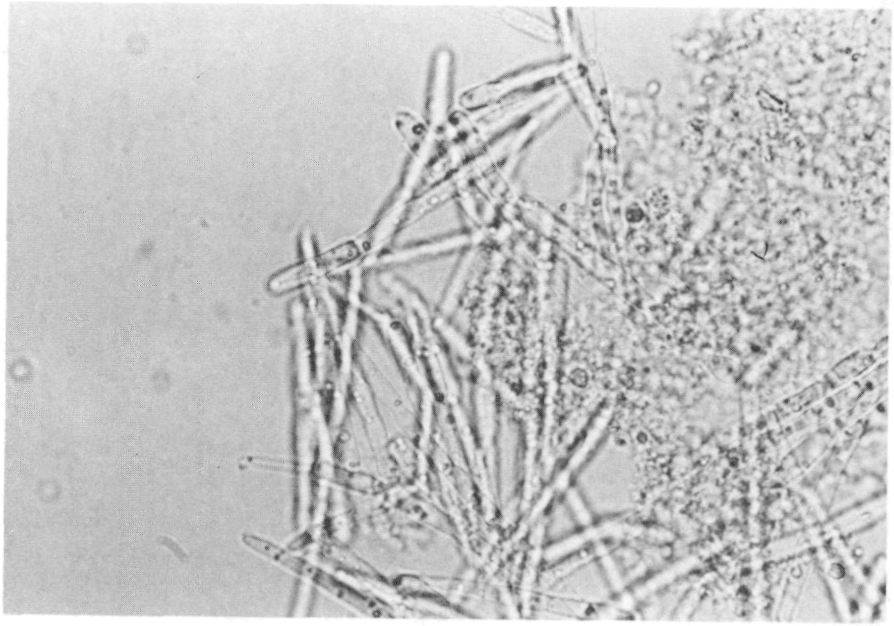

FIG. 13 FILAMENTOUS MICROORGANISMS FROM THE REACTOR IN PHASE 2 OF THE SINGLE-STAGE OPERATION (WITH COMPRESSED AIR) x 400

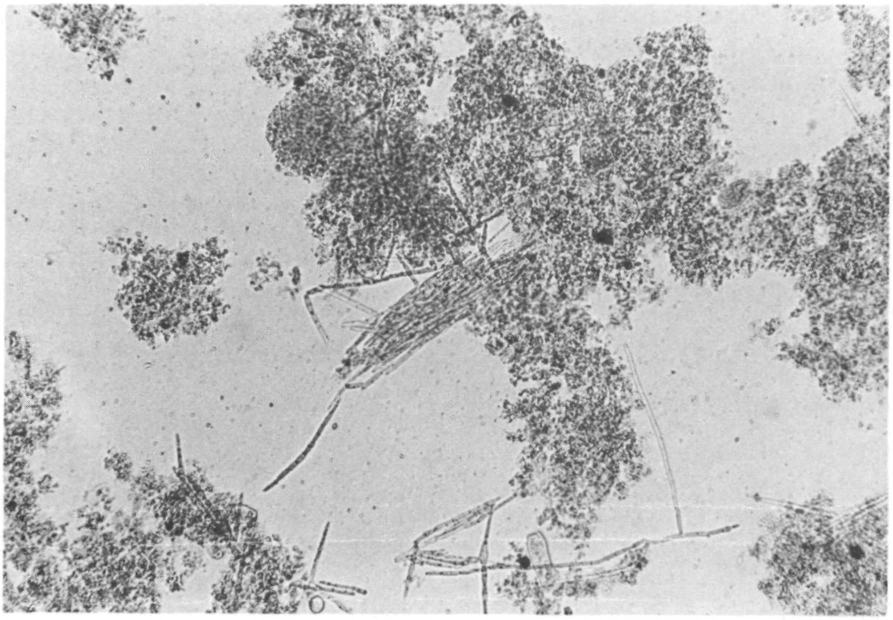

FIG. 14 TYPICAL SLUDGE FLOCS FROM THE REACTOR IN PHASE 2 OF THE SINGLE-STAGE OPERATION (WITH PURE OXYGEN ADDITION x 100

mixture of domestic sewage and sea water having the total dissolved solids between 32,000 and 38,000 mg/l, reported that the high salinity wastewater caused a disruption of clarifier performance, resulting in lower BOD_5 removal efficiency, suspended solids losses and changes in protozoa populations. Ludzack and Noran (13) also reported that difficulty in solid-liquid separation was encountered in activated sludge treatment of wastewater containing high total dissolved solids.

4.2.3 Phase 3

Results of Phase 2 of the single-stage operation indicated that an increase in organic loading resulted in oxygen deficiency in the reactor and poor treatment efficiency. Although improvement in BOD_5 reduction was obtained due to the addition of pure oxygen, bulking sludge conditions were encountered. Since consistently good results were obtained in the Phase 1 operation when the reactor was operated at the feed rate of 7.5 l/day, it was decided to reduce the feed rate to this level again and use compressed air for aeration.

With the MLSS concentration being close to 5,000 mg/l at the beginning of the operation, the organic loading was 0.1 kg BOD_5/kg MLSS•day which is the same as in the Phase 1 operation. Due to a continuous loss of sludge from the clarifier during the operation, there was a steady decrease in the concentration of MLSS, resulting in a gradual increase in organic loading from 0.1 to 0.2 kg BOD_5/kg MLSS•day toward the end of this phase of operation.

At the organic loading of 0.1 kg BOD_5/kg MLSS•day, no problem was encountered in maintaining adequate dissolved oxygen in the reactor during the Phase 1 operation. However, during Phase 3, at the same rate of air supply as was used in Phase 1, maintenance of the same level of dissolved oxygen was not possible. This could be attributed to a lower oxygen transfer efficiency caused by the substantial increase in the strength of wastewater, particularly the high concentration of total dissolved solids in this phase of the operation. Increasing the rate of air supply resulted in extensive foaming. Installation of a foam breaker in the aeration tank did not improve the situation significantly.

The performance of the clarifier was again unsatisfactory. Shortly after the reduction in feed rate, the sludge flocs dispersed to such an extent that the settling and recycling of sludges became ineffective. Small sludge flocs were suspended throughout the clarifier and were continuously discharged over the weir of the clarifier. Effluent suspended solids increased steadily from 930 to 1,280 mg/l and the MLSS concentration decreased from 4,200 mg/l to 2,400 mg/l over this phase of the operation.

The average operating results are presented in Table 9, indicating a BOD_5 reduction of only 70%. The high effluent quality obtained in the first phase of the operation under similar conditions was never achieved. Comparing results shown in Tables 7 and 9, it can be seen that the concentration of total dissolved solids in the treatment system increased significantly during this phase of the operation. It is well known that a high concentration of dissolved solids could create an osmotic pressure detrimental to microbial activity. An investigation on how and to what extent the high osmotic pressure affects the performance of the treatment system was not carried out. Based on the studies of Burnett (12) and Ludzack and Noran (13), it was considered that the poor performance of the clarifier was closely related to the high concentration of total dissolved solids.

TABLE 9. AVERAGE OPERATING RESULTS IN PHASE 3 OF THE SINGLE-STAGE OPERATION

Parameters	Influent	Effluent	% Red.
pH	6.8	--	--
BOD_5 (mg/l)	13,600	4,100	70
SS (mg/l)	1,350	990	27
TOC (mg/l)	14,100	9,900	30
COD (mg/l)	52,700	31,900	39
TDS (mg/l)	50,000	48,300	3
TKN (mg/l)	228	153	33
TP (mg/l)	31	17	45

Small and partially disintegrated sludge flocs were observed during microscopic examination. The population of filaments increased significantly as can be seen from the photomicrograph in Figure 15. No protozoa were present in sludge flocs.

4.2.4 Summary

Although satisfactory results were obtained in the single-stage reactor operated as an extended aeration system during the first phase of the operation, poor performance was encountered in subsequent phases of the operation. As in the two-stage operation, problems such as excessive foaming, oxygen deficiency and sludge bulking developed after the increase in organic loading. Efforts to improve the performance of the system by reducing the organic loading to the initial level were unsuccessful. The addition of pure oxygen solved the foaming and oxygen deficiency problems, but the bulking sludge condition remained unchanged. Filamentous microorganisms detrimentally affected the compaction of sludge flocs; solid-liquid separation was also adversely affected by a non-filamentous bulking sludge condition. Considering the difficulties encountered in the long term operation and the uncontrollable nature of the sludge bulking, it was concluded that the single-stage activated sludge system operated as an extended aeration unit was not suitable for the treatment of this particular wastewater.

4.3 Bioassay Results and Discussions

During the operation of activated sludge systems, bioassays were conducted on the untreated and biologically treated effluents to evaluate the toxicity reduction capabilities of the treatment systems. Results presented in Table 10 indicate that the high strength NSSC mill effluent was toxic with the MST being approximately four hours. Although there was an increase in MST for treated effluents, neither the two-stage nor the single-stage activated sludge system produced effluents which met the toxicity requirements specified in the Pulp and Paper Effluent Regulations (9).

FIG. 15 TYPICAL SLUDGE FLOCS FROM THE REACTOR IN PHASE 3 OF THE SINGLE-STAGE OPERATION x 100

Continuous adjustment of pH to maintain a constant level during the bioassay resulted in a doubling of the MST for effluents from both the two-stage and the single-stage systems. No difference in toxicity was observed between the effluents from the two-stage reactor operated at 26 l/day and those from the single-stage reactor operated at 7.5 l/day. Although the MST for the untreated wastewater remained constant at four hours, the reduction in toxicity by the two-stage reactor during test number three was not as great as in previous tests; no explanation could be provided for this variation in the toxicity reduction. The decrease in detention time from 20 to 10 days in the single-stage system did not cause any significant change in effluent toxicity.

TABLE 10. RESULTS OF BIOASSAYS

Test Number	Sample Description	Aeration Tank Detention Time (days)	MST (hr)	pH
1	Raw wastewater	--	4.0	7.0
	Effluent from two-stage system (without pH adjustment during bioassay)	2	12.0	Increased from 7.6 to 9.3
	Effluent from single-stage system (without pH adjustment during bioassay)	20	12.0	Increased from 7.6 to 9.3
2	Raw wastewater	--	4.0	7.0
	Effluent from two-stage system (with continuous pH adjustment to 7.6 during bioassay)	2	24.5	7.6
	Effluent from single-stage system (with continuous pH adjustment to 7.6 during bioassay)	20	24.5	7.6
3	Raw wastewater	--	4.0	7.0
	Effluent from two-stage system (without pH adjustment during bioassay)	2	5.8	Increased from 7.6 to 8.6
	Effluent from single-stage system (without pH adjustment during bioassay)	10	10.6	Increased from 7.6 to 8.7

REFERENCES

1. Bruley, A.J., "The Basic Technology of the Pulp and Paper Industry and its Waste Reduction Practices", EPS Training Manual, EPS 6-WP-74-3, 1974.

2. Gehm, H., "State-of-the-Art Review of Pulp and Paper Waste Treatment", EPA Report, Series EPA-R-2-73-184, 1973.

3. Perman, B.V., Jr. and O.B. Burns, Jr., "Activated Sludge Treatment of Kraft and Neutral Sulfite Mill Wastes", Sewage and Industrial Wastes, 29(10):1145, 1957.

4. Farrell, P.J., L.R. Heble and A.G. Steuhser, "Treatment of Domestic Wastewater and NSSC Pulp and Paper Mill Wastes", Environmental Protection Technology Series, EPA-660/2-73-010, 1973.

5. Voelkel, K.G., D.W. Martin and R.W. Deering, "Joint Treatment of Municipal and Pulp Mill Effluents", J. Water Pollution Control Federation, 46(4):634, 1974.

6. "Joint Municipal and Semichemical Pulping Waste Treatment", Federal Water Pollution Control Administration Report, Series ORD-1, 1969.

7. Standard Methods for the Examination of Water and Wastewater; 13th Edition, American Public Health Association, New York, 1971.

8. "Guidelines for the Pulp and Paper Effluent Regulations", Environmental Protection Service Report No. EPS 1-WP-72-2, 1972.

9. "Pulp and Paper Effluent Regulations", Environmental Protection Service Report No. EPS 1-WP-72-1, 1971.

10. Davis, S.C. and B. Mason, "Bioassay Procedures to Evaluate Toxicities of Neutralized Bleached Kraft Pulp Mill Effluent to Pacific Salmon", J. Fisheries Research Board of Canada, 30(10): 1565, 1973.

11. Guo, H.M., "Untersuchung über den Einfluss unterschiedlicher Betriebszustände des Belebungsverfahrens auf die Schlammaktivität", Veröffentlichung des Institutes für Siedlungswasserwirtschaft der Technischen Universität Hannover, W. Germany, 38, 147, 1973.

12. Burnett, W.E., "The Effect of Salinity Variations on the Activated Sludge Process", Water & Sewage Works, 121(3):37, 1974.

13. Ludzack, F.J. and D.K. Noran, "Tolerance of High Salinities by Conventional Wastewater Treatment Processes", J. Water Pollution Control Federation, 37(10):1404, 1965.

14. Eckenfelder, W.W. and D.L. Ford, Water Pollution Control - Experimental Procedures for Process Design, Jenkins Publishing Company, New York, 1970.

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

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APPENDIX A

PHYSICAL-CHEMICAL TREATMENT OF A HIGH STRENGTH NSSC MILL EFFLUENT

Appendix A

Physical-Chemical Treatment of a High Strength NSSC Mill Effluent

Preliminary studies were conducted in the laboratory to investigate the amenability of the high strength NSSC mill effluent to physical-chemical treatment methods. Results are presented in the following sections.

A-1 Air Stripping

Air stripping was carried out to remove the volatile organic compounds and hydrogen sulphide from the wastewater. The results shown in Table A-1 indicated that air stripping removed hydrogen sulphide but was not effective for TOC and COD removal.

TABLE A-1. RESULTS OF AIR STRIPPING

Sample Volume (litre)	Water Temperature (°C)	Air Flow Rate (l/min)	Duration of Air Stripping (hr)	TOC (mg/l)	COD (mg/l)	H_2S (mg/l)
10	10	16	0	1,600	--	8
			1	1,500	--	--
			2	1,500	--	--
			4	1,550	--	nil
			5	1,550	--	--
10	16	16	0	11,100	36,300	2
			1	11,280	36,700	0.1
			2	11,500	35,400	nil
			4	11,350	36,000	--
			5	11,500	36,500	--
			6	11,600	35,900	--

A-2 Coagulation

Jar tests using the most common coagulants such as calcium hydroxide, alum, ferric chloride and polymer, were carried out to evaluate the treatment efficiency of coagulation. The dark colour of the wastewater made it impossible to observe the floc formation and floc sizes during the test; therefore, a suspended solids determination was used as a measure of the quantity of flocs produced after the test.

Samples were placed in six 1-litre jars and rapidly mixed at 100 rpm for three minutes, followed by slow mixing at 15 rpm for 30 minutes. After 30 minutes of settling, samples were taken for analyses. Data shown in Table A-2 indicated that none of the coagulants used resulted in any significant TOC removal.

Results of additional jar tests carried out on samples whose pH had been adjusted to the range considered optimum for coagulation also indicated no improvement in the TOC removal.

A-3 Carbon Adsorption

Based on the adsorptive capacity recommended by the supplier, six grams of powdered activated carbon were placed in one litre of sample and agitated thoroughly for one hour. Samples for TOC analyses were taken at specific time intervals. The results are shown in Table A-3. With the minimal TOC reduction as shown in the table, it must be assumed that the high strength NSSC mill effluent contained a considerable amount of adsorption-resistant compounds.

TABLE A-2. RESULTS OF JAR TESTS

Coagulant	Sample Characteristics before Jar Test	Chemical Dosage (mg/l)	After Jar Test		
			pH (unit)	TOC (mg/l)	SS (mg/l)
$Ca(OH)_2$	pH = 6.8 TOC = 12,000 (mg/l) SS = 430 (mg/l)	100* 500 1,000 2,000 3,000 4,000	7.3 9.0 10.4 11.8 12.0 12.2	12,250 12,300 11,800 11,800 11,600 11,400	690 2,300 4,100 4,800 7,000 8,800
$FeCl_3 \cdot 6H_2O$	Same as above	5** 10 20 40 80 200	6.9 6.8 6.7 6.7 6.6 6.4	12,400 12,400 12,500 12,600 12,500 12,200	510 370 400 360 430 400
$Al_2(SO_4)_3 \cdot 16H_2O$	Same as above	5*** 10 20 40 80 200	6.8 6.8 6.7 6.6 6.4 6.0	13,900 12,600 12,600 12,900 12,400 11,900	420 440 370 410 400 490
Polymer# Aqua Floc 462 (Anionic)	pH = 6.8 TOC = 12,100 (mg/l) SS = 1,800 (mg/l)	1 5 10 20 40 80	6.8 6.8 6.8 6.8 6.8 6.8	12,000 12,000 11,900 12,000 11,700 11,500	1,900 2,000 2,100 2,000 2,000 1,500
Polymer## AL FLOC 82070 (Non-ionic)	Same as above	1 5 10 20 40 80	6.8 6.8 6.8 6.8 6.8 6.8	12,400 12,300 11,900 11,800 13,400 11,700	2,700 2,000 2,000 2,000 1,800 1,600

* As mg Ca^{++}/l
** As mg Fe^{+++}/l
*** As mg Al^{+++}/l
# Product of Dearborn Chemical Co. Ltd., Mississauga, Ontario.
Product of Alchem Ltd., Burlington, Ontario.

TABLE A-3. RESULTS OF CARBON* ADSORPTION

Contact Time (min)	TOC (mg/l)	pH	Colour units**
0	5,600	8.6	35,000
5	5,100	--	--
10	5,200	--	--
20	5,300	--	--
30	5,100	--	35,000
40	5,100	--	--
60	5,100	8.6	35,000

* The activated carbon used was Aqua Nuchar, a product of Westvaco Corporation, Corington, Virginia, U.S.A.
** Platinum-cobalt unit as specified in Standard Methods (7).

A-4 Ozonation

Ozone generated from a Welsbach ozonator (manufactured by Welsbach Ozone Systems Corporation, Pennsylvania, U.S.A.) was introduced into samples at a constant rate. Results of ozonation are presented in Table A-4. It can be seen from the table that ozone treatment was very promising with respect to colour removal. In the first experiment when the sample of exceptionally low strength was used, slight reduction of TOC was observed after ozone treatment. However, the reduction of TOC was negligible when the high strength sample was investigated.

Results shown above indicate that neither air stripping nor chemical precipitation using lime, alum, ferric chloride and polymers significantly reduce the TOC and suspended solids. Ozonation significantly reduced the colour, but was not effective in removing TOC from the high strength NSSC mill effluent.

TABLE A-4. RESULTS OF OZONE TREATMENT

Sample Volume (ml)	Ozone Dosage (mg O_3/min)	Ozone Contact Time (min)	Colour Units*	TOC (mg/l)
500	50	0	9,500	1,000
		10	2,400	--
		20	1,100	--
		30	740	850
1,000	43	0	88,000	15,840
		10	76,000	16,230
		20	72,000	15,300
		30	68,000	16,750
		60	46,000	15,920

* Platinum-cobalt unit as specified in Standard Methods (7).

APPENDIX B

DETERMINATION OF MASS TRANSFER AND OXYGEN TRANSFER COEFFICIENTS

Appendix B

Determination of Mass Transfer and Oxygen Transfer Coefficients

Since oxygen deficiency was a major operational problem in the treatment of NSSC mill effluent, an investigation of the mass transfer and oxygen transfer coefficients was carried out in order to understand the oxygenation characteristics of the wastewater.

The mass transfer coefficients were calculated from the following mathematical equation as described by Eckenfelder and Ford (14):

$$K_L a = 2.303 \log_{10} \frac{C_s - C_1}{C_s - C_2} / (t_2 - t_1)$$

where: $K_L a$ = overall mass transfer coefficient

C_s = saturated dissolved oxygen concentration

C_1 = dissolved oxygen concentration at time t_1

C_2 = dissolved oxygen concentration at time t_2

The oxygen transfer coefficient (α) was determined from the ratio of the overall mass transfer coefficient of the wastewater to that of tap water:

$$\alpha = \frac{K_L a \text{ wastewater}}{K_L a \text{ tap water}}$$

Table B-1 shows the results of four experiments carried out at 20°C. Nitrogen gas was used for deoxygenation.

For comparison, the oxygen transfer characteristics of some industrial wastes are shown in Table B-2.

Comparing the results shown in the above two tables, it can be concluded that the oxygen transfer coefficient of the high strength NSSC mill effluent was very low. This partially explains the reason for the oxygen deficiency frequently encountered in the reactors during the operation of the activated sludge systems.

TABLE B-1. COEFFICIENTS OF MASS TRANSFER AND OXYGEN TRANSFER

Air Flow (l/min)	Mass transfer coefficients K_La (hr^{-1})		Oxygen transfer coefficients (α)
	Tap water	NSSC	
8	8.8	3.0	0.35
12	14.9	4.5	0.30
20	24.3	10.0	0.41
23	27.9	11.1	0.40

TABLE B-2. OXYGEN TRANSFER CHARACTERISTICS OF INDUSTRIAL WASTES PRIOR TO BIO-OXIDATION (15)

Types of Waste	BOD_5 (mg/l)	α
Paper repulping	187	0.68
Semi-chemical machine backwater	1872	1.40
Mixed kraft mill	150 - 300	0.48 - 0.86
Pulp & Paper (bleach plant)	250	0.83 - 1.98
Pulp & Paper (pulp mill)	205	0.66 - 1.29
Pharmaceutical	4500	1.65 - 2.15
Synthetic fibre	5400	1.88 - 3.23
Board mill	660	0.53 - 0.64

APPENDIX C

MEASUREMENT OF FILTERING CHARACTERISTICS OF SLUDGE

Appendix C

Measurement of Filtering Characteristics of Sludge

Specific resistance was used to measure the filtering characteristics of sludge. The procedure and method as described by Eckenfelder and Ford (14) was used to determine this parameter. Figure C-1 shows the results of filtration tests on samples taken from the aeration tank. The calculated values of 1.4×10^{11} and 2.3×10^{11} sec^2/g for sludges from the first stage and the single-stage reactors indicated that sludges generated from the treatment of high strength NSSC mill effluent had a very high specific resistance or very low filterability. This provided an explanation for the difficulty encountered in the measurement of suspended solids as discussed in Section 3.6.1.

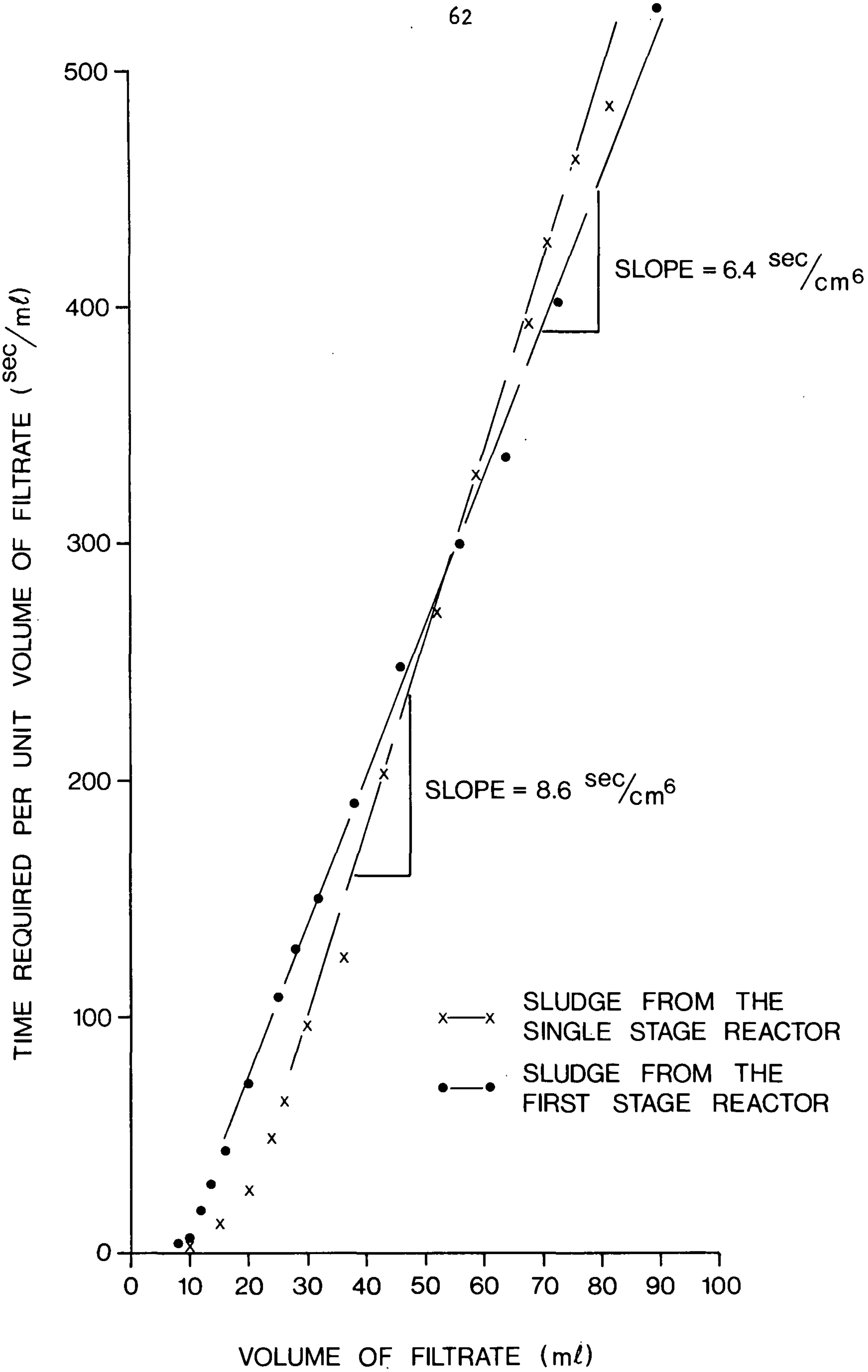

FIG. C-1 RESULTS OF FILTRATION TESTS.

APPENDIX D

DETERMINATION OF CORRECTION FACTORS FOR SUSPENDED SOLIDS

TABLE D-1. CORRECTION FACTORS FOR SUSPENDED SOLIDS CONCENTRATION OF UNTREATED WASTEWATER

Paper Filtration A (mg/l)	Centrifuging-Washing* B (mg/l)	Ratio $\frac{A}{B}$
1,810	1,290	1.4
1,660	1,120	1.5
2,190	1,430	1.5
2,440	1,270	1.9
2,000	1,290	1.6
940	1,050	0.9
920	1,110	0.8
2,390	1,450	1.6
3,080	1,210	2.5
2,210	1,180	1.9
1,920	1,320	1.4
2,740	1,130	2.4
2,060	1,250	1.6
2,520	1,440	1.7
2,190	1,550	1.4
3,120	1,220	2.6
2,440	1,090	2.2
1,760	950	1.9
	Average	1.7

* Results after second washing.

TABLE D-2. CORRECTION FACTORS FOR CONCENTRATION OF MIXED LIQUOR SUSPENDED SOLIDS

Paper Filtration A (mg/l)	Centrifuging-Washing* B (mg/l)	Ratio A/B
17,640	3,640	4.0
20,310	3,680	4.8
19,570	4,010	5.0
18,610	3,830	4.8
18,680	4,550	4.2
23,820	5,810	4.2
23,290	5,290	4.3
23,380	7,160	3.3
19,800	5,230	3.8
23,010	6,490	3.5
21,250	5,750	3.7
19,000	5,270	3.6
19,540	4,680	4.2
21,600	4,680	4.6
23,400	4,780	4.9
22,930	4,850	4.7
23,250	4,920	4.7
26,310	5,300	4.9
24,200	5,070	4.8
24,150	5,650	4.3
23,570	6,300	3.7
23,180	6,030	3.8
24,770	8,350	3.0
23,660	6,280	3.8
	Average	4.2

* Results after second washing

TABLE D-3. CORRECTION FACTORS FOR SUSPENDED SOLIDS CONCENTRATION OF EFFLUENTS

Paper Filtration A (mg/l)	Centrifuging-Washing* B (mg/l)	Ratio A/B
1,890	510	3.7
1,860	536	4.3
8,900	1,590	5.6
13,960	2,930	4.8
17,100	3,350	5.1
21,400	4,610	4.6
19,900	4,590	4.3
20,860	4,810	4.3
21,000	4,790	4.4
23,780	5,090	4.7
23,520	4,840	4.9
21,780	4,890	4.5
22,920	4,890	4.7
21,820	4,840	4.5
22,920	4,920	4.7
29,160	5,250	5.6
24,940	5,090	4.4
25,160	5,700	4.4
17,620	5,740	3.1
22,320	6,970	3.2
25,460	8,110	3.1
	Average	4.4

* Results after second washing

APPENDIX E

DAILY OPERATIONAL DATA

RW: Raw Waste

E1: First Stage Effluent

E2: Second Stage Effluent

E3: Single-Stage Effluent

A1: First Stage Aeration Tank

A2: Second Stage Aeration Tank

A3: Single-stage Aeration Tank

DATE	MLSS (mg/l)			DO (mg/l)			pH			
	A1	A2	A3	A1	A2	A3	RW	A1	A2	A3
Oct. 22	3020	1980	3220	0.3	0.2	0.3	7.4	8.1	8.5	8.5
23	3530	1950	3020	0.2	0.2	0.4	7.3	8.1	8.5	8.4
24	3430	2070	3250	0.3	0.3	0.2	7.2	8.1	8.6	8.5
25	3490	1920	3610	0.3	0.2	0.4	6.6	8.1	8.6	8.5
26	3470	1820	3220	0.2	0.2	0.4	7.4	8.1	8.5	8.4
29	3170	2020	2960	0.3	0.2	0.2	6.4	7.9	8.2	8.4
30	3650	2450	3430	0.3	0.2	0.2	6.7	7.9	8.5	8.2
31	3410	2580	3300	0.1	0.2	0.2	6.4	7.7	8.3	8.3
Nov. 1	3400	2730	3490	5.3	0.3	0.3	6.1	7.9	8.4	8.3
2	--	--	2880	4.2	0.2	0.4	6.1	8.0	8.6	8.3
5	5600	3040	2780	3.5	0.4	0.4	6.6	8.6	8.5	8.1
6	5000	3610	3000	1.8	0.4	0.4	6.4	8.6	8.6	8.2
7	4690	3540	3030	0.8	0.2	0.3	6.3	8.4	8.7	8.2
8	5180	3200	3390	0.3	0.3	0.3	6.3	8.5	8.7	8.1
9	4660	2980	2810	0.4	0.2	0.3	6.2	8.5	8.7	8.1
13	3770	2930	2530	0.4	0.3	0.3	6.2	8.2	8.3	8.0
14	4330	3520	3070	0.4	0.3	0.3	6.1	8.3	8.5	8.1
15	3610	2050	2560	0.4	0.3	0.3	6.2	8.4	8.5	8.1
16	4390	2710	2950	0.4	0.3	0.3	7.1	8.3	8.6	8.0
19	3290	1280	2980	--	0.2	1.4	6.5	8.2	8.7	7.9
20	3170	2620	3090	0.4	--	--	6.4	8.3	8.6	8.3
21	4080	2250	2890	0.3	0.3	0.3	6.4	8.2	8.5	8.1
22	2360	3160	3280	0.4	0.3	0.5	6.5	8.3	8.6	8.1
23	2660	2550	2970	0.3	0.3	1.4	7.2	8.1	8.6	8.0
26	2850	1940	2900	0.3	0.3	2.0	6.6	8.1	8.4	8.2
27	2220	2160	2702	0.3	0.3	2.8	6.3	8.2	8.5	8.4
28	2720	2230	2430	0.3	0.2	2.1	6.3	8.2	8.4	8.5
29	2800	1910	3380	0.3	0.3	0.7	6.8	8.3	8.5	8.4
30	2980	2500	2900	0.3	0.4	0.6	7.2	8.1	8.5	8.4
Dec. 3	2440	2880	3710	0.3	0.3	0.8	6.6	8.1	8.3	8.4
4	3040	3470	3650	0.3	0.3	0.6	--	8.0	8.4	8.5
5	4670	3220	4260	0.5	0.3	0.7	6.4	8.2	8.6	8.4
6	3800	3230	4300	0.3	0.3	4.4	6.5	8.1	8.6	8.5
7	4250	3380	4200	0.4	0.3	3.2	7.1	7.9	8.6	8.6
10	4210	3300	5070	0.3	0.4	0.6	6.5	7.8	8.6	8.6
11	4570	3550	4650	0.4	0.4	0.5	6.5	8.0	8.7	8.8
12	4330	2950	4800	0.6	4.4	0.4	6.4	8.2	8.8	8.8
13	4010	3120	4570	0.6	1.9	0.5	6.4	8.3	8.7	8.7
14	3070	3010	5060	0.4	2.4	2.6	6.3	8.4	8.7	8.6
17	3090	2750	5140	0.6	3.0	0.6	6.7	8.6	8.5	8.5
18	2710	1880	4950	0.7	1.7	0.9	--	8.7	8.7	8.6
19	3020	2390	--	0.6	6.0	0.6	6.5	8.6	8.7	--
20	2920	2080	3700	0.5	4.1	0.5	6.5	8.5	8.8	8.6
21	2920	3580	--	0.5	6.5	0.6	6.4	8.6	8.9	--
24	--	--	--	0.5	5.0	0.4	6.5	8.6	9.1	8.0
27	2500	1530	3330	0.4	5.1	0.3	--	8.5	8.8	8.8
28	2200	1950	2340	4.7	1.1	1.4	--	8.7	8.7	8.7
31	2660	2350	2430	5.8	5.1	0.3	--	8.7	8.8	8.6
Jan. 2/74	3210	2390	--	2.0	7.0	0.3	6.5	8.6	9.1	8.8
3	2590	1580	3370	3.0	6.2	0.3	6.5	8.6	9.1	8.8
4	2890	3000	3570	2.7	6.6	0.3	7.0	8.5	9.1	8.7
7	3290	2680	2970	0.4	6.7	0.2	6.6	8.7	9.0	8.8
8	3540	2630	1920	0.5	0.7	0.5	6.5	8.4	8.9	8.7
9	3680	2830	2700	0.5	0.3	0.4	6.4	8.4	8.8	8.8
10	3750	3240	2360	0.3	0.3	0.3	6.6	8.4	8.9	8.8
11	1700	1600	2680	0.3	0.3	0.2	6.6	8.4	8.9	8.6
14	3020	2330	2360	0.3	5.6	0.2	6.7	8.2	8.7	8.5
15	3490	2610	2470	0.2	3.7	0.4	6.5	8.4	8.7	8.6
16	3170	2140	2530	0.2	0.2	0.2	--	8.3	8.6	8.7
17	2850	3060	2930	0.3	0.2	0.2	6.6	8.3	8.7	8.9
18	2150	2240	2230	0.3	0.3	0.2	6.4	8.4	8.8	8.8
21	2110	2580	2300	0.2	0.3	0.3	--	8.2	8.5	8.7
22	2470	2500	2400	--	--	--	--	8.5	8.6	8.7

DATE	MLSS (mg/l)			DO (mg/l)			pH			
	A1	A2	A3	A1	A2	A3	RW	A1	A2	A3
July 30	2120	2140	2830	0.5	0.5	7.3	--	7.0	8.6	8.2
31	2620	1410	2760	0.4	0.5	7.3	--	7.1	7.8	7.6
Aug. 1	2880	2240	2950	0.2	0.4	3.2	--	7.6	8.0	8.1
3	--	--	--	3.4	0.3	4.4	--	8.6	8.1	8.1
7	--	--	--	0.3	0.5	7.4	7.8	7.6	8.1	8.0
8	3220	1600	2670	1.3	6.4	7.6	7.3	8.3	8.5	8.3
9	3760	1970	2480	5.9	7.6	7.3	6.3	8.4	8.6	8.2
10	2360	1900	2580	8.8	7.8	8.3	--	--	--	--
13	2040	1650	2100	8.5	9.1	8.3	6.0	7.8	8.1	7.8
14	2110	1410	2280	8.0	8.8	8.2	5.9	8.0	8.3	8.2
15	2060	1310	2240	4.7	8.3	8.6	7.0	7.7	7.9	7.8
16	2230	1320	2120	3.3	8.3	8.3	7.5	8.0	7.9	7.8
17	2300	1350	2510	3.4	8.3	8.3	7.0	8.0	8.5	8.1
20	3140	1300	2420	0.6	2.0	6.3	7.8	7.8	8.5	7.6
21	3710	1680	2730	5.2	8.0	6.2	7.0	7.7	8.6	7.6
22	3950	2170	2700	3.8	8.0	6.2	8.6	8.8	8.8	7.3
23	4690	2050	2900	0.2	7.0	6.3	8.2	8.3	8.6	7.6
24	3890	2930	3220	3.9	3.1	5.7	7.2	8.8	8.7	8.0
27	3400	3050	3080	3.2	0.4	6.0	6.8	8.9	8.7	8.9
28	--	--	--	--	--	4.2	--	--	--	8.1
29	--	--	--	--	--	4.1	7.8	8.2	--	8.0
30	3950	2530	3540	0.5	4.8	4.9	6.8	7.6	8.2	8.2
31	3600	2090	2930	6.7	5.8	2.6	7.5	--	--	--
Sept. 4	--	--	--	--	7.6	2.2	6.4	--	8.2	7.8
5	2300	2330	3270	0.5	4.2	2.2	6.6	8.2	8.4	8.5
6	2520	2200	3080	0.2	2.2	1.2	7.7	8.3	8.6	7.7
7	2810	2250	3150	0.5	2.7	2.8	7.4	8.6	8.9	8.7
10	2930	2077	2910	0.7	3.0	2.8	6.5	8.1	8.3	7.1
11	3360	1830	2930	0.3	2.9	2.3	7.8	8.1	8.4	7.8
12	3520	1860	3020	0.2	3.1	2.0	7.6	8.2	8.5	8.1
13	2420	1880	2720	0.5	4.8	0.6	7.9	8.2	8.4	7.9
14	3350	1930	3110	0.5	3.2	1.7	7.0	8.3	8.4	7.8
17	3730	2330	3160	0.5	0.5	1.8	7.0	8.5	8.3	8.7
18	2580	2440	2970	0.5	0.5	1.1	6.7	8.5	8.3	8.7
19	2830	2340	2950	0.5	3.6	0.8	6.2	8.6	9.0	8.8
20	2820	2540	3110	0.5	3.8	0.7	6.1	8.6	9.1	8.8
21	2768	2450	3080	0.5	2.1	0.7	6.5	8.5	9.2	8.8
24	2780	2680	3080	0.5	3.6	1.3	6.0	8.4	9.0	8.7
25	2500	2490	2840	0.5	0.5	2.0	6.0	8.3	8.7	8.7
26	2470	2480	3160	0.5	0.4	2.3	6.0	8.5	9.0	9.0
27	2970	3080	3680	0.4	0.2	2.4	6.5	8.5	9.0	9.0
28	2640	2880	3360	0.5	0.3	1.6	6.0	8.5	9.0	9.0
Oct. 1	2700	2240	2310	0.5	0.3	1.3	6.2	8.4	9.0	9.1
2	2750	2300	2630	0.3	0.4	1.5	6.0	8.0	8.6	8.6
3	2880	2800	2390	0.5	0.4	1.5	5.9	7.9	8.5	8.6
4	2410	4570	2440	0.5	0.3	1.5	7.1	7.9	8.6	8.6
5	2630	2390	2410	0.4	0.2	4.0	6.0	7.7	8.5	8.6
9	2670	2120	2660	0.4	0.2	0.4	6.5	7.7	8.3	8.6
10	2830	2040	3210	0.4	0.3	2.7	6.0	7.7	8.4	8.7
11	2907	1990	2770	0.5	0.5	1.6	6.0	7.8	8.5	8.6
12	2800	1880	2940	0.4	0.2	1.8	6.6	8.2	8.6	8.8
15	2800	1880	2560	0.4	0.4	0.5	7.0	8.2	8.6	8.9
16	2690	1880	3040	0.4	0.5	1.0	--	8.3	8.6	8.9
17	--	--	--	0.3	0.2	0.1	7.2	--	--	--
18	2790	1900	3000	0.3	0.3	0.4	6.0	8.0	8.4	8.5
19	3080	1830	3180	0.4	0.3	0.2		8.0	8.4	8.6

DATE	BOD (mg/1)				COD (mg/1)				TOC (mg/1)				SUSPENDED SOLIDS (mg/1)			
	RW	E1	E2	E3	RW	E1	E2	E3	RW	E1	E2	E3	RW	E1	E2	E3
Oct. 22	7020	5370	3130	--	32800	23000	18000	12000	9100	7600	5500	3850	620	190	330	470
23	8280	5140	2870	1810	--	--	--	--	10190	8050	6000	4300	440	280	170	580
24	6330	5240	2840	1760	33500	24300	18500	13800	9820	7410	6040	4650	340	420	180	840
25	8170	5610	2890	2000	--	00	--		11010	8540	6520	4725	1190	490	140	780
26	7250	3400	3490	2170	32700	24400	19900		11475	9005	7075	4660	1820	580	220	550
29	7250	5980	4310	2910	27500	24700	21900		8110	7780	7100	4460	1510	1340	210	1210
30	11900	5700	4310	3430	--	00	--		14520	8460	7140	5420	340	990	210	1210
31	13900	7760	4830	4310	43800	29900	22700		12670	11950	7300	6150	910	1160	290	480
Nov. 1	12300	7610	5230	4930	--	--	--		13200	10850	780	6720	1760	120	210	440
2	11400	--	--	3160	46200	--	--		14500	--	--	7320	3080	--	--	350
5	11600	6070	5060	5850	46200	22500	25900		14500	10820	9070	8570	650	340	390	320
6	12000	6770	5000	5340	--	--	--		14360	10810	9530	8800	3470	430	290	740.
7	--	8300	5120	5240	96800	34800	27400		13650	10360	8360	8600	--	930	410	430
8	12700	7460	4660	5540	--	--	--		13700	10220	8770	8860	810	520	410	450
9	15700	7150	4260	5240	44800	34200	26200		13200	11270	8650	9060	560	850	380	400
13	13700	7730	5870	7550	--	--	--		13940	10890	9370	9920	830	320	1040	320
14	13400	6760	5180	5850	47200	34400	29600		14350	10980	10170	10340	850	360	390	310
15	12400	7150	4950	6000	--	--	--		12680	11260	9860	1060	600	4300	360	310
16	10700	7000	4720	5850	42700	33300	24400		13100	10740	9720	10350	610	570	350	340
19	11900	7760	4260	7240	44600	33900	2760		12740	10360	9320	10420	910	400	340	420
20	11300	6840	4950	6780	--	--	--		14000	11260	10000	10570	760	660	360	580
21	11200	6770	5060	7080	42700	33900	28600		11900	10450	10100	10370	710	390	430	390
22	11700	7760	4690	6160	--	--	--		13270	11370	9980	10300	560	300	370	480
23	10200	8320	5520	4850	42900	33200	28800		13450	11270	10570	10220	650	460	350	500
26	8300	7380	5520	3630	45600	33600	30300		12770	11000	10170	9820	1450	350	420	520
27	9790	7840	5350	3110	--	--	--		12270	11140	10350	8900	720	230	350	720
28	11100	8150	5870	3080	41700	33700	30600		11720	11420	10100	7800	870	490	380	--
29	10300	7900	5300	3100	--	--	--		11300	10400	9740	7910	2050	400	470	690
Nov. 30	12300	8230	6730	2100	44000	33000	30400	15200	13170	10660	9930	8000	620	490	990	560
Dec. 3	11100	8920	6270	1960	43100	34900	31400	26300	12610	11160	10050	7260	2080	240	480	520
4	10500	9000	6500	1960	--	--	--	--	13140	11270	10250	7540	810	220	500	750
5	12400	6760	8280	2650	44300	32900	35300	2800	11670	9690	9620	7450	1000	210	1310	830
6	11900	8380	6330	1630	--	--	--	--	11900	9980	10200	7860	880	510	700	990
7	15300	8800	7700	2400	52600	35300	33900	27700	15900	11520	10520	8070	1710	860	640	730
10	15500	10000	7600	3100	51400	36400	35000	28200	13850	12070	10740	9520	2370	310	980	1090
11	15500	10400	8100	3300	--	--	--	--	14210	1160	11160	9300	2260	910	860	1170
12	15000	10200	7100	3400	49800	35600	34400	30400	13720	10870	11450	9090	2190	1280	860	1040
13	13800	8600	6500	3600					13350	10300	10100	9100	2130	820	910	910
14	14000	7230	5230	3330	54100	30400	30200	31900	14580	9820	9600	9900	2200	620	1150	910
17	12200	3840	4030	3060	53500	23700	22700	31900	14650	7170	6950	10500	940	460	720	1040.
19	12900	2840	1610	--	61500	22300	17900	--	15540	6160	4890	--	1140	420	520	--
20	12500	2690	1150	--	--	--	--	--	14070	6270	5240	--	930	390	440	--
21	12800	2770	1150	--	53500	21700	16300	--	13420	6250	4240	--	1090	610	380	--
24	13100	3080	--	--	51200	22100	15400	33500	13670	6070	3850	10460	--	--	--	770
28	--	--	--	--		--	--	--	13570	7240	5170	--	--	--	--	--
Jan. 2/74	10300	--	--	51600	51600	--	--	33700	14850	--	--	11600	--	--	--	--
4	13500	4730	1710	51500	51500	22500	19900	33700	14520	6350	--	11470	820	450	--	850
7	12000	3230	1380	44200	44200	23900	20900	33900	14840	7920	7040	8950	930	1120	780	--
9	14600	--	--	49700	49700	--	--	34100	--	--	--	11340	710	--	--	--
10	20300	--	--	--	--	--	--	--	14450	7530	--	10360	570	--	--	540
11	--	--	--	--	--	--	--	--	14840	8800	8480	9980	710	--	--	480
14	12300	8690	3680	68000	6800	28270	30350	32400	13460	10980	10710	14840	2980	250	--	1580
15	1300	7920	3630	--	--	--	--	--	13480	9950	9160	9370	740	320	--	1260
16	13100	7370	5810	49600	49600	30950	29500	--	11470	10220	11050	--	1130	350	--	--
17	13200	7530	5230	--	--	--	--	--	13980	9660	11520	7170	910	460	--	--
18	13800	7760	6440	48000	48000	31950	31150	--	13500	9920	9070	8750	1090	440	--	--
21	13500	9380	6440	--	52500	36250	33600	--	13500	9600	9010	8390	--	450	--	--
22	14000	8230	6210	4900	--	--	--	--	14200	9590	10400	10670	820	450	1210	1280

DATE	TKN (mg/1)				TOTAL P (mg/1)				TDS (mg/1)			
	RW	E1	E2	E3	RW	E1	E2	E3	RW	E1	E2	E3
July 30	366	266	102	42	82	62	32	26	--	--	--	--
Aug. 1	386	260	184	55	74	64	54	30	--	--	--	--
3	486	372	308	126	96	78	70	24	--	--	--	--
8	618	382	236	96	132	98	76	50	--	--	--	--
9	--	--	--	--	--	--	--	--	3050	15180	10480	18180
10	--	--	--	--	80	92	71	60	--	--	--	--
13	431	555	325	204	92	74	72	61	--	--	--	--
15	380	322	78	86	84	60	28	50	--	--	--	--
16	--	--	--	--	--	--	--	--	5510	--	--	8660
17	335	248	252	96	63	48	50	56	--	--	--	--
20	362	208	135	74	70	60	44	48	--	--	--	--
21	--	--	--	--	--	--	--	--	37900	23300	16900	9500
22	323	--	65	85	63	--	23	43	--	--	--	--
23	--	--	--	--	--	--	--	--	36300	28200	20100	11200
24	339	223	59	92	67	49	22	43	---	--	--	--
27	332	111	61	91	69	30	22	42	--	--	--	--
28	--	--	--	--	--	--	--	--	38820	--	--	12560
29	235	--	--	76	50	--	--	29	--	--	--	--
30	--	--	--	--	--	--	--	--	36220	29580	24180	13470
31	323	132	175	204	64	27	24	37	--	--	--	--
Sept. 4	--	--	--	--	--	--	--	--	20500	--	--	14190
5	220	91	105	106	51	20	39	40	--	--	--	--
6	---	--	--	--	--	--	--	--	22690	15040	18710	14970
7	226	75	88	100	43	17	29	40	--	--	--	--
10	228	--	60	82	44	--	15	34	--	--	--	--
11	--	--	--	--	--	--	--	--	19470	15320	14210	14630
12	245	95	55	82	44	19	15	35	--	--	--	--
13	--	--	--	--	--	--	--	--	23260	15950	14140	14560
14	279	198	56-	81	53	24	18	38	--	--	--	--
17	169	129	53	80	33	25	15	37	--	--	--	--
18	--	--	--	--	--	--	--	--	26330	19170	18500	14080
19	305	117	50	88	55	24	16	40	--	--	--	--
20	--	--	--	--	--	--	--	--	24930	20220	14910	14130
21	179	115	51	07	36	22	14	40	--	--	--	--
24	203	117	53	90	37	21	13	36	--	--	--	--
25	--	--	--	--	--	--	--	--	26210	21230	17180	15460
26	193	137	72	96	26	15	8	26	--	--	--	--
27	--	--	--	--	--	--	--	--	24610	21850	17550	15110
28	157	114	59	80	27	20	12	33	---	--	--	--
Oct. 1	196	91	103	66	34	11	16	29	--	--	--	--
2	--	--	--	--	--	--	--	--	21730	21500	20280	15060
33	160	95	95	54	29	13	14	26	--	--	--	--
4	--	--	--	--	--	--	--	--	24060	22010	19660	15180
5	114	81	97	60	17	12	12	28	--	--	--	--
9	--	--	--	--	--	--	--	--	25940	23830	22910	15850
10	119	80	88	76	18	12	12	32	--	--	--	--
11	--	--	--	--	--	--	--	--	27460	22960	22708	15850
12	133	77	81	67	19	4	7	25	--	--	--	--
15	120	83	85	71	17	4	7	25	--	--	--	--
16	--	--	--	--	--	--	--	--	27310	22740	22500	15610
17	56	58	95	63	10	4	7	21	--	--	--	--
18	--	--	--	--	--	--	--	--	30760	15030	19560	14410
19	164	70	88	65	27	6	7	23	--	--	--	--
22	145	108	96	90	24	13	10	30	--	--	--	--
23	--	--	--	--	--	--	--	--	30880	26350	22850	18270
24	139	100	100	89	24	10	7	28	--	--	--	--

DATE	TKN (mg/1) RW	TKN E1	TKN E2	TKN E3	TOTAL P (mg/1) RW	TOTAL P E1	TOTAL P E2	TOTAL P E3	TDS (mg/1) RW	TDS E1	TDS E2	TDS E3
Oct. 25	--	--	--	--	--	--	--	--				
26	138	97	92	103	21	10	40	29	29620	27770	23790	20140
29	148	124	99	111	24	14	9	39	--	--	--	--
30	--	--	--	--	--	--	--	--	--	--	--	--
31	186	122	108	123	27	13	11	41	45170	30400	26080	23480
Nov. 1	--	--	--	--	--	--	--	--	--	--	--	--
2	224	--	--	134		--	--		41990	35120	27650	25770
5	199	185	130	126	34	21	12	38	--	--	--	--
6	--	--	--	--	--	--	--	--	--	--	--	--
7	286	196	160	154	47	26	17	42	43480	40050	31600	31300
8	--	--	--	--	--	--	--	--	--	--	--	--
9	188	168	144	141	34	20	13	36	43050	37230	35150	31970
13	--	--	--	--	--	--	--	--	--	--	--	--
14	245	162	145	149	29	8	22	12	42900	38200	37570	34600
15	--	--	--	--	--	--	--	--	--	--	--	--
16	186	169	150	142	26	16	16	25	40830	39730	36510	36080
19	372	174	157	149	55	16	14	25	--	--	--	--
20	--	--	--	--	--	--	--	--	--	--	--	--
21	183	159	155	167	27	19	20	32	39710	38010	36690	35620
22	--	--	--	--	--	--	--	--	--	--	--	--
23	188	149	165	130	27	20	22	22	39430	39000	36380	36310
26	394	141	156	11y	65	17	20	14	--	--	--	--
27									--	--	--	--
28	195	181	168	124	26	24	23	13	40320	37120	38320	30940
29									--	--	--	--
30	216	130	118	116	57	20	14	21	38960	36540	37220	34010
Dec. 4	176	187	168	131	23	17	20	16	--	--	--	--
5	215	171	172	122	31	24	24	17	--	--	--	--
6	--	--	--	--	--	--	--	--	39610	36600	38770	35350
7	173	152	159	97	25	17	20	14	--	--	--	--
10	278	186	189	148	40	21	21	21	--	--	--	--
11	--	--	--	--	--	--	--	--	50120	41910	43520	40580
12	230	201	223	157	40	31	35	31	--	--	--	--
13	--	--	--	--	--	--	--	--	48090	35700	37150	40610
14	231	185	199	141	36	19	21	12	--	--	--	--
17	436	164	136	137	71	18	14	17	--	--	--	--
19	297	165	104	--	44	15	8	--	--	--	--	--
20	--	--	--	--	--	--	--	--	52950	28210	20990	--
21	247	158	90	--	37	15	8	--	--	--	--	--
24	201	161	100	144	30	17	10	17	--	--	--	--
Jan. 2/74	182	--	--	136	21	--	--		--	--	--	--
4	183	94	128	139	21	3	9	13	--	--	--	--
7	185	120	97	159	24	11	6	13	--	--	--	--
9	193	--	--	165	25	--	--	15	--	--	--	--
10	--	--	--	--	--	--	--	--	51640	--	--	46890
11	192	--	--	156	27	--	--	13	--	--	--	--
14	248	178	140	228	38	19	12	28	--	--	--	--
15	--	--	--	--	--	--	--	--	47800	41100	44000	71460
16	203	154		188	19	7	--	18	--	--	--	--
17	--	--	--	--	--	--	--	--	49300	39900	40860	42000

DATE	BOD (mg/l)				COD (mg/l)				TOC (mg/l)				SUSPENDED SOLIDS (mg/l)			
	RW	E1	E2	E3	RW	E1	E2	E3	RW	E1	E2	E3	RW	E1	E2	E3
July 30	10600	8710	4100	158	28850	24150	16450	4425	13400	9300	7300	1660				
31	10947	8587	5541	327	--	--	--	--	19800	9700	7250	1630				
August 1	10400	5720	4080	404	27750	19400	16500	5150	12950	8700	5900	3400				
3	8350	4660	3340	183	20900	19070	4480	5140	8500	6410	1850	5450				
7	10360	5070	1730	501	--	--	--	--	8000	4650	3750	1850	1920	640	380	340
8	7700	2990	748	163	18850	16300	9300	5100	7800	5300	3150	2250	1720	410	190	520
9	7890	2020	489	181	--	--	--	--	8800	4650	3400	1800	400	520	490	540
10	2020	1440	144	145	21000	6800	5700	4000	720	2400	2700	1800	120	870	250	450
13	1497	980	575	153	2798	3932	2110	4518	950	600	800	1450	190	60	130	580
14	1610	1040	489	63	--	--	--	--	--	500	570	1350	60	240	160	470
15	1958	1037	489	90	2420	1285	1021	3913	950	500	560	1350	100	200	120	580
16	1550	--	144	71	--	--	--	--	1630	530	440	1300	70	30	40	530
17	1610	201	230	100	3660	2320	1320	2960	1490	540	730	1154	90	40	60	610
20	9833	4890	1360	59	24726	14140	8200	3724	10000	5950	2770	1295	2890	630	620	220
21	9720	--	1035	173	26600	--	9725	3700	10400	--	3320	1350	1160	--	380	170
22	8290	--	403	35	25860	--	11490	4800	10350	--	3650	1520	480	--	540	100
23	8630	1960	460	47	--	--	--	--	11400	5720	4500	1800	630	--	640	210
24	7600	2300	230	51	25100	20400	11900	9300	11650	5050	4400	1850	3810	--	180	310
27	9210	800	288	82	37100	18870	15740	5950	10400	5200	4300	1900	1250	--	--	520
28	7390	--	--	<40	--	--	--	--	11500	--	--	2080	740	--	--	230
29	8400	--	--	<40	3860	--	--	6320	11200	--	--	2170	800	--	--	230
30	7944	3742	259	39	--	--	--	--	9200	6900	5230	1980	770	420	750	270
31	7370	806	518	39	30200	20620	16390	6720	9100	6300	5650	2080	910	800	580	300
Sept. 4					--	--	--	--	6250	--	--	2150	880	--	940	120
5	7370	1037	400	61	21000	9400	11400	6400	4830	2580	3130	1850	1080	540	130	240
6	6907	864	463	65	--	--	--	--	6800	2450	3060	1970	570	230	130	170
7	7820	1037	288	46	22900	8700	9100	6230	6810	2600	2750	2100	360	210	190	200
10	6900	--	403	38	20600	--	6700	5630	4950	--	1780	1860	2790	--	190	130
11	6790	1380	--	42	20200	9900	6300	6030	5500	2820	1850	1860	1170	1170	200	130
12	6040	891	173	38	22900	10300	6500	6130	7400	2900	1870	1850	1160	430	760	190
13	6210	1320	--	53					6600	2800	1730	1730	410	290	170	290
14	6610	1490	--	53	24400	12000	6700	6200	7330	3300	1650	1750	2790	340	130	160
17	5950	2130	--	42	28240	13460	6900	6100	9800	4400	2000	2100	2990	410	220	330
18	6210	2760	--	45					10300	4750	1790	1630	--	300	170	340
19	8510	3380	129	63	27400	15900	7500	6000	9060	5500	2100	2100	3400	330	100	270
20	7070	3660	95	63					8000	5430	2400	2150	870	320	210	350
21	6900	3840	84	50					7330	5700	2470	1870	980	400	170	300
24	7300	2920	91	63	28800	18000	13700	9400	8420	5550	2750	2150	2530	410	140	240
25	7420	3050	97	69					8550	5620	2850	2100	1580	300	220	320
26	6840	3240	188	78	26000	9400	10400	7400	7950	5800	3120	2200	650	210	200	270
27	7940	4020	377	92					7560	5950	3250	2230	380	250	310	230
28	6900	3700	222	102	27300	19800	10800	6780	8010	6200	3400	2100	470	200	270	290
Oct. 1	6960	4260	<470	69	29600	20400	16300	7350	8080	6600	4910	2230	1600	140	350	260
2	6440	3610	<480	48	26100	18800	14300	6840	7750	6300	4600	2150	740	170	250	210
3	7070	4580	<470	61	21500	19900	16100	7160	8500	6500	5000	2230	520	160	280	260
4	7500	5200	1680	57					7700	6850	5070	2420	1080	150	200	250
5	7160	5210	1660	61	27300	20500	16400	7200	8300	6560	5100	2200	840	150	230	220
9	7220	6040	3630	340					8010	6770	6200	2500	310	170	210	490
10	6810	5580	3630	236	26900	21500	19100	8500	8000	7100	5950	2450	400	160	210	560
11	10100	4930	4420	129					8000	6550	5600	2370	1000	150	190	430
12	6760	5570	3960	103	28200	20970	18600	7800	8220	6500	6050	2700	1310	160	190	340
15	6410	4790	3670	93	28200	21200	19600	8400	7600	7000	6050	2870	810	170	170	720
16	1810	3980	3560	72		--			2700	5850	5700	2530	170	150	170	350
17	1610	2960	2960	59	6000	12600	16400	6700	2300	5300	3800	1980	370	90	160	230
18	7480	3680	3200	80					9250	3850	5000	2270	760	70	160	470
19	7530	2730	1710	188	33400	15600	14400	7800	8870	5070	4110	2940	1080	120	100	500