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Biological Treatment of Airport Wastewater Containing Aircraft De-Icing Fluids

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BIOLOGICAL TREATMENT
OF
AIRPORT WASTEWATER
CONTAINING AIRCRAFT DE-ICING FLUIDS

by

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ABSTRACT

Aircraft de-icing fluids are used at Canadian airports to remove the ice and snow which accumulates on aircraft. Most of the de-icing fluid runs off the aircraft and enters the airport sewer collection system. The main component of de-icing fluid is glycol which exerts an extremely high oxygen demand and could cause a serious pollution problem if discharged to a receiving water without treatment.

A study was conducted to investigate the feasibility of treating a combination of de-icing fluids and airport wastewater using an activated sludge process. The results were to provide information for the design of treatment facilities at the new airport at St. Scholastique, Quebec, and for assessing alternatives at other airports across Canada.

The study was carried out in two parts. The first part was a bench-scale activated sludge study to determine the optimum loading condition and obtain design parameters for the treatment of de-icing fluids and municipal sewage at low temperatures. A 131 m^3/day IGPM pilot plant was operated at the optimum organic loading to verify the results from the laboratory-scale study and determine whether there were any operational problems. The second part of the program bioassay studies, was carried out to determine whether the aircraft de-icing fluids and process effluents were acutely toxic to rainbow trout.

The experimental results showed that an activated sludge system treating a combination of de-icing fluid and domestic sewage at less than 10^oC will produce an effluent having BOD and suspended solids concentrations not exceeding 20 mg/l and 25 mg/l, respectively at a loading of 0.15 kg BOD/kg MLSS • day. Growth of filamentous microorganisms and the resulting sludge bulking condition were responsible for the low loading condition. The bioassay results showed that, at an acceptable organic loading, the concentration of de-icer in the feed solution would be such that the effluent from the activated sludge process would not be toxic to rainbow trout.

RESUME

Dans les aéroports canadiens, on se sert des liquides de déglaçage pour enlever la glace et la neige qui s'accumulent sur les appareils. La majeure partie de ces liquides s'écoule de l'aéronef et aboutit dans les égouts. Le fluide de déglaçage se compose surtout de glycol, qui demande une très forte quantité d'oxygène et qui pourrait, s'il était versé dans les eaux réceptrices sans avoir reçu de traitement, entraîner un grave problème de pollution.

Une étude a été faite pour connaitre la possibilité de traiter un mélange de liquide de déglaçage et d'eaux usées aéroportuaires en emplyant des boues activées. Les résultats devraient servir à concevoir les installations de traitement pour le nouvel aéroport de Sainte-Scholastique, au Québec, et àévaluer les systèmes de traitement des autres aéroports canadiens.

L'étude a comporté deux parties. La première consistait en une étude des boues activées sur banc d'essai pour déterminer la condition de charge optimale et obtenir les paramètres de conception pour le traitement des liquides de déglaçage et des eaux usées à basse température. On a exploité une usine pilote de 20 gal imp/mn à sa charge organique optimale pour vérifier les résultats de l'étude en laboratoire et déterminer les problèmes d'exploitation. La seconde partie du programme consistait en des bio-analyses pour déterminer si les déglaçage et les effluents de traitement étaient très dangereux pour la truite arc-en-ciel.

Les résultats des expériences montrent qu'un système de boues activées pour traiter le liquide de déglaçage et les eaux usées àmoins de 10^{o}C produit un effluent qui possède les qualités souhaitées lorsque sa charge est de 0.15 kg DBO/kg/SSM/j. La croissance de micro-organismes filamenteux ainsi que l'apparition de masses de boues sont la cause de la faible condition de charge. Les résultats des bio-analyses montrent qu'à la charge organique acceptable, la concentration du liquide de déglaçage dans la solution d'alimentation serait telle que l'effluent produit par le traitement des boues activées ne serait pas toxique pour la truite arc-en-ciel.

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Conclusions

The objectives of the study were to determine the design parameters and potential operational problems for an activated sludge process treating a mixture of aircraft de-icing fluids and airport municipal sewage. Bioassays were conducted to determine whether process effluents were acutely toxic to rainbow trout. Studies were carried out using UCAR de-icer, ADF-C1, and Dow de-icer, ADF-1050. The following conclusions can be made:

1. An adequately designed and properly operated extended aeration activated sludge system treating either Dow de-icer and sewage or UCAR de-icer and sewage at a mixed liquor temperature of 2, 5 or 10^{o}C and an organic loading not exceeding 0.15 kg BOD/kg MLSS • day will produce an effluent having the desired quality; i.e., a BOD of less than 20 mg/l and a suspended solids concentration less than 25 mg/l.
2. Wastewater containing a mixture of de-icing fluid and sewage could be treated in an activated sludge system operated at an organic loading of approximately 0.30 kg BOD/kg MLSS • day if the mixed liquor temperature is 20^{o}C.
3. The growth of filamentous microorganisms will occur when a conventional activated sludge process is used for the treatment of de-icing fluid and sewage. The presence of the filamentous microorganisms and the resulting bulking sludge condition is the

controlling factor in the system design as the growth limits the maximum allowable organic loading for the readily biodegradable waste.

4. For the design of an activated sludge system treating de-icing fluid and sewage at 5 and $10^{o}C$, the oxygen requirement can be determined using a coefficient of dissimilation (a') equal to 0.5 and a coefficient of endogenous respiration (b') equal to 0.06. The sludge production rate can be determined using sludge yield coefficients (a) of 0.7 and 0.55 at temperatures of 5 and $10^{o}C$, respectively, and a coefficient of auto-oxidation (b) equal to 0.03 for both temperatures.
5. The pH levels encountered in the activated sludge systems treating de-icing fluids and sewage were always within the range considered to be acceptable for microbial growth; therefore, no chemicals will be required for pH control.
6. The nutrient requirements for the treatment of the de-icing fluids and sewage at a temperature of $10^{o}C$ can be determined using the accepted BOD:N:P ratio of 100:5:1. Additional nitrogen may be required at low temperatures as the results indicate that for the treatment of de-icing fluids and sewage at 2 and $5^{o}C$, it will be necessary to provide BCD:N:P ratios of approximately 100:9:1 and 100:7:1, respectively.
7. The majority of problems encountered in the operation of the extended aeration pilot plant were caused by the growth of filamentous microorganisms and the resulting bulking sludge condition.

Other operational problems were of a minor nature and should not affect the operation of a properly designed full-scale plant.

8. In the treatment of de-icing fluids using an activated sludge process at an acceptable organic loading, the concentration of de-icer in the feed solution would be such that the effluent would not be acutely toxic to rainbow trout. Following aeration, the number of toxic units contributed by the de-icer under maximum loading conditions would be within the "no effect" range determined for many other toxic substances.

9. In treating a mixture of de-icing fluid and domestic wastewater in laboratory and pilot-scale reactors, many of the effluents were acutely toxic to rainbow trout. The toxicity was found to be contributed by the municipal sewage.

10. The 96-hr LC50 for Dow de-icer was approximately 9,200 mg/l and the 96-hr equilibrium loss concentration was 4,600 mg/l; comparable values for UCAR de-icer were 6,600 and 3,500 mg/l. The results show that median equilibrium loss is a more sensitive method than median mortality for determination of the short-term effects of de-icer on rainbow trout.

11. Aeration of test solutions increased the 96-hr LC50 for both de-icing fluids to greater than 12,000 mg/l. The toxicity of the de-icer solutions removed during aeration was attributed to the components of the inhibitor package and not the ethylene and propylene glycol.

Recommendations for Further Study

The results of the investigation indicated that studies should be undertaken to provide additional information required for design and operation of a full-scale plant. They are as follows:

1. As BOD of sewage at airports is reported to be approximately 300 mg/1, a study should be conducted to determine whether the organic loading to the treatment plant could be increased when treating de-icer and high-strength domestic waste. It is anticipated that as the ratio of BOD contributed by the sewage to that contributed by the de-icer increases, the allowable organic loading should increase primarily due to a reduction in filamentous microbial growth resulting from a balanced feed solution.
2. In order to increase the organic loading to the activated sludge system, an investigation should be undertaken to study methods of controlling the growth of filamentous microorganisms or the resulting bulking sludge condition. A number of alternatives have been reported in the literature and it would be advisable to study these prior to designing a full-scale treatment plant incorporating an activated sludge system.

1. INTRODUCTION

Airport de-icing fluids are used at Canadian airports to remove the ice and snow which accumulates on the aircraft. Heated de-icing fluid is sprayed on the aircraft; the major portion of the fluid spills onto the apron and eventually enters the airport sewer collection system. The main component of de-icing fluid is glycol which exerts an extremely high oxygen demand. Consequently, discharge of the untreated run-off into a receiving water will result in a rapid depletion of available dissolved oxygen, creating a serious pollution problem.

At present, the airport wastewater containing de-icing fluid is not treated at any of the major Canadian airports. In an attempt to upgrade the degree of wastewater treatment at all Canadian airports, the Federal Activities Protection Branch, Environmental Protection Service, requested information on the feasibility of treating a combination of de-icing fluid and airport wastewater to meet prescribed effluent quality objectives. The program was initiated to collect information for the design of treatment facilities at the new Montreal International Airport being constructed at St. Scholastique, Quebec, and will be used to assess treatment alternatives at other Canadian Airports.

A portion of the program was conducted by the Technology Development and Demonstration Division of EPS at the Wastewater Technology Centre (WTC) at the Canada Centre for Inland Waters (CCIW) in Burlington, Ontario. The program and results are presented in this report and include the following:

a) bench-scale activated sludge studies at low temperatures to determine the optimum loading conditions for various concentrations of a combination of de-icing fluids and airport wastewater;

b) pilot-scale operation at the optimum loading to study possible operational problems; and

c) bioassay studies to determine the acute toxicity to rainbow trout of aircraft de-icing fluids and effluents from the selected treatment process.

The remainder of the program was funded by the Ministry of Transport and carried out by the consulting engineering firm, Beaudry, Dupuis, Morin, Routhier and Associates, Laval, Quebec. The firm was retained by the Ministry of Transport to design the combined wastewater treatment facilities at St. Scholastique. In addition, the consultant was to evaluate:

a) methods of pre-treating the run-off so it could be discharged to the airport's wastewater treatment plant and;

b) advanced treatment processes, other than activated sludge, for the combined treatment of run-off and airport wastewater.

The study conducted by the Technology Development and Demonstration Division of the Environmental Protection Service at the Wastewater Technology Centre has been reported in two parts. The objective of the first part was to determine the optimum loading conditions and design parameters for the treatment of a combination of de-icing fluids and municipal sewage in the activated sludge system that would provide an effluent meeting specified criteria. The objective of the second part was to determine at what concentrations the de-icing fluids, and the effluents from the activated sludge system, were acutely toxic to rainbow trout. It was apparent that neither of these problems had been investigated as no relevant information was obtained from a thorough literature review.

ACTIVATED SLUDGE STUDIES

2. OBJECTIVES AND SCOPE

The studies conducted to determine the optimum loading of an activated sludge system treating dilute de-icing fluid and municipal water were conducted in two phases. The first phase was a laboratory-scale study conducted under controlled temperature conditions. This phase of the study provided the following design information:

a) optimum organic loading conditions to meet the specified effluent quality;
b) oxygen uptake rates;
c) sludge production rates;
d) nutrient requirements;
e) neutralization requirements and;
f) sludge settling characteristics.

The second phase of the study was a pilot-scale study conducted without temperature control. A 131 m^3/day (20 IGPM) activated sludge pilot plant was used for the following:

a) verification of the optimum loading conditions obtained from the laboratory-scale study and;
b) determination and correction of possible operational problems.

As de-icing fluids are only applied during the winter months, it was assumed that the temperature of the run-off would be less than 10^oC. As a result, the majority of experiments were conducted at temperatures of 5 and 10^oC with several runs at 2^oC and one run at room temperature. The activated sludge system was to produce an effluent having a suspended solids and BOD_5 concentration not exceeding 25 and 20 mg/1, respectively.

3. EXPERIMENTAL PROGRAM

3.1 Schedule of Experiments

The schedule of laboratory and pilot-scale experiments conducted between December and June is outlined in Table 1. Initial experiments were conducted over a range of F/M ratios to obtain design parameters for an activated sludge system. Additional studies related to the attainment of an acceptable effluent quality, and the collection of supplementary design data, were carried out by setting up extended aeration reactors and operating them at 2, 5 and 10°C. A two-stage activated sludge system was operated to determine whether the desired effluent quality could be obtained at high organic loading conditions.

The results of the laboratory-scale studies were used to define the operating parameters for the pilot plant. The unit was operated at a flow rate of 131 m^3/day (20 IGPM); two de-icer concentrations were used during the study period.

3.2 Reactors for Experimental

Five single-stage temperature-controlled reactors, as shown in Figure 1, were used for the initial phase of the laboratory study. The 2-litre settling compartment was separated from the 6-litre aeration tank by an adjustable baffle. The sides of the reactor were enclosed by a cooling jacket containing methanol. The coolant was circulated through a cooling unit to keep the contents of the reactor at a specific

TABLE 1

SCHEDULE OF EXPERIMENTS

A: LABORATORY-SCALE STUDIES

I Single-Stage Activated Sludge System

DATE From:	To:	SETS OF REACTORS	TYPE OF DE-ICER	DOSAGE OF DE-ICER (ml de-icer per 100 l feed solution)	TEMP. (°C)	FLOW RATE ml/min	REMARKS
Dec. 7, '72 -	Dec. 22	5	Dow	18, 55, 91, 127, 182	10	20	- single-stage temperature controlled reactors
Jan. 4, '73 -	Jan. 23	5	Dow	18, 55, 91, 127, 182	5	20	
Jan.24, '73 -	Jan. 28	5	Dow	18, 55, 91, 127, 182	2	20	
Jan.29, '73 -	Feb. 6	5	Dow	18, 55, 91, 127, 182	5	20	- aeration tank volume, 6 litres
Feb. 8, '73 -	Feb. 21	5	UCAR	9, 27.5, 45.5, 63.5, 91	5	20	
Feb.22, '73 -	Mar. 9	5	UCAR	9, 27.5, 45.5, 63.5, 91	10	20	
Apr.24, '73 -	May 4	3	Dow	80, 80, 80	20	14.4, 21.7, 25.5	- No temperature control
May 25, '73 -	June 15	1	Dow	130	10	23.8	- Reactor located in temperature controlled room

II Two-Stage System

DATE From:	To:	SETS OF REACTORS	TYPE OF DE-ICER	DOSAGE OF DE-ICER	TEMP. (°C)	FLOW RATE ml/min	REMARKS
Mar. 8, '73 -	Mar. 30	2	Dow	80, 160	10	22	- Reactors located in temp. controlled room

III Extended Aeration

DATE From:	To:	SETS OF REACTORS	TYPE OF DE-ICER	DOSAGE OF DE-ICER	TEMP. (°C)	FLOW RATE ml/min	REMARKS
Apr. 5, '73 -	Apr. 20	2	Dow	65, 65	10	70, 35	- Reactors located in temp. controlled room
		2	UCAR	32.5, 32.5	10	70, 35	
Apr.21, '73 -	May 5	2	Dow	65, 65	5	70, 35	- Aeration tank volume, 51 litres
		2	UCAR	32.5	5	70, 35	
May 7, '73 -	May 18	2	Dow	65, 65	2	70, 35	
		2	UCAR	32.5, 32.5	2	70, 35	
May 25, '73 -	June 15	3	Dow	65, 65, 130	10	35, 70, 70	
		1	UCAR	65	10	70	

B: PILOT-SCALE STUDIES

DATE From:	To:	SETS OF REACTORS	TYPE OF DE-ICER	DOSAGE OF DE-ICER	TEMP. (°C)	FLOW RATE	REMARKS
Mar. 6, '73 -	Mar. 26	1	Dow	74 ml/min	8-10	131 m^3/day	- Pilot plant located outside, no temp. control
Mar 27, '73 -	Apr. 4	1	Dow	150 ml/min	10-12	131 m^3/day	
Apr. 5, '73 -	May 24	1	Dow	74 ml/min	10-14	131 m^3/day	
May 25, '73 -	June 15	1	--	--	--	131 m^3/day	

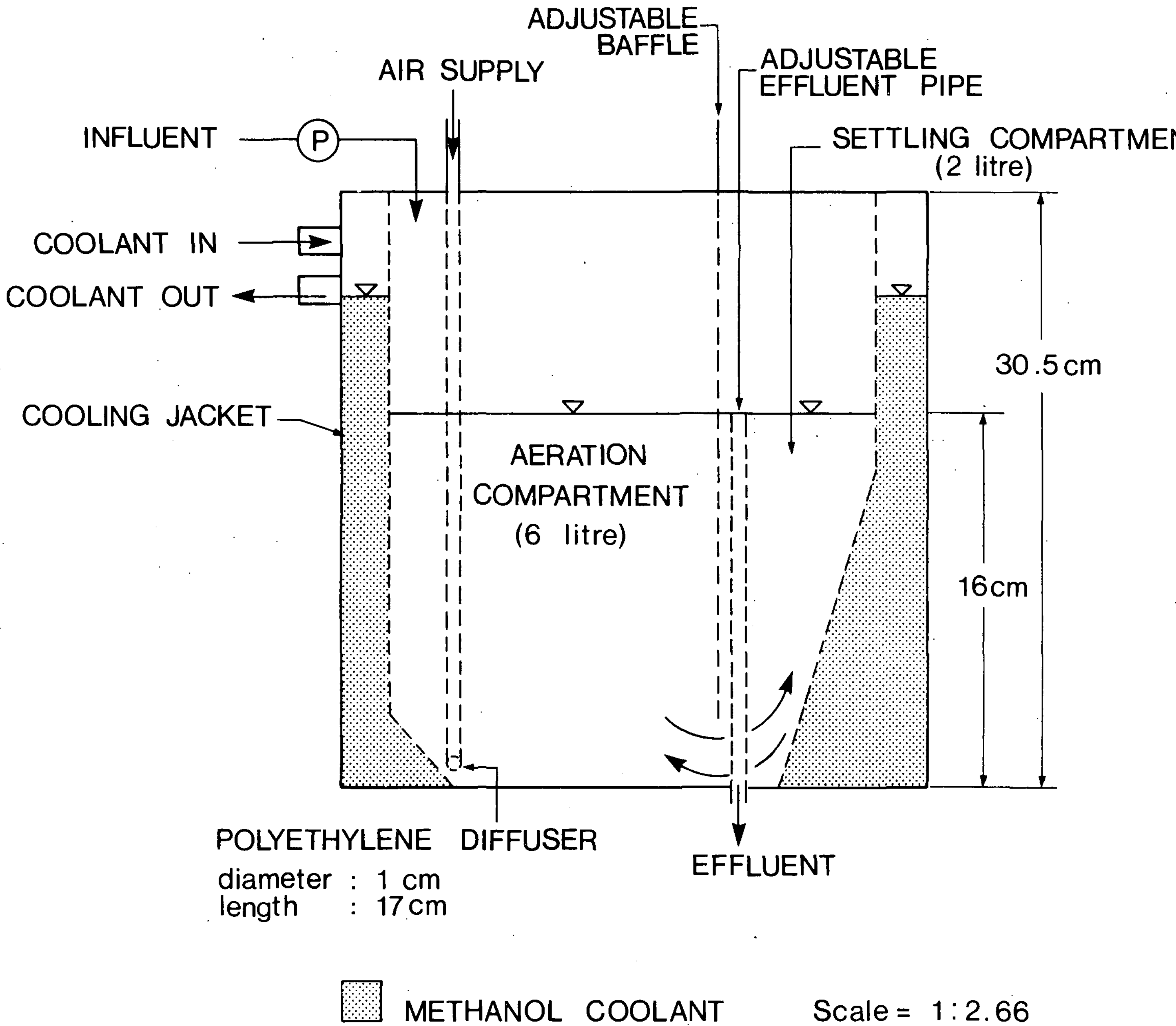
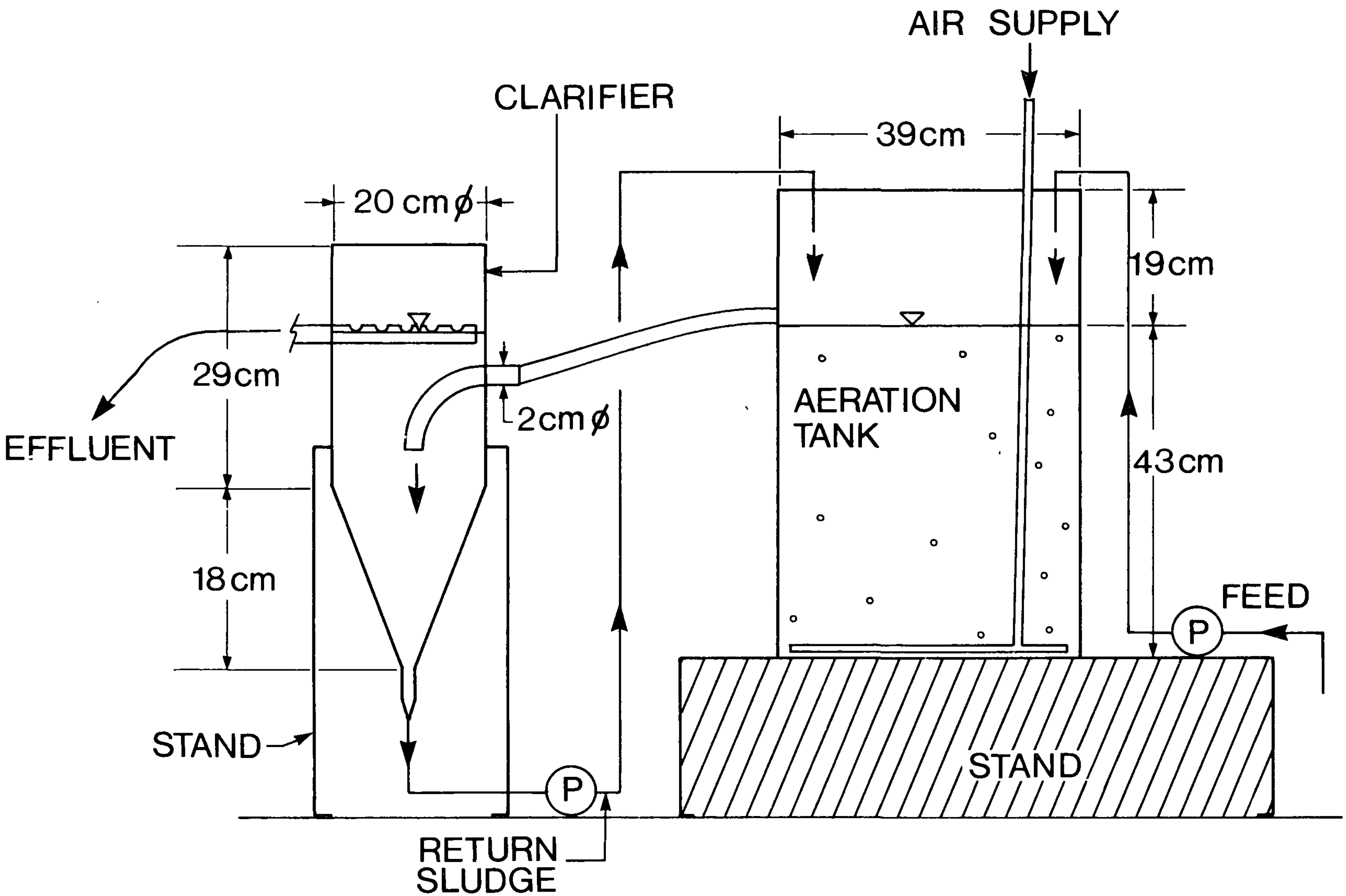


FIG. 1 SINGLE STAGE TEMPERATURE CONTROLLED REACTOR

temperature. This type of reactor is difficult to operate as the rate of sludge return from the clarifier to the aeration tank can not be controlled. Operational problems were more pronounced at 2 and 5°C and the experimental program was continued using a controlled-temperature room when the facilities became available.

Single-stage, extended aeration and two-stage reactors were operated in the controlled-temperature room. The extended aeration reactor shown in Figure 2 consisted of a 51-litre aeration tank and an 8.5-litre clarifier. The unit was operated at flow rates of 35 and 70 ml/min, providing a retention time of 12 and 24 hours, respectively. The reactors used for the two-stage operation are shown in Figure 3. Aeration tanks had a volume of 5 litres and the clarifiers 8.5 litres. The aeration tank and clarifier for the single-stage reactors used in the controlled-temperature room were the same as the individual components used for the two-stage reactors.

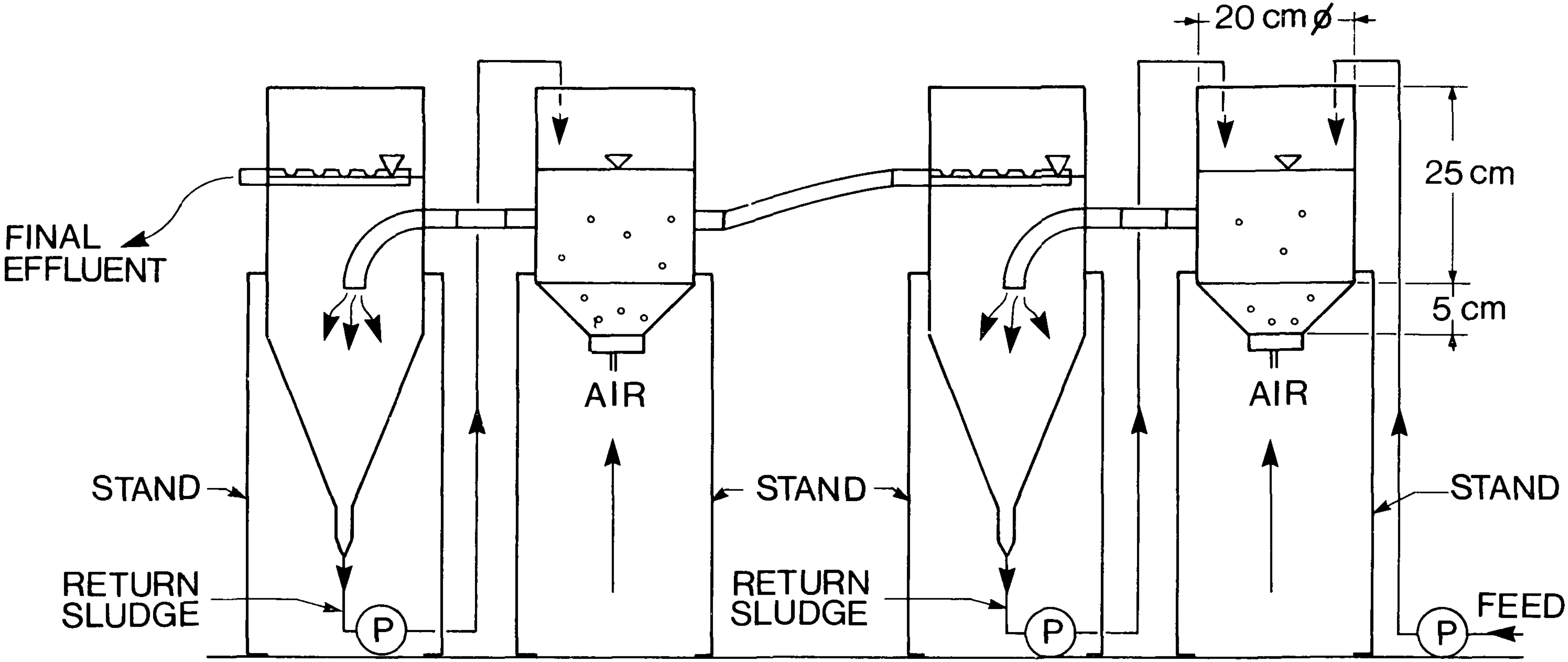
A cross-section of the 131 m^3/day extended aeration plant used for the pilot-scale study is shown in Figure 4. The aeration tank and clarifier had a capacity of 132 m^3 and 26 m^3, respectively. The aeration tank was divided into six compartments creating a plug flow system. A six-inch diameter pipe transferred the mixed liquor from the aeration tank to the stilling well at the centre of the clarifier. The settled sludge in the clarifier was returned to the influent of the aeration tank by an airlift pump. To ensure proper mixing of the raw sewage and de-icing fluid, a 30-litre polyethylene tank divided into three compartments, was installed at the head end of the aeration tank. The raw sewage and de-icing fluid were added to the first compartment of the tank,



AERATION TANK - 51 litre
CLARIFIER - 8.5 litre

Scale - 1: 8

FIG. 2 LABORATORY SCALE EXTENDED AERATION REACTOR



AERATION TANK - 5.0 litre
CLARIFIER - 8.5 litre

Scale - 1:8

FIG. 3 TWO STAGE REACTOR

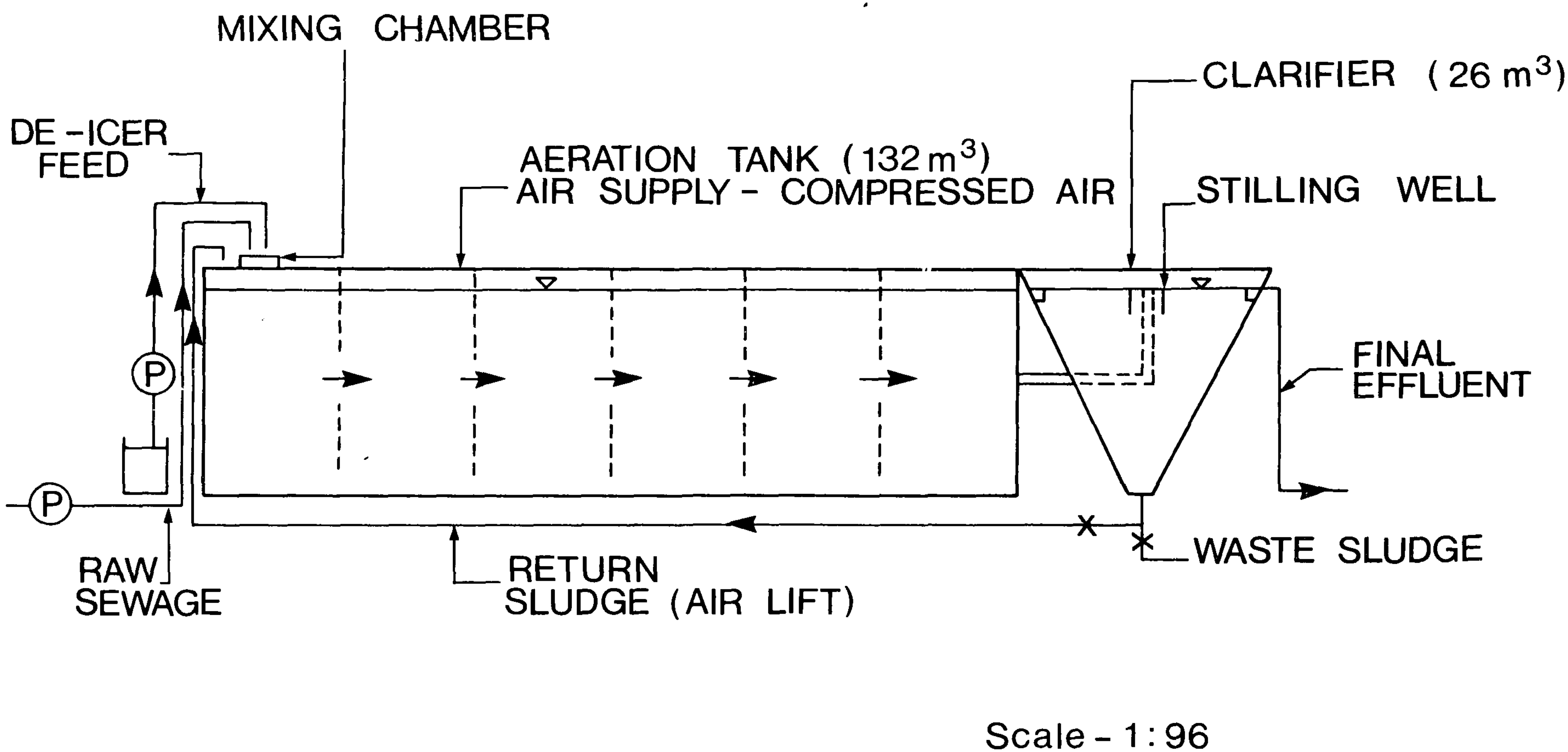


FIG. 4 EXTENDED AERATION PILOT PLANT

discharged into the second compartment through an opening at the base of the partition, and flowed over a baffle into the third compartment. The waste was discharged into the aeration tank through an opening in the third compartment. Influent samples were taken by placing the suction end of an automatic sampler in the third compartment.

3.3 Composition and Storage of Feed Solution

3.3.1 Characteristics of De-Icer

The two de-icing fluids used in the study were ADF-1050, produced by Dow Chemical of Canada Limited, and UCAR ADF-Cl, produced by Union Carbide Canada Limited; throughout the report, the two products have been referred to as Dow and UCAR de-icer. The chemical composition and characteristics of the two aircraft de-icing fluids are presented in Table 2. Specific components of the inhibitor package have not been identified; however, they include wetting, thickening and anti-foaming agents and a corrosion inhibitor.

The main organic components in the de-icing fluid are ethylene glycol and propylene glycol. According to data presented in an internal report by Davis (1), ethylene glycol has a theoretical oxygen demand of 1,260,000 mg/l, a total carbon content of 500,000 mg/l and a BOD of 750,000 mg/l. The BOD and TOC values presented in Table 2 are averages of analytical determinations made during the experimental program and compare with the values reported by Davis.

TABLE 2

COMPOSITION AND CHARACTERISTICS OF DE-ICER

	DOW	UCAR
COMPOSITION:		
-- water	50%	5%
-- ethylene glycol	32%	56%
-- propylene glycol	16%	38%
-- inhibitor package	2%	1%
CHARACTERISTICS:		
-- TOC (mg/l)	261,000	460,000
-- BOD* (mg/l)	362,000	712,000
-- pH	8.0	8.7

* -- BOD refers to BOD_5 (5-day Biochemical Oxygen Demand), unless specified otherwise.

3.3.2 Characteristics of Sewage

The feed solution used for both the laboratory and pilot-scale study was a mixture of Dow or UCAR de-icer and raw sewage. The raw sewage was pumped to the laboratory from the Skyway Sewage Treatment Plant in Burlington. The Skyway Plant receives a low strength domestic and industrial wastewater. The characteristics of the raw sewage were determined by analyzing 8-hour composite samples. Twenty-one composite samples were prepared by combining grab samples collected one per hour for one week. The analytical results are presented in Table 3. Assuming that the BOD:N:P ratio of 100:5:1 represents the nutrient requirement for an activated sludge system, the concentration of nitrogen and phosphorus in the raw sewage is adequate for the treatment of a wastewater having a BOD of 400 mg/l.

TABLE 3

CHARACTERISTICS OF RAW SEWAGE

PARAMETER	MEAN	RANGE OF VALUES
BOD (mg/l)	134	23 -- 280
TOC* (mg/l)	28	16 -- 84
Suspended Solids (mg/l)	187	58 -- 510
Total Kjeldahl Nitrogen (mg/l)	20.5	9 -- 33
Total Phosphorus (mg/l)	5.2	1.8 -- 11.5
pH	7.7	7.1 -- 8.6

* -- Samples were filtered for TOC; the remainder were unfiltered samples.

3.3.3 Storage of Feed Solution

The rate of microbial degradation of feed solutions containing sewage and glycol was investigated as during the initial phases of the program the contents of the storage tanks were held at room temperature for several days. Two of the feed solutions used in the experimental program were prepared and stored at room temperature. Samples were taken for TOC and glycol analysis at specific time intervals. Analytical results are presented in Table 4. The results indicated that the feed solution could

TABLE 4

DEGRADATION OF FEED SOLUTION DURING STORAGE

TEST NUMBER	STORAGE PERIOD (hr)	Feed Solution for Reactor #1				Feed Solution for Reactor #5			
		TOC		Glycol		TOC		Glycol	
		mg/l	%*	mg/l	%	mg/l	%	mg/l	%
1	0	58	--	42	--	438	--	430	--
	1	58	0	42	0	438	0	440	0
	2	56	3.4	43	0	428	2	420	2
	6	55	5.2	41	2.4	440	0	430	0
	72	--	--	15	64	--	--	240	44
2	0	108	--	--	--	474	--	--	--
	24	88	19	--	--	400	19	--	--
	48	70	35	--	--	375	21	--	--

* -- Percent degradation

be stored up to 6 hours without microbial degradation; however, significant reduction of organic material occurred prior to 24 hours of storage. Based on these results, it was decided that feed solutions for the laboratory should be prepared daily.

3.4 Experimental Procedure

3.4.1 Laboratory-Scale Studies

Activated sludge for the laboratory-scale reactors was taken from the Burlington Skyway Sewage Treatment Plant. The mixed liquor was screened to remove any large particulate matter which might have interfered with the operation of the laboratory-scale reactors. The sludge was examined under the microscope to ensure that a suitable microbial population was present. On initial start-up and following a shift in temperature or feed strength, several days were allowed for acclimation of the sludge.

Cole Parmer Masterflex pumps were used for feeding the sewage and de-icer mixture to the laboratory-scale reactors. These pumps were also used as sludge return pumps for the reactors shown in Figures 2 and 3.

The dissolved oxygen in the aeration tank was greater than 3 mg/l for all laboratory experiments. Compressed air distributed by fritted glass diffusers was used to supply the dissolved oxygen and provide adequate mixing in the aeration tanks.

During acclimation of reactor contents, parameters measured daily to monitor performance were flow rate, return sludge rate, temperature, dissolved oxygen, pH and MLSS (mixed liquor suspended solids). When steady state was attained, grab samples were collected for a period of at least two weeks to establish the performance of the system. The analytical program followed for most of the laboratory-scale reactors is presented in Table 5; certain modifications were made to the program during barious phases of the study. Glass fibre filter

TABLE 5

ANALYTICAL PROGRAM

	INFLUENT	AERATION TANK	EFFLUENT
TOC (filtered)	5/wk	--	5/wk
BOD (unfiltered)	5/wk	--	5/wk
Glycol Analyses (filtered)*	3/wk	--	3/wk
Suspended Solids	5/wk	--	5/wk
Volatile Suspended Solids	1/wk	--	1/wk
Mixed Liquor Suspended Solids	--	5/wk	--
Mixed Liquor Volatile Suspended Solids	--	1/wk	--
Total Kjeldahl Nitrogen	2/wk	--	2/wk
Total Phosphorus	2/wk	--	2/wk
Nitrite	--	--	1/wk
Nitrate	--	--	1/wk
Dissolved Oxygen	--	5/wk	--
Temperature	Daily	Daily	Daily
pH	Daily	Daily	Daily
Oxygen Uptake Rate	--	3/wk	--
Sludge Production Rate	--	3/wk	--
Sludge Volume Index (SVI)	--	5/wk	--

* -- glycol analyses reduced to 1/wk following the establishment of the removal relationship.

papers having a pore size of one micron were used for filtration of samples. Excess sludge was wasted manually to maintain the desired solids concentration in the aeration tanks; the volume and concentration of wasted sludge were recorded.

3.4.2 Pilot-Scale Studies

The source of activated sludge for the aeration tank was secondary clarifier underflow from the Skyway Sewage Treatment Plant. Raw sewage was added to several thousand gallons of the concentrated sludge in the aeration tank and the unit placed in operation. A positive displacement pump delivered 91 l/min (20 IGPM) of raw sewage to the extended aeration plant located outside the WTC. During initial operation, de-icing fluid was added at a rate of 74 ml/min, using a diaphragm pump. As the hourly variation in sewage strength was quite significant, composite samples were collected. Two automatic samplers were set up to take a 500-ml grab sample of influent and clarifier effluent every two hours. From the 12 grab samples collected over a 24-hr period, three 8-hour composite samples were filtered and used for TOC analysis; one 24-hour composite sample was prepared for BOD, suspended solids and glycol analyses.

The flow rate of raw sewage, dosage of de-icer, return sludge rate, dissolved oxygen and MLSS were measured daily and, if necessary, adjusted to the designated values. Temperature (ambient and mixed liquor), pH and any operating problems were recorded. SVI's were determined daily. Samples of influent and effluent for total Kjeldahl nitrogen and total phosphorus, and effluent samples for nitrite and nitrate were collected twice a week. Excess sludge was wasted regularly to maintain the required concentration of MLSS in the aeration tank.

3.5 Analytical Procedures

BOD, COD and suspended solids analyses were performed according to procedures specified in Standard Methods (2). TOC's were determined using a Beckman Infrared Carbon Analyzer. Nitrogen (total Kjeldahl nitrogen, ammonia-nitrogen, nitrites and nitrates) and total phosphorus were analyzed by wet chemical colourimetric techniques according to methods specified by Technicon Instruments Corporation. Glycol analyses were performed by direct aqueous injection gas chromatography, using a porous polymer column.

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Single-Stage Experiments Using Dow De-icer

Five single-stage temperature-controlled reactors were used in the treatment of Dow de-icer at F/M ratios varying from 0.05 to 0.9 kg BOD/kg MLSS•day and mixed liquor temperatures of 2, 5 and 10^{o}C. As shown in Table 1, the reactors were operated at 2^{o}C for five consecutive days. Operational problems as reported in Section 3.2 were encountered at the low temperature and the experimental results for this phase of the operation have not been included.

4.1.1 Operating Parameters and Results

The operating conditions and experimental results of the experiments at 5 and 10^{o}C are summarized in Tables 6, 7, 8, and 9. The results presented are average values from the analyses of samples collected during operation at steady-state conditions. Each set of results represents a sampling period of at least two weeks.

BOD values measured in the feed solution and recorded in Table 7 are lower than predetermined dosage calculations. The low concentrations measured were partially due to degradation in the feed solution storage container and additional degradation during sample storage. Daily preparation of feed solutions and proper storage of samples prior to analyses improved the experimental results. Sample storage at 4^{o}C, following biological treatment at a low temperature, did not prevent continued biodegradation, and unless BOD's could be set up immediately, the samples were frozen until analyzed.

TABLE 6

OPERATING PARAMETERS
SINGLE-STAGE TEMPERATURE-CONTROLLED REACTORS
TREATING DOW DE-ICER AT 10°C

REACTOR NO.	1	2	3	4	5
Dosage of De-icer (ml de-icer per 100 l feed solution)	18	55	91	127	182
Organic Loading (kg BOD/kg MLSS.day)	0.05	0.3	0.8	0.6	0.8
Volumetric Loading (kg BOD/m^3.day)	0.2	0.8	1.4	2.2	3.0
Detention period:					
-- aeration compartment (hr.)	5	5	5	5	5
-- settling compartment (hr.)	1.7	1.7	1.7	1.7	1.7
MLSS in aeration compartment (mg/l)	3400	2500	1600	3600	3800
D.O. in aeration compartment (mg/l)	>3.0	>3.0	>3.0	>3.0	>3.0

TABLE 7

EXPERIMENTAL RESULTS

SINGLE-STAGE TEMPERATURE-CONTROLLED REACTORS

TREATING DOW DE-ICER AT 10°C

REACTOR NO	1			2			3			4			5		
	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.
Filtered BOD (mg/l)	34	6	82.4	156	31	80.1	288	213	26.0	452	297	34.3	630	474	24.8
TOC (mg/l)	66	35	47.0	134	58	56.7	203	165	18.7	290	209	27.9	387	310	19.9
Glycol (mg/l as C)	35	0	100	102	8	92.2	174	159	9.2	276	256	7.2	368	273	25.8
COD* (mg/l)	97	21	78.4	280	57	79.6	489	303	38.0	760	564	25.8	1066	826	22.5
Suspended Solids (mg/l)	--	27	--	--	20	--	--	260	--	--	28	--	--	53	--
TKN* (mg/l)	12.3	1.9	84.6	12.1	0.5	95.9	9.4	5.4	42.6	9.5	3.6	62.1	9.3	4.0	57.0
Total phosphorus (filtered) (mg/l)	1.8	1.2	33.3	2.0	0.8	60.0	1.5	1.0	33.3	2.2	1.0	54.5	2.9	1.6	44.8
SVI (ml/g)	143			148			379			115			93		

* COD -- Chemical Oxygen Demand

TKN -- Total Kjeldahl Nitrogen

TABLE 8

OPERATING PARAMETERS
SINGLE-STAGE TEMPERATURE-CONTROLLED REACTORS
TREATING DOW DE-ICER AT 5°C

REACTOR NO.	1	2	3	4	5
Dosage of De-icer (ml de-icer per 100 l feed solution)	18	55	91	107	182
Organic Loading:					
-- kg BOD (filtered)/kg MLSS.day	0.1	0.2	0.3	0.7	0.9
-- kg BOD (unfiltered)/kg MLSS.day	0.2	0.3	0.4	0.9	1.1
Volumetric Loading:					
-- kg BOD (filtered)/m^3.day	0.3	0.9	1.6	2.3	3.2
-- kg BOD (unfiltered)/m^3.day	0.8	1.5	2.0	2.9	3.8
Detention period:					
-- aeration compartment (hr)	5	5	5	5	5
-- settling compartment (hr)	1.7	1.7	1.7	1.7	1.7
MLSS in aeration compartment (mg/l)	3200	3500	4700	3000	3500
D.O. in aeration compartment (mg/l)	>3	>3	>3	>3	>3

TABLE 9

EXPERIMENTAL RESULTS
SINGLE-STAGE TEMPERATURE-CONTROLLED REACTORS
TREATING DOW DE-ICER AT 5°C

REACTOR NO.	1			2			3			4			5		
	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.
Filtered BOD (mg/l)	68	15	77.9	194	32	83.5	323	135	58.2	477	339	28.9	667	542	18.7
Unfiltered BOD (mg/l)	159	53	66.7	309	109	64.7	434	212	51.2	597	429	28.1	833	649	22.1
Unfiltered BOD/ Filtered BOD	2.3	3.5	--	1.6	3.4	--	1.3	1.6	--	1.3	1.3	--	1.2	1.2	--
TOC (mg/l)	48	18	62.5	112	34	69.6	165	74	55.2	258	177	31.4	384	300	21.9
COD (mg/l)	143	57	60.1	344	137	60.2	545	230	57.8	798	528	33.8	1180	876	25.8
Glycol (mg/l as C)	28	9	67.9	74	26	64.9	121	52	57.0	190	108	43.2	291	203	30.2
Suspended Solids (mg/l)	115	43	62.6	115	40	65.2	115	31	73.0	115	22	80.9	115	63	45.2
TKN (mg/l)	18.5	4.7	74.7	18.2	6.6	63.8	18.5	3.2	82.7	17.7	8.1	54.3	18.5	12.3	33.5
NH_4-N (mg/l)	18.0	4.5	75.0	17.6	3.8	78.4	18.2	3.0	83.5	18.2	7.6	58.3	18.2	8.3	52.2
NO_2-N (mg/l)	--	0.22	--	--	0.10	--	--	0.10	--	--	0.13	--	--	0.09	--
NO_3-N (mg/l)	--	3.4	--	--	1.5	--	--	1.5	--	--	0.6	--	--	0.2	--
Total Phosphorus (filtered) (mg/l)	5.0	3.7	26.0	5.1	3.8	25.5	5.9	3.6	39.0	6.2	4.8	22.6	7.8	6.7	--
Alkalinity (mg/l as $CaCO_3$)	254	176	--	248	230	--	238	218	--	216	254	--	208	258	--
SVI (ml/g)	172			109			127			83			82		

The single-stage temperature-controlled reactors were operated over a wide range of loading conditions to establish engineering design parameters. The relationship between organic loading and effluent quality for Dow de-icer is shown in Figure 5. The results plotted represented filtered BOD's, indicating that an effluent BOD of 20 mg/l or less could only be attained if the organic loading was less than 0.2 kg BOD/kg MLSS•day.

The high concentration of suspended solids and unfiltered BOD in the effluents can be partially attributed to the inadequate design of the reactors. In addition, the characteristics of the influent wastewater were such that sludge bulking occurred. This combination resulted in poor settling and high suspended solids in the effluent. Because of these problems, the extended aeration reactors, as shown in Figure 2, were used to collect specific information regarding effluent quality at the optimum loading conditions. The extended aeration reactors were also used to obtain additional information for determination of sludge production and oxygen uptake rates. Details of this phase of the experimental program are presented in Section 4.3.

4.1.2 Sequential Degradation of Dow-icer

Sequential degradation of ethylene and propylene glycol was observed in the biological treatment system. A detailed analysis of several effluent samples containing glycol revealed that only propylene glycol and low molecular weight degradation products were present. The degradation products were tentatively identified as methanol, ethanol, acetone and two other unidentified compounds. As ethylene

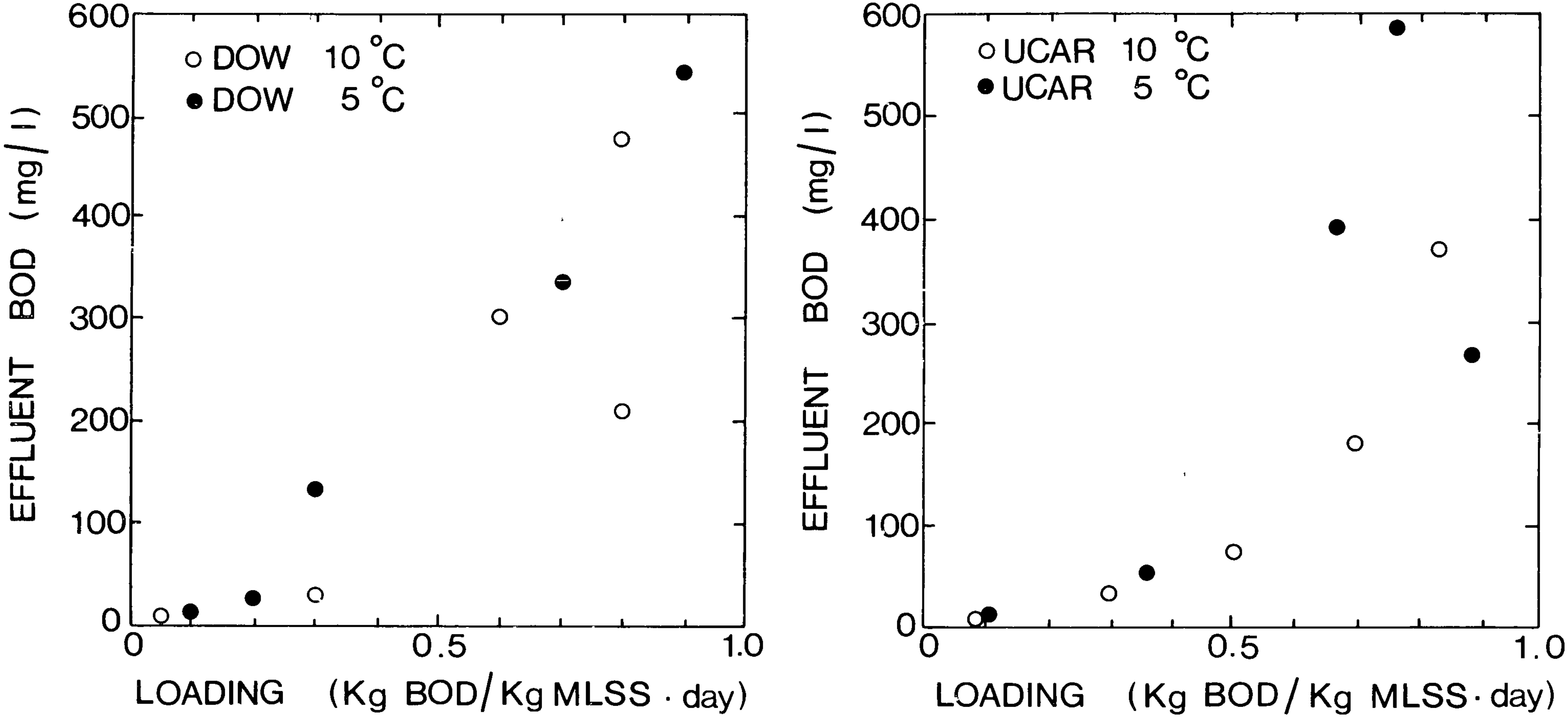


FIG. 5 RELATIONSHIP BETWEEN ORGANIC LOADING AND EFFLUENT BOD FOR DOW AND UCAR DE-ICER

glycol was not detected in these samples, it was concluded that sequential removal was occurring.

4.1.3 Neutralization Requirements

The undiluted Dow de-icing fluid had a pH of 8.0. Because of the small volumes of de-icer added to the sewage, the pH of the feed solution was dependent on the pH of the raw sewage. The range of pH values for the mixed liquor in the five reactors during the two weeks of operation at steady-state are summarized in Table 10. All pH values reported were within the range considered to be acceptable for optimum microbial growth. As this trend was reported for all loading conditions, no chemical addition was required for pH control.

TABLE 10

RANGE OF pH VALUES FOR MIXED LIQUOR

REACTOR NO.	1	2	3	4	5
Dow De-icer @ 10°C	7.3-8.2	7.3-8.1	7.5-8.3	7.5-8.3	7.4-8.3
Dow De-icer @ 5°C	7.4-8.2	7.6-8.3	7.5-8.2	7.6-8.4	7.6-8.4
UCAR De-icer @ 5 and 10°C	7.3-8.0	7.3-8.1	7.3-8.0	7.3-8.1	7.2-7.9

4.1.4 Sludge Characteristics

Settling characteristics of sludges in certain reactors were affected by the presence of filamentous microorganisms. Reactor number

3, operated at 10°C, had a heavy filamentous growth tentatively identified as Sphaerotilus natans which resulted in a bulking sludge and a high SVI; the performance of the reactor was affected as the average effluent suspended solids concentration was 260 mg/l. Photomicrographs of typical sludge flocs from the five reactors treating Dow de-icer and sewage at 10°C are presented in Figures 6 to 10, inclusive. The filamentous nature of the sludge in Reactor number 3 can be seen in Figure 8. Sludge in the remaining four reactors, Figures 6, 7, 9 and 10, was relatively free of filamentous growth and can be considered as representative of healthy sludge flocs.

Filamentous growth in reactors treating Dow de-icer at 5°C was not significant. Growth became more pronounced in Reactors number 1 and 2 at the end of the experimental run. The bulking condition was greater in Reactor number 1 as indicated by the higher SVI reported in Table 9.

As shown in Figures 6, 9 and 10, a large number of protozoa were present in the sludge flocs. The predominant types were tentatively identified as species of Aspidisca, Carchesium and Vorticella.

4.1.5 Nutrient Requirements

Nutrient requirements for the single-stage temperature-controlled units were based on BOD reduction and the corresponding nitrogen and phosphorus consumption. This approach was used to show that the nutrient supply was adequate for cell growth, for the range of influent BOD concentrations used in varying the influent loading conditions.

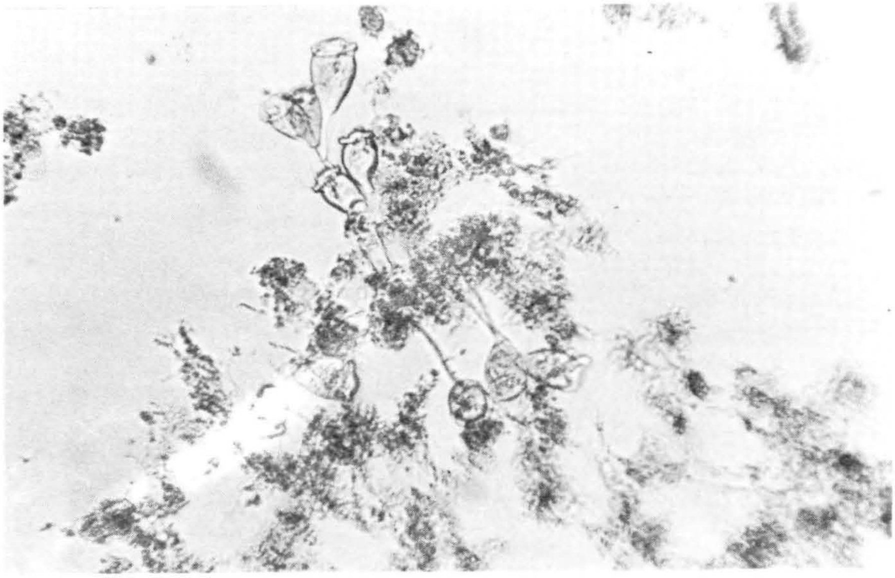


FIG. 6
Typical sludge flocs from reactor #1.
(Dow, 10°C)
x100

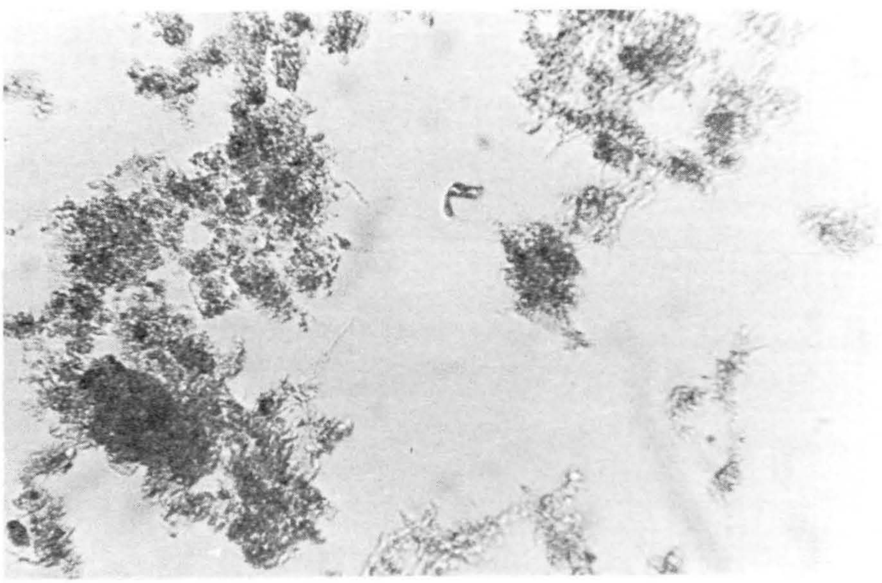


FIG. 7
Typical sludge flocs from reactor #2.
(Dow, 10°C)
x 100

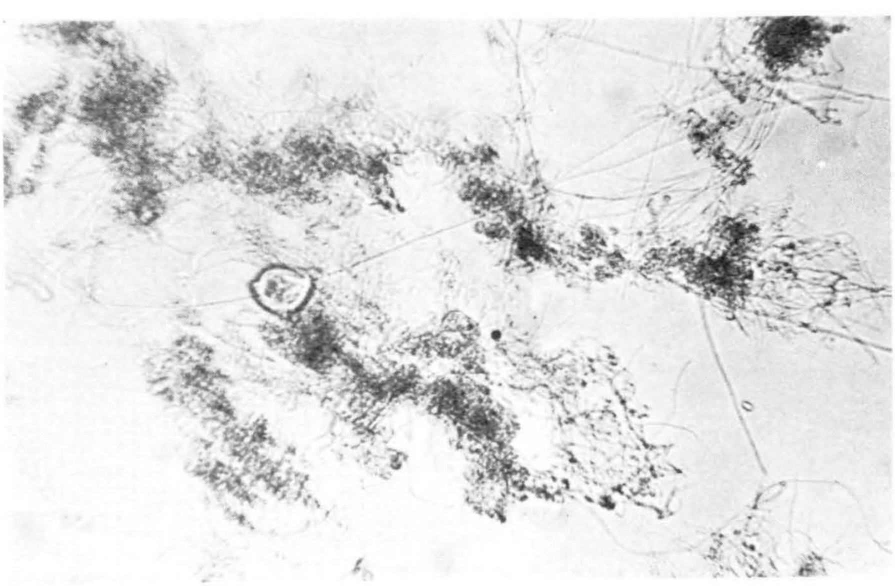


FIG. 8
Typical sludge flocs from reactor #3
(Dow, 10°C)
x 100

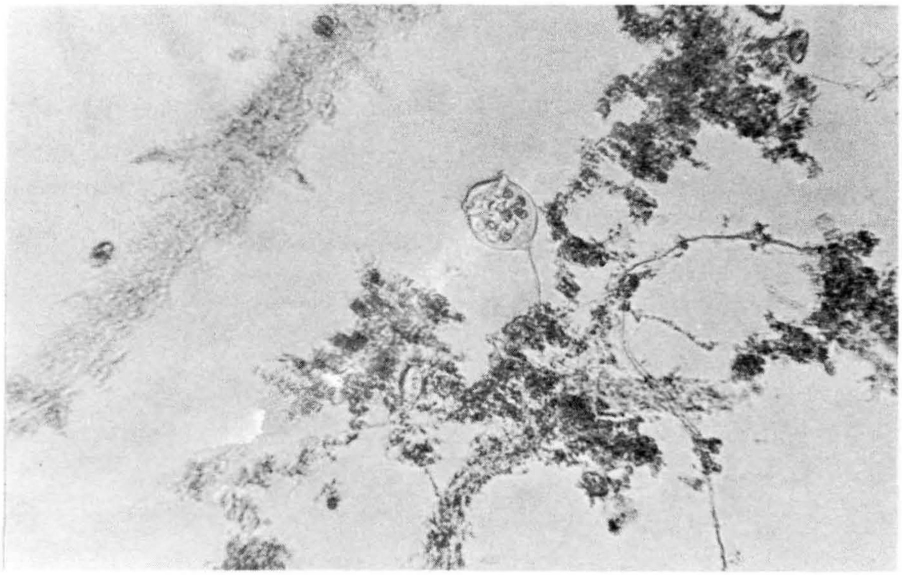


FIG.9
Typical sluge flocs
from reactor #4
(Dow , 10°C)
x 100

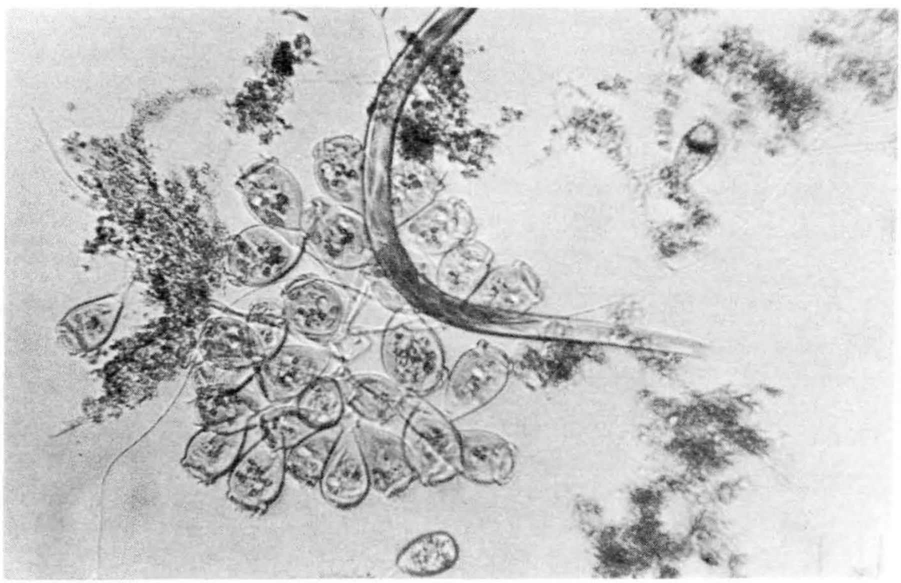


FIG.10
Typical sluge flocs
from reactor #5
(Dow , 10°C)
x 100

The ratio between BOD reduction and nutrient consumption was 100:5:1 and 100:7:1 for operations at 10^oC and 5^oC, respectively. These figures compare favourably with the accepted ratio of 100:5:1 generally used in the calculation of the nutrient requirements for an activated sludge system and were considered to be adequate for the loading conditions studied.

4.2 Single-stage Experiments Using UCAR De-icer

Following the completion of experiments using Dow de-icer, the mixed liquor was replaced in the five single-stage temperature-controlled reactors and studies initiated using UCAR de-icing fluid. The five reactors were operated at approximately the same loading conditions used in previous studies.

4.2.1 Operating Parameters and Results

The operating parameters and experimental results representing the treatment of UCAR de-icer and sewage at 10^oC and 5^oC are reported in Tables 11 to 14, inclusive. Problems were again encountered with sludge return and clarification; thus, the suspended solids and total BOD of effluent samples are not indicative of the capabilities of the system.

The relationship between effluent quality and organic loading for UCAR de-icer is presented in Figure 5. Filtered BOD values have again been used and the performance at comparable loadings is very similar to that obtained in the treatment of Dow de-icer and sewage.

TABLE 11

OPERATING PARAMETERS
SINGLE-STAGE TEMPERATURE-CONTROLLED REACTORS
TREATING UCAR DE-ICER AT 10°C

REACTOR NO.	1	2	3	4	5
Dosage of De-icer (ml de-icer per 100 l feed solution)	9	27.5	45.5	63.5	91
Organic loading:					
-- kg BOD (filtered)/kg MLSS.day	0.09	0.3	0.5	0.7	0.8
-- kg BOD (unfiltered)/kg MLSS.day	0.14	0.3	0.5	0.7	0.9
Volumetric loading:					
-- kg BOD (filtered)/m^3.day	0.5	1.2	1.9	2.7	3.6
-- kg BOD (unfiltered)/m^3.day	0.7	1.3	2.0	2.8	3.7
Detention period:					
-- aeration compartment (hr)	5	5	5	5	5
-- settling compartment (hr)	1.7	1.7	1.7	1.7	1.7
MLSS in aeration compartment (mg/l)	4700	3900	3700	3900	4300
D.O. in aeration compartment (mg/l)	>3.0	>3.0	>3.0	>3.0	>3.0

TABLE 12

EXPERIMENTAL RESULTS

SINGLE-STAGE TEMPERATURE-CONTROLLED REACTORS

TREATING UCAR DE-ICER AT 10°C

REACTOR NO.	1			2			3			4			5		
	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.
Filtered BOD (mg/l)	94	4	95.7	248	33	86.7	390	73	81.3	568	181	68.1	752	376	50.0
Unfiltered BOD (mg/l)	137	30	78.1	277	99	64.3	421	196	53.4	581	316	45.6	765	440	42.5
Unfiltered BOD/ Filtered BOD	1.5	7.5	--	1.1	3.0	--	1.1	2.7	--	1.0	1.7	--	1.0	1.2	--
TOC (mg/l)	66	11	83.3	142	28	80.3	244	61	75.0	326	146	55.2	467	226	51.6
Glycol (mg/l as C)	45	6	86.7	110	11	90.0	203	28	86.2	294	87	70.4	432	171	80.4
Suspended Solids (mg/l)	84	15	82.1	84	49	41.6	84	43	48.8	84	35	58.3	84	20	76.2
TKN (mg/l)	19.9	2.6	87.0	19.9	1.6	92.0	20.1	3.2	84.1	19.7	2.9	85.3	20.4	1.1	94.6
NH_4-N (mg/l)	16.8	1.6	90.5	16.9	1.2	92.8	16.9	21	87.6	16.9	2.3	96.4	17.0	0.7	95.9
NO_2-N (mg/l)	--	0.15	--	0.12	--	--	0.06	--	--	0.07	--	--	0.07	--	--
NO_3-N (mg/l)	--	5.16	--	1.94	--	--	0.56	--	--	0.46	--	--	0.21	--	--
Total Phosphorus (filtered) (mg/l)	2.1	1.1	47.6	2.4	0.7	70.8	2.9	1.3	55.2	3.0	1.6	46.7	--	--	--
Alkalinity (mg/l as $CaCO_3$)	134	114	15.0	--	--	--	--	--	--	170	131	23.0	--	--	--
SVI (ml/g)	119			145			203			167			131		

TABLE 13

OPERATING PARAMETERS
SINGLE-STAGE TEMPERATURE-CONTROLLED REACTORS
TREATING UCAR DE-ICER AT 5°C

REACTOR NO.	1	2	3	4	5
Dosage of de-icer (ml de-icer per 100 l of feed solution)	9	27.5	45.5	53.5	91
Organic loading:					
-- kg BOD (filtered)/kg MLSS.day	0.1	0.4	0.9	0.7	0.8
-- kg BOD (unfiltered)/kg MLSS.day	0.2	0.4	0.9	0.7	0.8
Volumetric loading:					
-- kg BOD (filtered)/m^3.day	0.5	1.3	2.1	2.8	3.8
-- kg BOD (unfiltered)/m^3.day	0.7	1.4	2.1	2.9	4.1
Detention period:					
-- aeration compartment (hr)	5	5	5	5	5
-- settling compartment (hr)	1.7	1.7	1.7	1.7	1.7
MLSS in aeration compartment (mg/l)	4300	3500	2300	4200	5000
D.O. in aeration compartment (mg/l)	>3	>3	>3	>3	>3

TABLE 14

EXPERIMENTAL RESULTS

SINGLE-STAGE TEMPERATURE-CONTROLLED REACTORS

TREATING UCAR DE-ICER AT 5°C

REACTOR NO.	1			2			3			4			5		
	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.
Filtered BOD (mg/l)	96	13	86.5	266	55	79.3	431	270	37.4	589	390	33.8	794	585	26.3
Unfiltered BOD (mg/l)	138	56	59.4	282	112	60.3	441	326	26.1	611	439	28.2	846	620	26.7
Unfiltered BOD/ Filtered BOD	1.4	4.3	--	1.1	2.0	--	1.0	1.2	--	1.0	1.1	--	1.1	1.1	--
TOC (mg/l)	53	15	71.7	156	40	74.4	236	157	33.4	327	218	33.3	468	326	30.3
Glycol (mg/l as C)	69	16	76.8	141	50	64.5	190	120	36.8	214	165	22.9	400	290	27.5
Suspended Solids (mg/l)	73	58	19.4	72	40	44.4	72	29	59.7	72	55	23.6	72	36	50.0
TKN (mg/l)	14.9	1.5	89.9	14.2	0.6	95.8	14.5	4.4	69.7	14.5	6.8	53.1	14.8	3.4	77.0
NH_4-N (mg/l)	14.6	0.7	95.2	14.1	0.1	99.3	13.8	2.8	79.7	13.8	5.8	58.0	14.1	1.8	87.2
NO_2-N (mg/l)	--	1.2	--	--	0.02	--	--	0.01	--	--	nil	--	--	nil	--
NO_3-N (mg/l)	--	3.62	--	--	0.45	--	--	0.50	--	--	nil	--	--	nil	--
Total Phosphorus (filtered) (mg/l)	1.3	1.1	15.4	1.5	0.4	73.3	1.7	0.6	64.7	1.8	0.9	50.0	3.0	1.3	56.7
SVI (ml/g)	155			273			96			64			61		

4.2.2 pH Levels, Sludge Characteristics and Nutrient Requirements

Undiluted UCAR de-icer has a pH of 8.7. After mixing with raw sewage, the pH of the feed solution varied from 7.2 to 8.0. The pH of the mixed liquor for each of the five reactors is presented in Table 10. There was no significant difference in pH between experiments conducted at $5^{o}C$ and $10^{o}C$. All the pH values recorded were within the acceptable range for biological treatment; therefore, no pH control was required for the treatment of UCAR de-icer and raw sewage.

Growth of filamentous microorganisms was observed, especially during the operation of Reactors number 1 and 2 at $5^{o}C$. In general, the structure of the flocs and type of protozoa present were similar to those in the experiments carried out on Dow de-icer.

The ratio between BOD reduction and nutrient consumption, BOD_r :N:P, for the treatment of UCAR de-icer and sewage was 100:6:1 and 100:7:1 for experiments conducted at $10^{o}C$ and $5^{o}C$, respectively. These ratios compare favourably with the values reported for the treatment of Dow de-icer and sewage.

4.3 Extended Aeration Studies

Results presented in Figure 5 for both UCAR and Dow de-icer indicated that low organic loadings were required if the specified effluent objectives were to be met. For the range of loadings to be encountered in the treatment of de-icer, this practically limited the use of an activated sludge system to an extended aeration unit. As an alternate, a two-stage activated sludge system was considered; the experimental results for the two-stage reactors have been reported in Section 4.5.1.

Four extended aeration reactors treating de-icer and sewage were operated for 6 weeks at temperatures of 10, 5 and 2°C. The reactors, as shown in Figure 2, were operated in a controlled-temperature room. The operating parameters and results of the experiments at the three temperatures are reported in Tables 15 to 20, inclusive. The individual analytical results have been tabulated for the experiments conducted at the three temperatures and have been presented in Tables A-1, A-2 and A-3 of Appendix A; influent BOD, effluent BOD and suspended solids, MLSS and SVI's have been reported.

The effluent quality following the treatment of Dow and UCAR de-icer at similar loading conditions and temperatures of 2, 5 and 10°C was approximately the same. With the exception of two reactors, the average effluent concentrations met the specified objectives; i.e., a total BOD of 20 mg/l or less and a suspended solids concentration of 25 mg/l or less. Reactors producing an effluent having BOD and suspended solids concentrations greater than these values were both operated at the lower organic loading, 0.06 kg BOD/kg MLSS•day, at temperatures of 5 and 10°C.

Microscopic observation of the mixed liquor during the first week of operation revealed that the sludge had the desirable characteristics of a typical activated sludge. A slight growth of filamentous microorganisms was observed in the sludge flocs of Reactors number 1 and 3 during the second week. Following the reduction of the temperature from 10°C to 5°C there was an increased growth of filamentous microorganisms resulting in higher SVI's. The filamentous microorganisms

TABLE 15

OPERATING PARAMETERS

EXTENDED AERATION REACTORS, 10°C

REACTOR NO.	1	2	3	4
Type of de-icer used	Dow	Dow	UCAR	UCAR
Dosage of de-icer (ml de-icer per 100 l of feed solution)	65	65	32.5	32.5
Organic loading:				
-- kg BOD (unfiltered)/kg MLSS.day)	0.13	0.06	0.12	0.06
Detention period:				
-- aeration tank (hr)	12	24	12	24
-- settling tank (hr)	2	4	2	4
MLSS in aeration tank (mg/l)	5200	5200	5100	5000
D.O. in aeration tank (mg/l)	>3	>3	>3	>3
Operating temperature (°C)	10	10	10	10
Sludge return rate (% plant flow)	100	100	100	100

TABLE 16

EXPERIMENTAL RESULTS

EXTENDED AERATION REACTORS, 10°C

REACTOR NO.	1			2			3			4		
	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.
Unfiltered BOD (mg/l)	333	13	96.2	333	11	96.6	316	13	96.0	316	16	94.9
TOC (mg/l)	202	12	94.1	202	10	94.9	188	11	94.0	188	10	94.6
Suspended Solids (mg/l)	74	25	66.2	74	27	63.5	66	25	62.1	66	19	71.2
TKN (mg/l)	14.3	1.1	92.3	14.3	1.4	90.2	14.1	1.0	92.9	14.1	1.1	92.2
Total Phosphorus (filtered) (mg/l)	6.6	2.8	57.6	6.6	2.7	59.1	6.0	2.3	61.7	6.0	2.1	65.0
SVI (ml/g)	129			107			130			105		

TABLE 17

OPERATING PARAMETERS

EXTENDED AERATION REACTORS, 5°C

REACTOR NO.	1	2	3	4
Type of de-icer used	Dow	Dow	UCAR	UCAR
Dosage of de-icer (ml de-icer per 100 l of feed solution)	65	65	32.5	32.5
Organic loading:				
-- kg BOD (unfiltered)/kg MLSS.day	0.20	0.07	0.17	0.07
Detention period:				
-- aeration tank (hr)	12	24	12	24
-- settling tank (hr)	2	4	2	4
MLSS in aeration tank (mg/l)	3700	5600	4100	5300
D.O. in aeration tank (mg/l)	>3	>3	>3	>3
Operating Temperature (°C)	5	5	5	5
Sludge return rate (% plant flow)	100	100	100	100

TABLE 18

EXPERIMENTAL RESULTS

EXTENDED AERATION REACTORS, 5°C

REACTOR NO.	1			2			3			4		
	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.
Unfiltered BOD (mg/l)	368	13	96.4	367	9	97.5	351	14	96.0	351	23	93.3
TOC (mg/l)	190	11	94.1	190	10	94.6	179	9	95.2	179	15	91.8
Suspended Solids (mg/l)	163	24	85.3	163	18	89.0	154	25	83.8	154	58	62.3
TKN (mg/l)	21.1	3.6	82.9	21.1	1.4	93.3	21.8	2.4	89.0	21.8	2.9	86.2
Total Phosphorus (filtered) (mg/l)	4.6	2.0	56.5	4.6	2.2	52.2	4.5	0.8	82.0	4.5	2.8	37.8
SVI (ml/g)	192			121			183			140		

TABLE 19

OPERATING PARAMETERS

EXTENDED AERATION REACTORS, 2°C

REACTOR NO.	1	2	3	4
Type of de-icer used	Dow	Dow	UCAR	UCAR
Dosage of de-icer (ml de-icer per 100 l of feed solution)	65	65	32.5	32.5
Organic loading:				
-- kg BOD (unfiltered)/kg MLSS.day	0.16	0.07	0.14	0.07
Detention period:				
-- aeration tank (hr)	12	24	12	24
-- settling tank (hr)	2	4	2	4
MLSS in aeration tank (mg/l)	4400	5000	4900	4600
D.O. in aeration tank (mg/l)	>3	>3	>3	>3
Operating Temperature (°C)	2	2	2	2
Sludge return rate (% plant flow)	100	100	100	100

TABLE 20

EXPERIMENTAL RESULTS

EXTENDED AERATION REACTORS, 2°C

REACTOR NO.	1			2			3			4		
	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.
Unfiltered BOD (mg/l)	346	12	96.6	346	12	96.6	337	11	96.7	337	12	96.5
TOC (mg/l)	154	11	92.8	154	10	93.0	128	10	92.2	128	9	92.9
Suspended Solids (mg/l)	175	20	88.6	175	23	87.0	159	23	85.6	159	24	84.8
TKN (mg/l)	34.9	5.1	85.4	34.9	2.7	92.3	34.1	4.7	86.2	34.1	2.6	92.4
Total Phosphorus (filtered) (mg/l)	7.1	2.5	64.8	7.1	2.4	66.2	5.5	1.2	78.2	5.5	1.9	65.5
SVI (ml/g)	193			134			156			160		

flourished throughout the experimental runs at 5 and 2°C. The SVI's at 2°C were higher than at 5°C; however, the effluent quality had not deteriorated significantly during the 6 weeks of continuous operation.

Photomicrographs of sludge flocs taken from reactors operated at 5°C are presented in Figures 11, 12, 13 and 14. Filamentous growth was present in all reactors but was more abundant in reactors operated at the higher organic loadings.

The ratios between BOD reduction and nutrient consumption were 100:4:1, 100:6:1 and 100:9:1 for reactors operated at 10, 5 and 2°C, respectively. The nutrient requirements at 10 and 5°C are approximately the same as those reported in Section 4.1.5 for Dow de-icer and sewage, and in Section 4.2.2 for UCAR de-icer and sewage. As reported in Section 4.2.2, there was no significant difference in nutrient requirements for the treatment of either DOW or UCAR de-icer. In comparing the nutrient requirements at different operating temperatures, it was evident that at lower operating temperatures the nitrogen requirement for the treatment of both de-icing fluids increased.

4.4 Engineering Design Parameters

The experimental results from the single-stage temperature-controlled reactors and the extended aeration units were combined to define the engineering design parameters for the biological treatment of de-icing fluids and sewage. Optimum organic loadings were determined and can be used to select the aeration tank volume for the treatment of a de-icer and sewage mixture having a known flow rate and concentration. This procedure was used as data collected using the single-stage temperature-

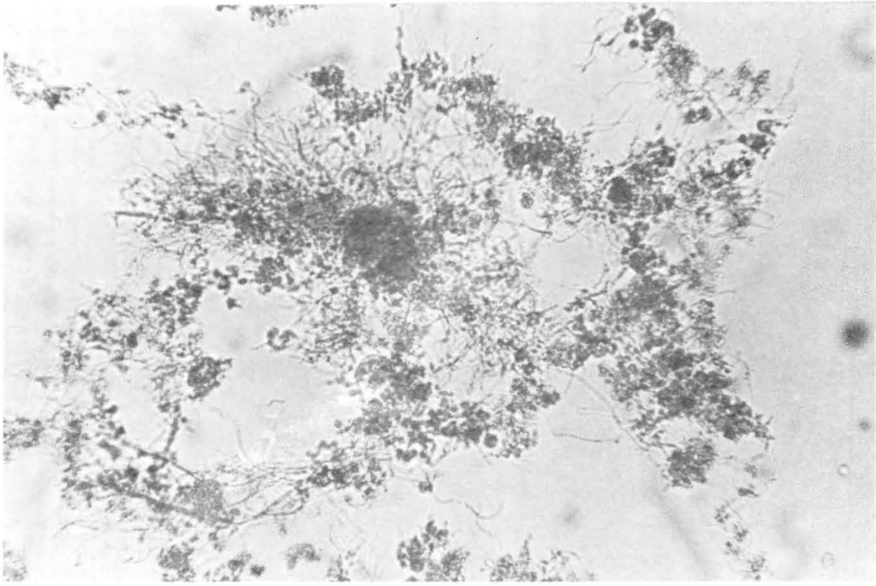


FIG. 11
Typical sludge flocs from extended aeration reactor #1 , F / M = 0.20 kg BOD / kg MLSS · day (Dow, 5°C)
x 100

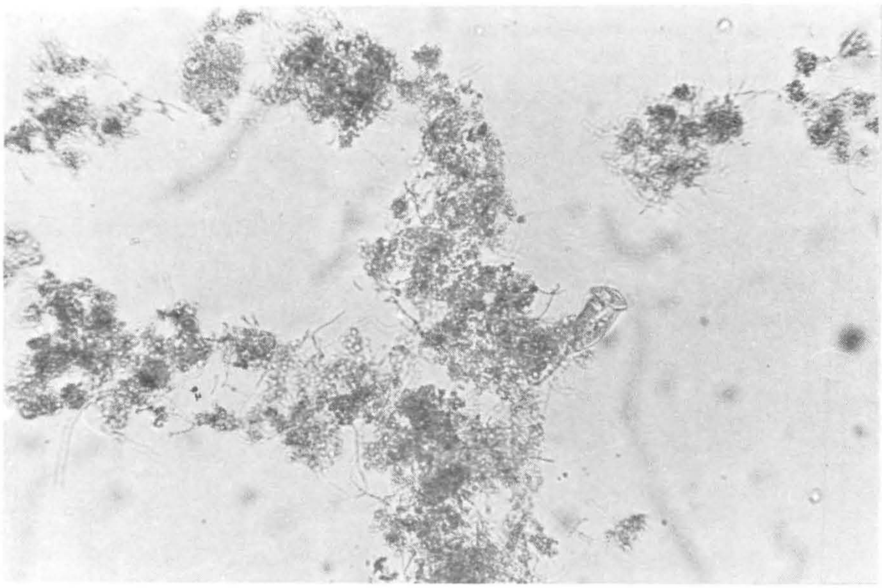


FIG. 12
Typical sludge flocs from extended aeration reactor #2 , F/M = 0.07 kg BOD / kg MLSS · day (Dow , 5°C)
x 100

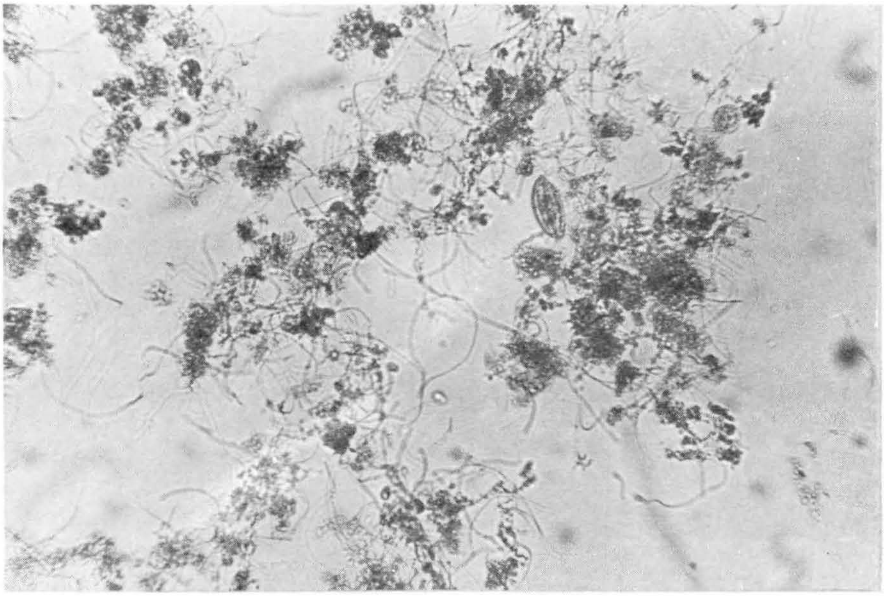


FIG.13
Typical sludge flocs from extended aeration reactor #3 , F/M = 0.17 kg BOD / kg MLSS · day (Ucar, 5°C) x 100

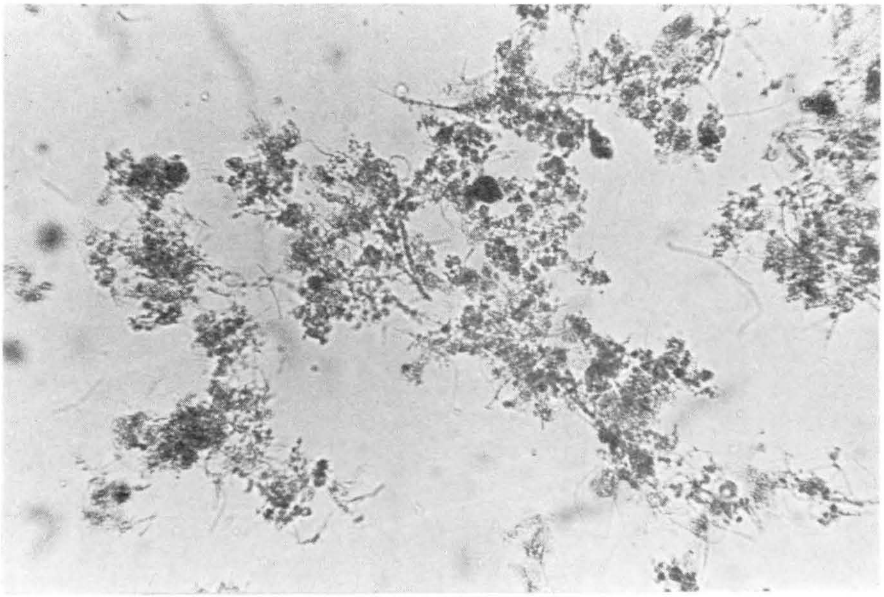


FIG.14
Typical sludge flocs from extended aeration reactor #4 , F/M = 0.07 kg BOD / kg MLSS · day (Ucar, 5°C) x 100

controlled reactors was not adequate for the determination of substrate removal rate constants. Oxygen uptake rates and sludge production were measured and the constants defining the oxygen requirements and sludge yield have been presented.

The experimental results presented in Table 19 indicate that an extended aeration system operated at 2°C would produce an effluent of the desired quality. There was only a slight improvement in effluent quality for the extended aeration reactors operated at 5 and 10°C. Based on the organic loadings at the temperatures of 2, 5 and 10°C and the acceptability of the effluent quality, the optimum organic loading at the low temperatures was considered to be 0.15 kg BOD/kg MLSS·day for the treatment of either Dow de-icer and sewage or UCAR de-icer and sewage. This optimum loading condition is to be used as the basis of design for an activated sludge system.

Oxygen requirements for the activated sludge system were determined using the relationship

$$R_r/S_a = a'\,(BOD_r/S_a t) + b' \qquad (4\text{-}1)$$

where R_r = oxygen uptake rate

S_a = average MLSS in aeration tank

BOD_r = BOD removed

t = residence time

a' = coefficient of dissimilation

b' = coefficient of endogenous respiration

Plots of oxygen uptake rate versus specific removal rate for Dow and UCAR de-icer are presented in Figures 15 and 16, respectively. The

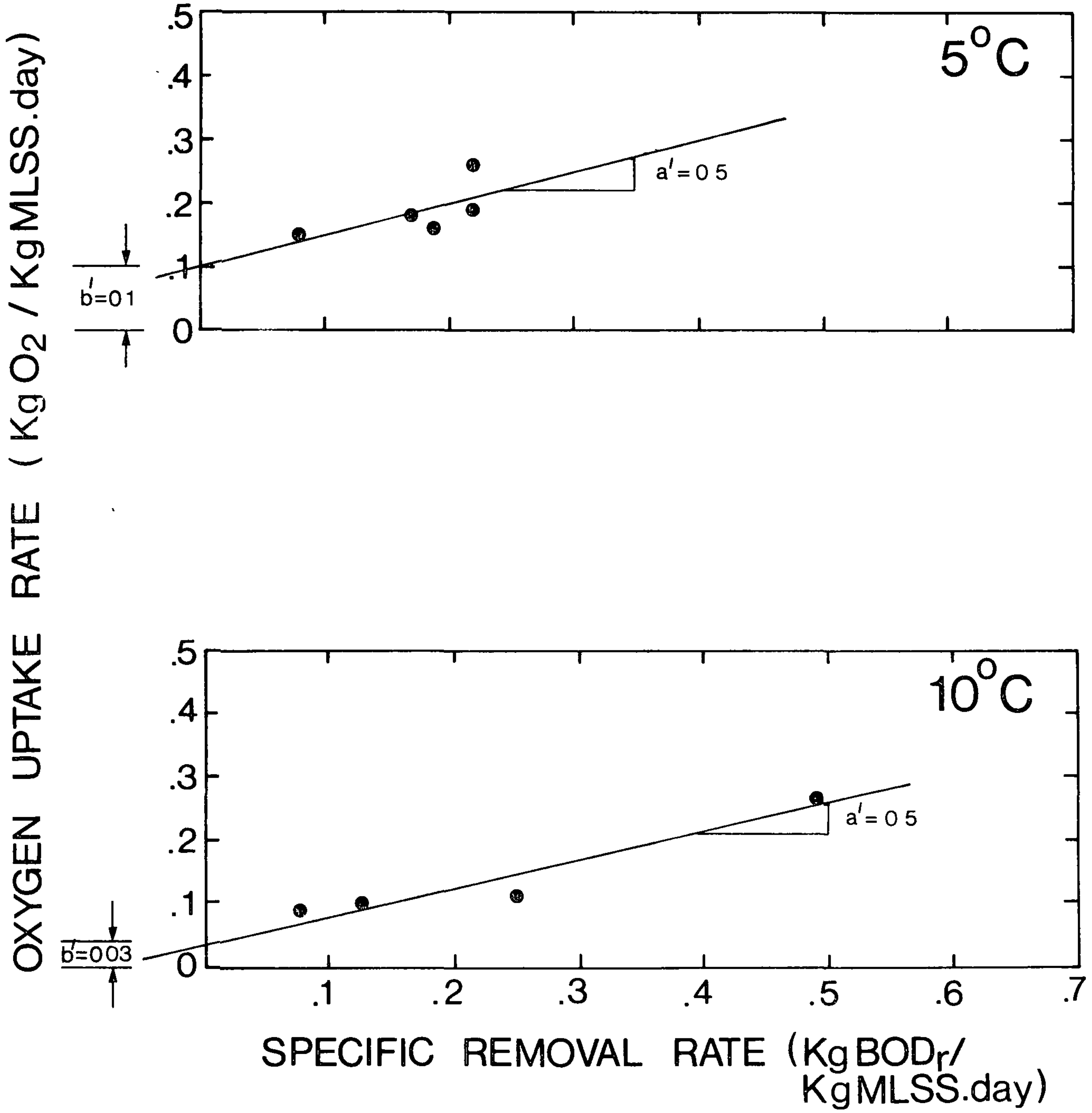


FIG. 15 OXYGEN UPTAKE RATE CONSTANTS FOR DOW DEICER AT 5 & 10°C.

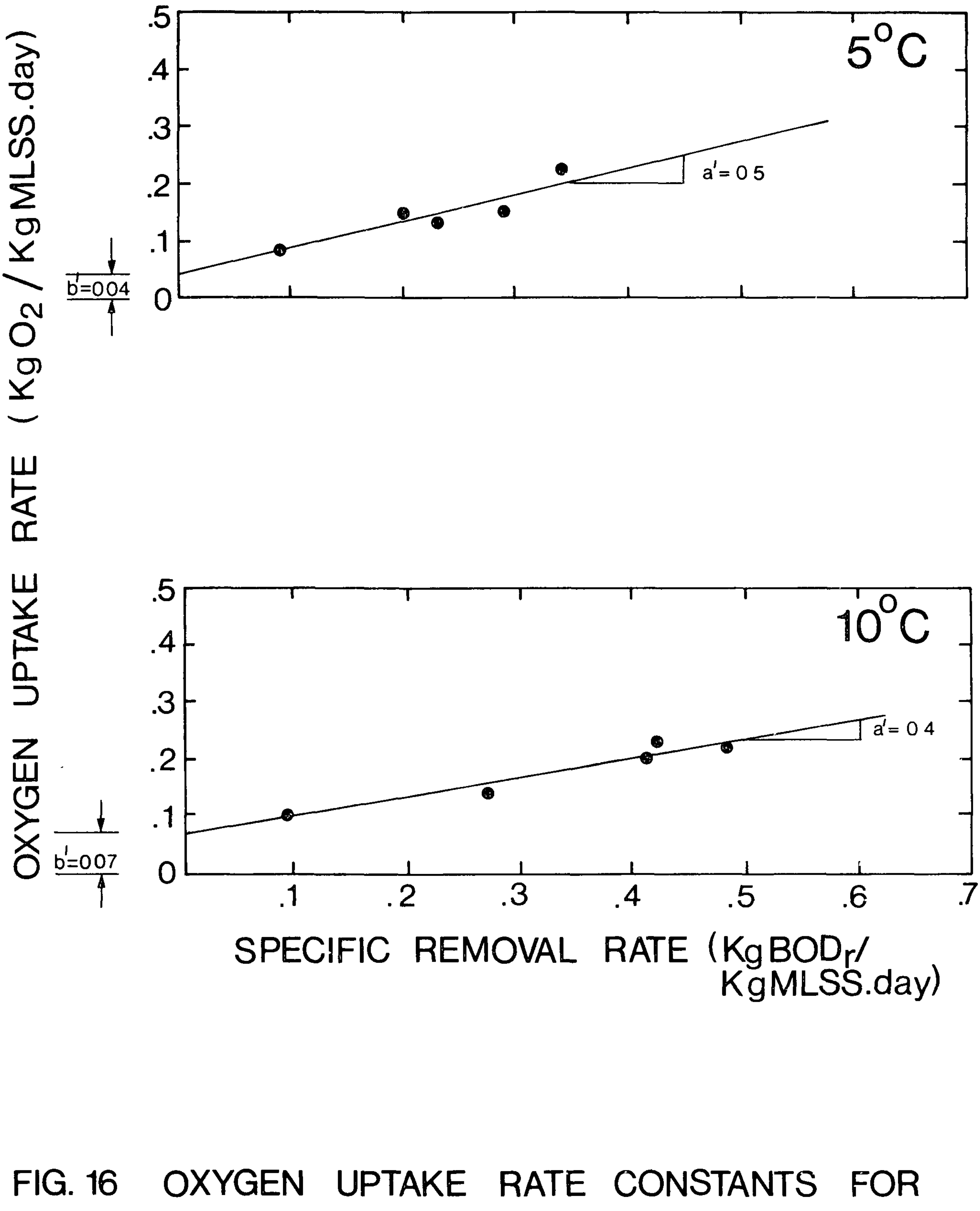


FIG. 16 OXYGEN UPTAKE RATE CONSTANTS FOR UCAR DEICER AT 5 & 10°C.

coefficients, a' and b', were calculated using the method of least squares. Experimental results from the single-stage temperature-controlled reactors, the extended aeration units and results from supplementary studies reported were used in calculating the coefficients. Oxygen requirements for the treatment of either de-icing fluid at temperatures of 5 and 10°C were approximately the same. For design purposes, the oxygen requirement of the activated sludge system can be determined using the average value of the coefficient; i.e., a' equal to 0.5 and b' equal to 0.06.

Sludge production for the activated sludge system was estimated from the relationship

$$\Delta S/S_a = a(BOD_r/S_a t) - b \qquad (4\text{-}2)$$

where ΔS = sludge production per day

a = cell yield coefficient

b = coefficient of auto-oxidation

Experimental results from single-stage temperature-controlled reactors, extended aeration reactors and the supplementary studies reported in Section 4.5.3 were used to determine the coefficients using the method of least squares. Plots of the sludge production rate versus specific removal rate for Dow and UCAR de-icer are presented in Figures 17 and 18, respectively. The results indicate that the sludge yield at 5°C was slightly higher than at 10°C while the rate of auto-oxidation was approximately the same for the four loading conditions. For design purposes, the rate of sludge production can be determined using a sludge yield of 0.7 and 0.55 at temperatures of 5 and 10°C, respectively, for both de-icing fluids, and an auto-oxidation rate of 0.03 for both de-icing fluids at 5 and 10°C.

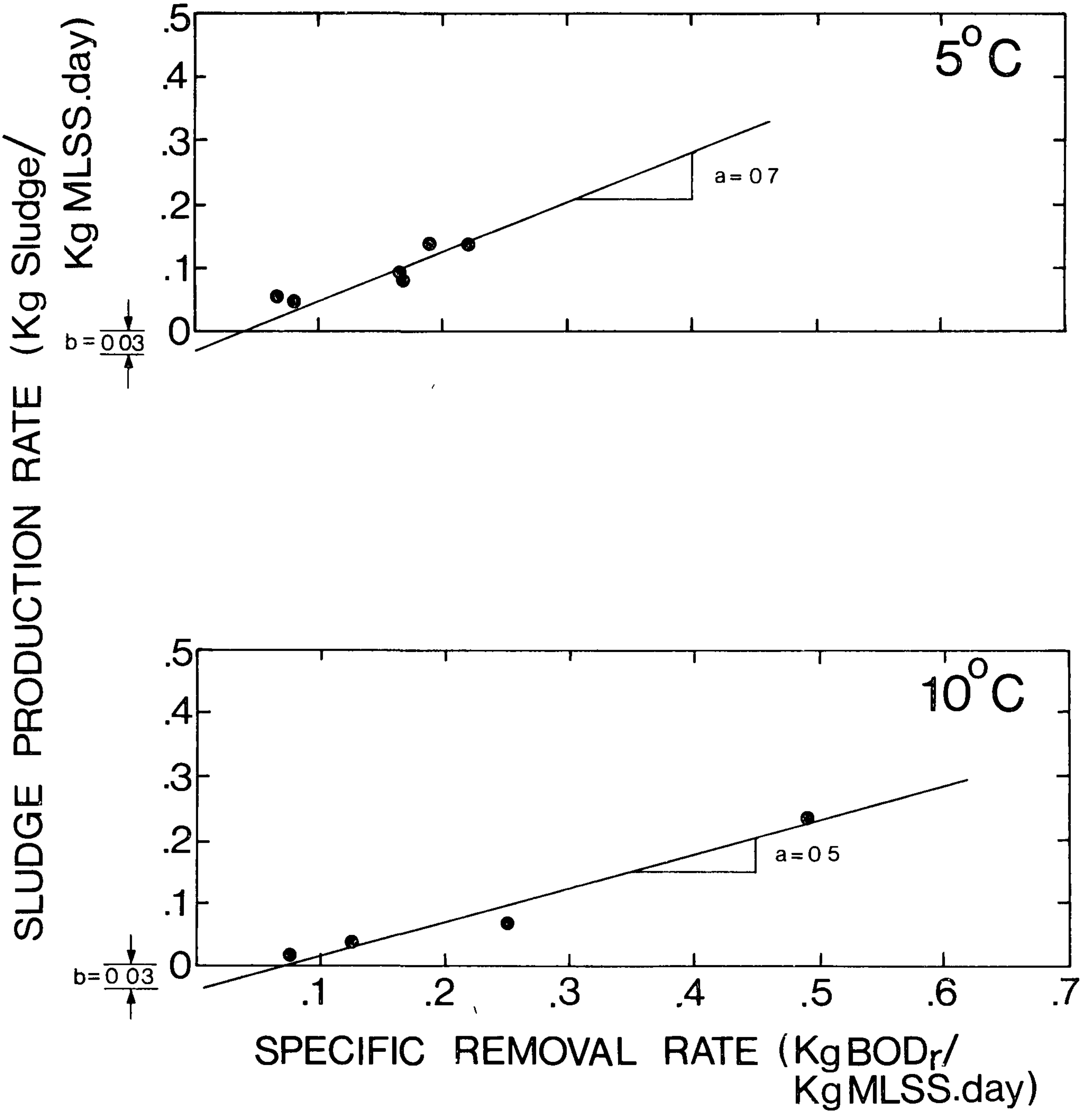


FIG. 17 SLUDGE PRODUCTION RATE CONSTANTS FOR DOW DEICER AT 5 & 10°C.

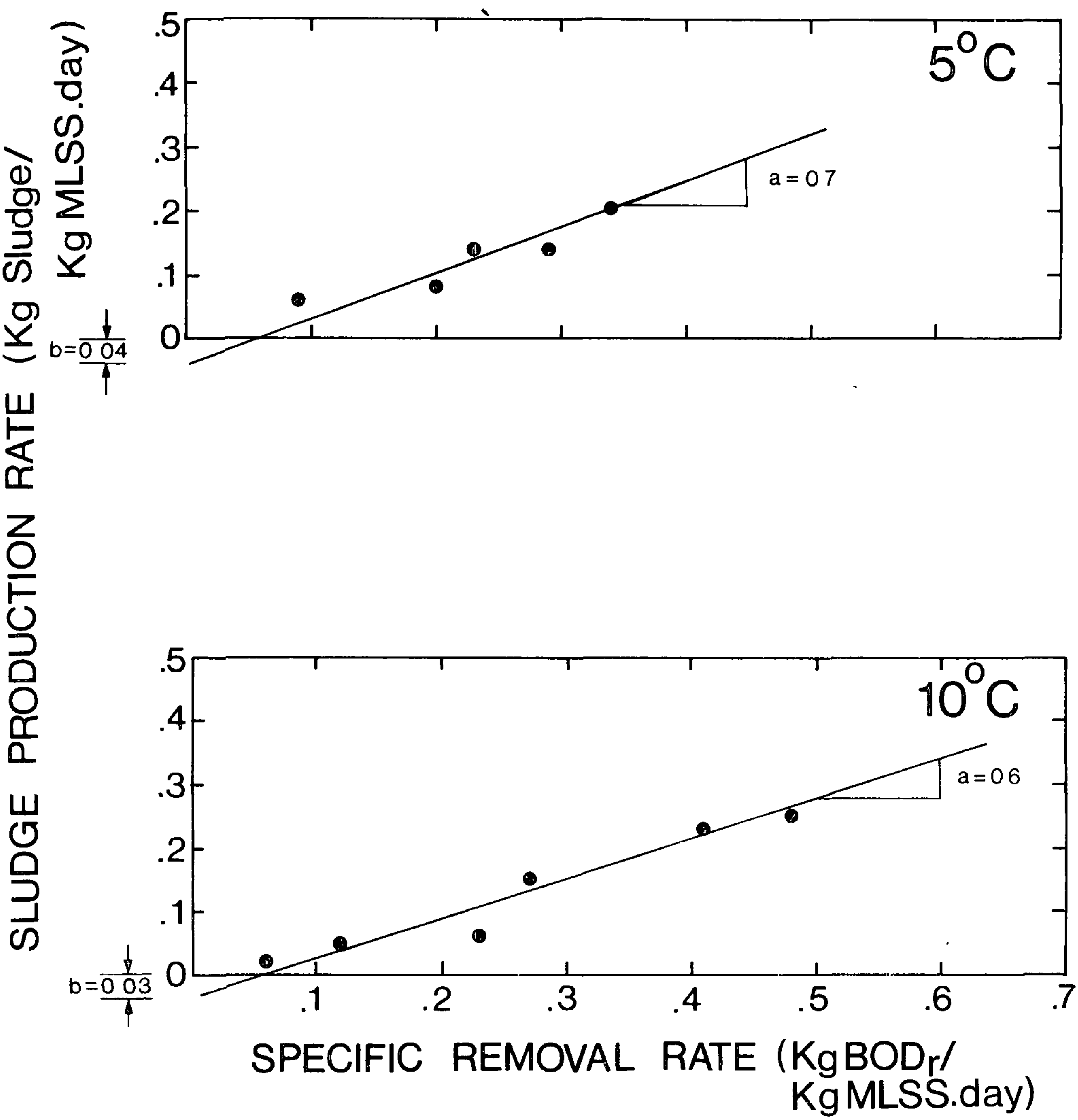


FIG. 18 SLUDGE PRODUCTION RATE CONSTANTS FOR UCAR DEICER AT 5 & 10°C.

4.5 Additional Laboratory Studies

Three supplementary laboratory studies were conducted during the experimental program. A two-stage activated sludge process was operated at high organic loadings, three single-stage activated sludge reactors were operated at room temperature and five single-stage activated sludge reactors were operated at $10^{o}C$ to obtain additional information for determination of engineering design parameters.

4.5.1 Two-stage Activated Sludge Experiments

Two two-stage activated sludge systems were set up and operated at $10^{o}C$ in the temperature-controlled room at different loading conditions. The two-stage system used in the treatment of Dow de-icer and sewage is shown in Figure 3. Operating parameters and experimental results for both sets of reactors are presented in Tables 21 and 22, respectively.

The BOD of the feed solution for the first set of reactors was 403 mg/l of which approximately 300 mg/l was exerted by the de-icing fluid. The first stage had an organic loading of 0.55 kg BOD/kg MLSS• day. Although the final effluent met the specified effluent objectives the unit could not be operated at this loading condition as excessive bulking occurred in the first stage. The average SVI for the first stage was 886 ml/g. The filamentous growth was transferred from the first stage to the second stage as the SVI gradually increased in the second stage. A photomicrograph of the profuse filamentous growth present in the first stage of reactor number 1 is shown in Figure 19.

TABLE 21

OPERATING PARAMETERS

TWO-STAGE REACTORS TREATING DOW DE-ICER AT 10°C

REACTOR NO.	1		2	
	First Stage	Second Stage	First Stage	Second Stage
Dosage of De-icer (ml de-icer per 100 l of feed solution)	81	81	162	162
Organic Loading:				
-- kg BOD/kg MLSS.day	0.55	0.08	1.18	0.79
Detention period:				
-- aeration tank (hr)	4	4	4	4
-- settling tank (hr)	6.8	6.8	6.8	6.8
MLSS in aeration tank (mg/l)	4400	3200	4400	3600
D.O. in aeration tank (mg/l)	>3.0	>3.0	>3.0	>3.0
Sludge return rate (% of plant flow)	100	100	100	100

TABLE 22

EXPERIMENTAL RESULTS

TWO-STAGE REACTORS TREATING DOW DE-ICER AT 10°C

REACTOR NO.	1							2						
	First Stage			Second Stage				First Stage			Second Stage			
	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Overall % red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Overall % red.
Unfiltered BOD (mg/l)	403	45	88.8	45	18	60.0	95.5	870	474	45.5	474	345	27.2	60.3
TOC (mg/l)	211	57	73.0	57	32	43.9	84.8	470	272	42.1	272	210	22.8	55.3
Suspended Solids (mg/l)	53	20	62.3	20	20	0	62.3	40	31	22.5	31	35	--	12.5
TKN (mg/l)	10.6	0.9	91.5	0.9	0.6	33.3	94.3	11.4	1.1	90.4	1.1	0.9	18.2	92.2
Total Phosphorus (filtered) (mg/l)	2.2	0.7	68.2	0.7	0.6	14.3	72.7	3.7	3.0	45.9	2.0	2.0	0	45.9
SVI (ml/g)	886			179				290			172			

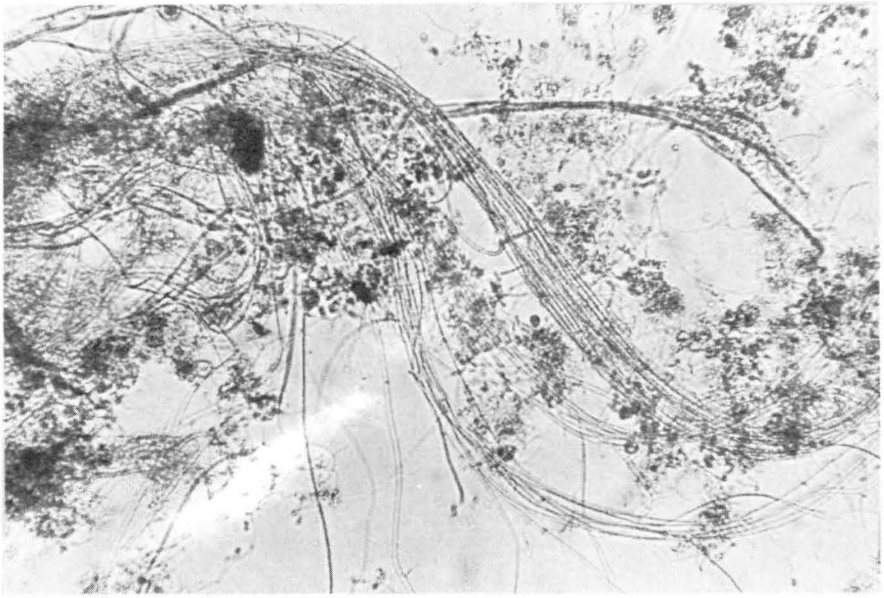


FIG.19
Filamentous growth in the first stage of the two stage reactor #1
F / M = 0.55
kg BOD / kg MLSS · day
(Dow , 10°C)
x 100

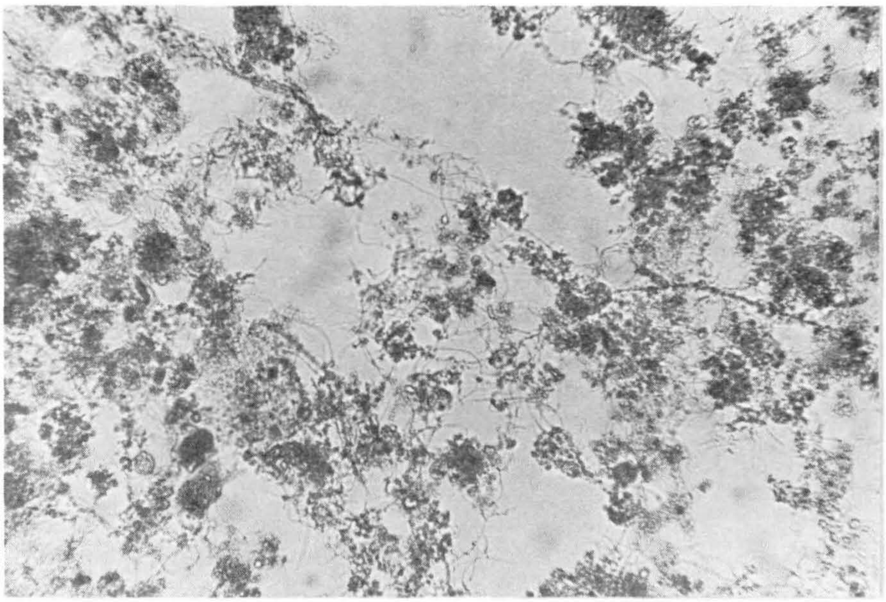


FIG. 20
Typical sludge flocs from the extended aeration pilot plant
F / M = 0.12
kg BOD / kg MLSS · day
(Dow)
x 100

The second set of two-stage reactors was loaded at a higher organic loading. The system was overloaded as the BOD of the effluent from the second stage was 345 mg/l. Bulking conditions occurred; however, the rate of growth of filamentous microorganisms was not as high as in Reactor number 1.

Based on the two loading conditions studied, it can be concluded that the de-icer sewage mixture can not be treated using a two-stage activated sludge system. The bulking sludge condition caused by the growth of filamentous microorganisms must be considered as a limiting factor in the use of an activated sludge system for the treatment of the glycol-based de-icing fluids.

4.5.2 Experiments at Room Temperature

Since aircraft de-icing fluids are only applied during the winter, emphasis was placed on determining methods of treatment of de-icer and sewage at low temperatures. One set of experiments was conducted at room temperature to determine the optimum organic loading at the higher operating temperature.

Three single-stage activated sludge reactors were operated at an average mixed liquor temperature of 20°C for two weeks. Operating parameters and experimental results are presented in Tables 23 and 24, respectively. The detailed analytical results have been presented in Table A-4; influent BOD, effluent BOD and suspended solids, MLSS and SVI's were reported.

Reactors loaded at 0.12 and 0.29 kg BOD/kg MLSS.day produced high quality effluents well below the specified effluent objec-

TABLE 23

OPERATING PARAMETERS

SINGLE-STAGE REACTORS TREATING DOW DE-ICER AT 20°C

REACTOR NO.	1	2	3
Dosage of de-icer (ml de-icer per 100 l of feed solution)	80	80	80
Organic loading:			
-- kg BOD (unfiltered)/ kg MLSS.day	0.76	0.29	0.12
Detention period:			
-- aeration tank (hr)	3.4	7.7	24.0
-- settling tank (hr)	5.5	6.5	10.0
MLSS in aeration tank (mg/l)	3700	4900	3200
D.O. in aeration tank	>3.0	>3.0	>3.0
Sludge return rate (% of plant flow)	100	100	100

TABLE 24

EXPERIMENTAL RESULTS

SINGLE-STAGE REACTORS TREATING DOW DE-ICER AT 20°C

REACTOR NO.	1			2			3		
	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.
Unfiltered BOD (mg/l)	396	63	84.1	396	8	98.0	396	6	98.5
TOC (mg/l)	215	30	86.2	215	9	96.0	215	10	95.5
Suspended Solids (mg/l)	74	23	68.9	74	7	90.5	74	9	87.9
SVI (ml/g)	472			167			106		

tives. Effluent quality from the reactor loaded at 0.76 kg BOD/kg MLSS.day was reasonably good; however, the average SVI was 472 ml/g as a filamentous growth was again present. The experimental results indicate that if the de-icer and sewage mixture could be treated at the higher temperature, a higher organic loading could be used.

4.5.3 Supplementary Experiments

Following a preliminary analyses of experimental results, it was discovered that additional information was required to determine the oxygen requirements and sludge production for an activated sludge system operated at 10°C. Five single-stage activated sludge reactors were operated in the temperature-controlled room for 3 weeks. Four of the reactors were operated as extended aeration units while the fifth was operated as a conventional activated sludge system. The operating parameters and experimental results for the five reactors are presented in Tables 25 and 26, respectively. The results were used in Section 4.4 in determination of the coefficients required to estimate the oxygen requirement and sludge production of the activated sludge system.

Organic loadings of 0.08 and 0.13 kg BOD/kg MLSS.day produced effluents which were below the specified objectives. Reactors loaded at higher organic loadings and having influent BOD concentrations of 700 mg/l produced reasonably good effluents. In particular, on the basis of effluent quality, the performance of Reactor number 5 loaded at 0.51 kg BOD/kg MLSS.day appeared to be exceptionally

TABLE 25

OPERATING PARAMETERS

FOR SUPPLEMENTARY STUDIES

REACTOR NO.	1	2	3	4	5
Type of de-icer used	Dow	Dow	Dow	UCAR	Dow
Dosage of de-icer (ml de-icer per 100 l of feed solution)	65	65	130	130	130
Organic loading:					
-- kg BOD/kg MLSS.day	0.08	0.13	0.27	0.24	0.51
Detention period:					
-- in aeration tank (hr)	24	12	12	12	7
-- in settling tank (hr)	4	2	2	2	6
MLSS in aeration tank (mg/l)	4800	5400	5200	5800	5500
D.O. in aeration tank (mg/l)	>3	>3	>3	>3	>3
Operating temperature (°C)	10	10	10	10	10
Sludge return rate (% plant flow)	100	100	100	100	100

TABLE 26

EXPERIMENTAL RESULTS

FOR SUPPLEMENTARY STUDIES

REACTOR NO.	1			2			3			4			5		
	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.	Inf.	Eff.	% red.
Unfiltered BOD (mg/l)	350	10	97.1	350	12	96.6	700	46	93.4	696	30	95.7	700	27	96.1
TOC (mg/l)	165	10	93.9	165	10	93.9	302	20	93.4	329	14	95.7	302	15	95.0
Suspended Solids (mg/l)	102	18	82.4	102	16	84.3	158	85	46.2	102	73	28.4	158	32	79.8
TKN (mg/l)	19.6	1.9	90.3	19.6	2.3	88.3	20.8	3.2	84.6	20.0	6.1	69.5	20.8	3.1	85.1
Total Phosphorus (filtered) (mg/l)	4.9	1.8	63.3	4.9	1.4	71.4	5.1	2.6	49.0	4.6	1.9	58.7	5.1	2.4	52.9
SVI (ml/g)	79			114			107			142			191		

good; however, the average SVI was 191 ml/g, filamentous growth increased throughout the 3 weeks of operation and the SVI at the end of the test period was 360 ml/g. These specific cases indicate the importance of selecting a loading condition at which the growth of filamentous microorganisms can be controlled.

4.6 Extended Aeration Pilot Plant Studies

The pilot plant studies were conducted to verify the results of the laboratory-scale studies and determine what operational problems might be encountered in full-scale operation. The pilot plant was operated as an extended aeration unit treating Dow de-icer and sewage at two organic loading conditions.

4.6.1 Experimental Program and Results

The sampling and analysis programs were conducted from March 7 to May 6. During the test period, the rate of de-icer addition was 74 ml/min from the first to the twentieth day, 150 ml/min from the twenty-first to the twenty-ninth day and 74 ml/min from the thirtieth to the sixty-first day of operation. The higher organic loading from the twenty-first to the twenty-ninth resulted in excessive sludge bulking and it was necessary to reduce the organic loading.

The average operating parameters during de-icer addition at 74 ml/min have been presented in Table 27. The organic loading for the 53 days averaged 0.12 kg BOD/kg MLSS·day. Mixed liquor temperatures varied from 7.5 to 13.5^{o}C with the temperature greater than

TABLE 27

OPERATING PARAMETERS

EXTENDED AERATION PILOT PLANT

PARAMETERS	
Type of de-icer used	Dow
Dosage of de-icer (ml/min)	74
Feeding rate of raw sewage (Igpm)	20
Operating temperature (°C)	8 to 14
Organic loading:	
-- kg BOD/kg MLSS.day	0.12
Detention period in aeration tank (hr)	24
MLSS in aeration tank (mg/l)	3900
Sludge return rate (% plant flow)	100
Settling tank:	
-- Detention period (hr)	4
-- Surface loading (m^3/m^2.hr)	0.4
-- Weir loading (m^3/m.hr)	0.4

$12^{o}C$ for the last 20 days of operation. Average ambient temperatures for the 61 days varied from -2 to $20^{o}C$.

Average experimental results for the extended aeration pilot plant loaded at 0.12 kg BOD/kg MLSS.day have been presented in Table 28. The detailed analytical results have been tabulated and presented in Table A-5, Appendix A. Influent and effluent BOD and suspended solids concentrations, MLSS, SVI and percent BOD reduction versus days of operation have been plotted and presented in Figures 21 and 22.

The data collected during the first 20 days of the experiment revealed that, with an average influent BOD of 550 mg/l, the effluent BOD and suspended solids were less than the allowable levels specified in the effluent objectives. The SVI fluctuated significantly and there was an increased growth of filamentous microorganisms. The lack of an adequate supply of dissolved oxygen as noted in Table A-5 would contribute to the filamentous growth. The filamentous nature of the sludge following 2 weeks of operation is shown in the photomicrograph presented in Figure 20.

As the desired effluent quality was being attained, the rate of addition of de-icer was increased to 150 ml/min. At the higher organic loading the filamentous growth was excessive and the SVI increased accordingly. The filamentous microorganisms prevented sludge compaction in the clarifier and, with excess sludge wasting, the MLSS decreased. Following 9 days of operation at the higher loading, the rate of de-icer addition was decreased to 74 ml/min. The

TABLE 28

EXPERIMENTAL RESULTS

EXTENDED AERATION PILOT PLANT

	Influent	Effluent	% Reduction
Unfiltered BOD (mg/l)	479	11	97.8
TOC (mg/l)	220	13	94.0
Suspended Solids (mg/l)	294	17	94.2
Glycol (mg/l as C)	193	0	100.0
TKN (mg/l)	21.1	2.1	90.0
Total Phosphorus (filtered) (mg/l)	6.9	1.5	78.4

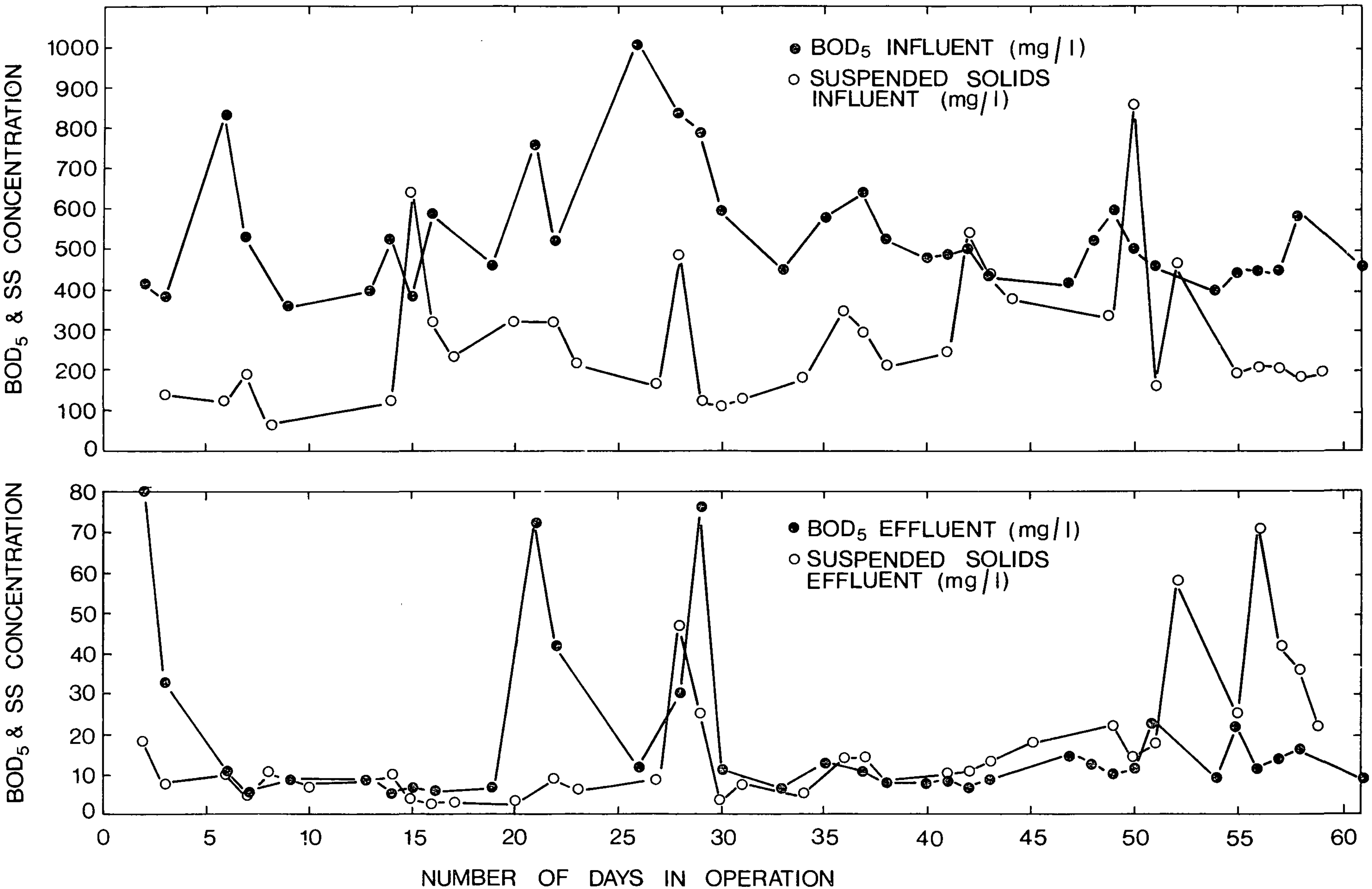


FIG. 21 SUSPENDED SOLIDS AND BOD_5 CONCENTRATIONS FOR THE EXTENDED AERATION PILOT PLANT

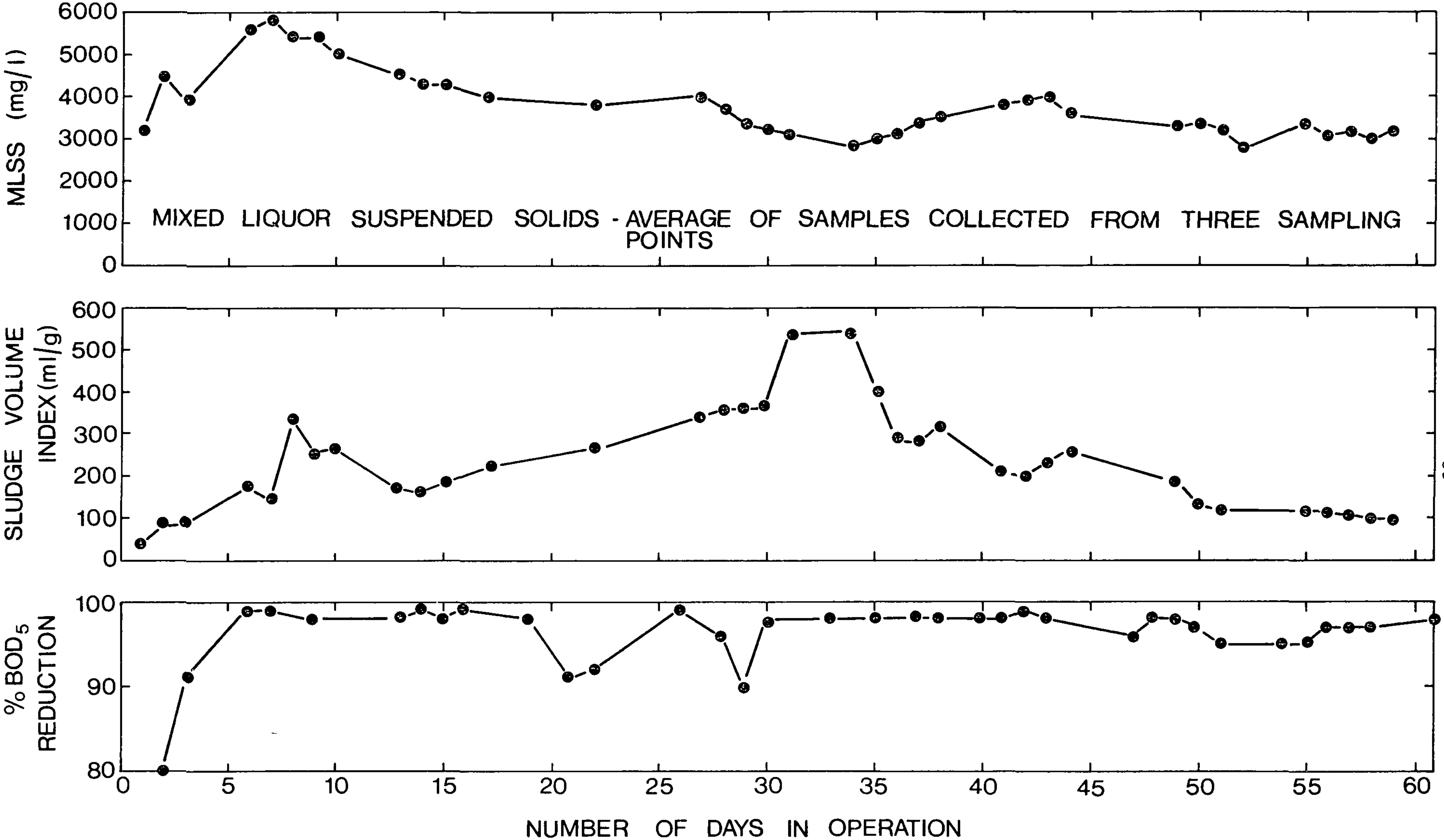


FIG. 22 MIXED LIQUOR SUSPENDED SOLIDS, SLUDGE VOLUME INDEX AND PERCENT BOD_5 REDUCTION FOR THE EXTENDED AERATION PILOT PLANT

effluent quality improved within 24 hours; however, the SVI continued to rise and the MLSS decreased to 2800 mg/l. After 5 days of operation at the lower loading, the SVI started to decrease and the MLSS increase. By the end of the experimental run the SVI was down to 100 ml/g.

Effluent quality was not good during the last 10 days of operation as the effluent suspended solids concentrations were higher than normal. Following the excessive bulking sludge condition which developed at the high organic loading, a pin point floc was present in the clarifier effluent. In addition, there was a fairly thick scum formation on the clarifier surface with a portion discharged in the effluent. These two factors were responsible for the higher suspended solids and BOD concentrations in the effluent.

The ratio between BOD reduction and nutrient consumption was 100:4:1. This ratio is consistent with the value obtained from the laboratory-scale extended aeration unit operated at 10°C.

4.6.2 Operational Problems

The following problems were encountered in the operation of the pilot plant:

1. There was an oxygen deficiency in the aeration compartments at the influent end of the aeration tank. The pilot plant was equipped with two rotary positive displacement compressors with a timed switching mechanism. Each blower delivered 175 cfm of air at 6 psig and operated alternately on a 12-hour cycle. During the initial phase of the experiment, no dissolved oxygen was measured in the first compartment of the

aeration tank, even at a dosage of 74 ml of de-icing fluid per minute. The air supply system was repiped so that each compressor delivered air to one-half of the aeration tank. With the two compressors in continuous operation, it was possible at the low organic loading to maintain a dissolved oxygen of greater than 1 mg/l throughout the aeration tank.

2. There was a considerable carry-over of scum and floating solids in the effluent as the skimming device of the pilot-scale unit was not adequate for the abnormal conditions encountered. The skimming device, a 1.5" diameter air lift which transferred the material to the aeration tank did not provide sufficient capacity. Special consideration should be given to ensure that an adequate skimming device is provided in the design of a clarifier for a full-scale treatment facility.

3. The contents of the air lift system used for sludge return and scum removal froze on a number of occasions; this problem was only encountered at extremely low ambient temperatures.

The operational problems encountered in the pilot-scale unit are not likely to occur in the operation of a properly designed full-scale plant.

BIOASSAY STUDIES

5. OBJECTIVES AND SCOPE

Bioassay studies were carried out using rainbow trout to determine at what concentrations the de-icing fluids were toxic and whether effluents from activated sludge processing treating a mixture of the de-icing fluid and municipal sewage were toxic. The studies were extended to determine which components contributed the toxicity in the de-icing fluids and treated effluents. Bioassay studies were conducted on:

a) the two aircraft de-icing fluids (DOW and UCAR) used in the experimental program;

b) reagent grade ethylene glycol; and

c) effluents from the laboratory and pilot-scale activated sludge reactors.

6. MATERIALS AND METHODS

6.1 Bioassay Procedures

During the experimental program, acute toxicity of the treated effluent was determined on juvenile rainbow trout (Salmo gairdneri). Bioassays followed the standard procedures outlined by Sprague (3). An effort was made to provide at least 2 litres of solution per gram of fish and, in all cases where static tests were necessary, the effluent was renewed once every 24 hours.

The rainbow trout used for the acute toxicity tests were obtained from Shamrock Springs Trout Farm, Erin, Ontario. The fish were certified to be disease free. They were held in 200-gallon fiberglass tanks at a volume-to-weight ratio of 6.5 litres per gram per day. Fish holding tanks were stored in a controlled-temperature room having a 12-hour photoperiod maintained by dimming fluorescent daylight bulbs. Water supplying the laboratory was dechlorinated municipal water from the City of Burlington. Dechlorination was achieved with carbon filtration. The physical and chemical characteristics of the water are presented in Table B-1.

Fish were held at $10 \pm 1^{\circ}C$ for at least 30 days before being used in the bioassay. No mortality occurred in any of the holding tanks during the six-month experimental period. Fish were fed Martin Feed Mills dry pellet food, daily, but were not fed 2 days prior to testing. Dry food was occasionally supplemented with fresh beef liver.

The fish were exposed to a reference toxicant at intervals throughout the experiment to indicate changes in fish resistance. The compound used in the control study was DSS (dodecyl sodium sulphate) which was reported by La Roche et al (4) to be a non-selective reference toxicant. Bioassays using the reference toxicant were static. Solutions were renewed once every 24 hours and were not aerated as oxygen levels in the DSS after 24 hours were greater than 8 mg/l. Five fish were used in each concentration with a volume-to-weight ratio of 2 l/g/day.

6.2 Bioassays on Dow and UCAR De-icers

Dow and UCAR de-icers were shipped from Dow Chemical of Canada Ltd. and Union Carbide of Canada Ltd. in 45-gallon metal drums. Dow de-icer was shipped as a 50 per cent solution while UCAR was shipped as 100 per cent de-icer and was diluted to 50 per cent with water before use. Bioassays on the two de-icers were carried out in 20-litre polyethylene containers lined with disposable polyethylene bags. The solutions were renewed every 24 hours. Five rainbow trout were exposed to each concentration, providing a volume-to-weight ratio of 2 l/g/day. Bioassays were conducted on both aerated and non-aerated de-icers to determine if toxicity was due to the presence of volatile components. Bioassays were also carried out using reagent grade ethylene glycol and the results compared with Dow and UCAR de-icers. Ethylene glycol bioassays were non-aerated.

Fish were held in fiberglass screen baskets while in the bioassay containers to expedite transferring the fish to fresh solutions every 24 hours. Static tests were employed to duplicate the bioassays on biologically treated de-icers. Observations were made on an almost continuous basis and toxicity curves were prepared by plotting individual mortality versus glycol concentration on log-probit paper.

6.3 Bioassays on Effluents from Treatment Processes

The details of the experimental program conducted to provide the design information for an activated sludge system have been presented in Section 3. For purposes of identification of effluent streams on which bioassays were conducted, a summary of the experimental program schedule and type of bioassay carried out is presented as Table 29. Bioassay procedures used in the testing of effluents from the four types of reactors are outlined in the following sub-sections.

6.3.1 Bioassays on Effluent from Temperature-Controlled Single-Stage Reactors

The low flow rate from the single-stage reactors (20 ml per min) made it necessary to collect effluent for 16 hours to provide the proper volume-to-weight ratio (2 l/g/day). As the reactors were located in a laboratory, the effluent was at room temperature by the time 20 litres had been collected. The effluent was cooled for 10 hours before being used for the bioassay. Five fish were used for each concentration. Solutions were continuously aerated (10 cc/l/min); however, as volatile substances had been "stripped" during biological treatment, it was assumed that additional aeration would not affect the results. Fish were exposed to 100 per cent effluent from each of the five reactors.

6.3.2 Bioassays on Effluent from the Two-Stage Reactors

The two-stage reactors were set up in a constant temperature room at $10^{o}C$. Continuous bioassays were carried out by allowing the effluent to flow directly from the second clarifier into the bioassay containers, providing the fish with 3 l/g/day.

TABLE 29

SCHEDULE FOR BIOASSAY STUDIES

DATE	REACTOR	DE-ICER	TEMP. (°C)	CONC. OF GLYCOL IN FEED (mg/l)	FLOW RATE (ml/min)	BIOASSAY TYPE
Dec. 7 - 22	Single-stage (5)*	Dow	10	100, 300, 500, 700, 1000	20	None
Jan. 4 - 23	Single-stage (5)	Dow	5	100, 300, 500, 700, 1000	20	Static
Jan. 24 - 28	Single-stage (5)	Dow	2	100, 300, 500, 700, 1000	20	Static
Jan. 29 - Feb. 6	Single-stage (5)	Dow	5	100, 300, 500, 700, 1000	20	Static
Feb. 8 - 21	Single-stage (5)	UCAR	10	100, 300, 500, 700, 1000	20	Static
Feb. 22 - Mar. 9	Single-stage (5)	UCAR	5	100, 300, 500, 700, 1000	20	Static
Mar. 8 - 30	Two-stage (2)	Dow	10	440, 880	22.2	Continuous
Apr. 5 - 20	Extended Aeration (4)	Dow	10	358	35, 70	Continuous
	" " (4)	UCAR	10	358	35, 70	Continuous
Apr. 21 - May 5	Extended Aeration (4)	Dow	5	358	35, 70	Continuous
	" " (4)	UCAR	5	358	35, 70	Continuous
May 7 - 18	Extended Aeration (4)	Dow	2	358	35, 70	None
	" " (4)	UCAR	2	358	35, 70	None
Apr. 5 - May 27	Extended Aeration Pilot Plant	Dow	10 ± 1	460	131 m^3/day	Continuous
May 29 - June 15	Extended Aeration Pilot Plant	None	10 ± 2	0	131 m^3/day	Continuous

* -- Number of reactors used specified in parentheses.

Solutions were continuously aerated. As the test was continued for 10 days, fish were fed small amounts of dry pellet food daily after the fourth day of the experiment.

6.3.3 Bioassays on Effluent from the Laboratory-Scale Extended Aeration Reactors

As specified in Table 29, the extended aeration reactors were fed 358 mg/l glycol mixed with raw sewage at rates of 70 and 35 ml/min. Continuous bioassays were set up with the effluent from the clarifier feeding directly into the bioassay containers. All test solutions were at $10^{o}C$ and were continuously aerated. When toxicity occurred, samples were collected, acidified and filtered through 0.45 micron filter paper. The filtrate was analyzed for glycol, glycol degradation products and heavy metals. Ten fish were used to monitor each operating condition. Fish were provided with 2 and 4 l/g/day at the flow rates of 35 to 70 ml/min, respectively. When mortality occurred, the test was repeated.

6.3.4 Bioassays on Effluent from the Extended Aeration Pilot Plant

Effluent was collected from the extended aeration pilot plant in 45-gallon polyethylene containers lined with disposable polyethylene bags. The pilot plant received 460 mg/l glycol in raw sewage and had a flow rate of 131 m^3/day. Bioassays were continuous with ten fish per test. Fish were held at $10 \pm 1^{o}C$ with a volume-to-weight ratio of 2 l/g/day. The solution had a 90% replacement in 10 hours.

Effluent from the pilot plant during de-icer addition was toxic. To determine if toxicity was due to de-icer or raw sewage, operation of the extended aeration plant was continued for 2 weeks without de-icer in the influent waste. Bioassays were performed in the same manner as they had been during de-icer addition.

7. EXPERIMENTAL RESULTS AND DISCUSSION

7.1 Results for Dow and UCAR De-icers

The toxicity curves for UCAR and Dow de-icers are presented as Figures 23 and 24. The curves indicate that the lethal concentration for 50% of the fish (96-hr LC50) is approximately 6,600 mg/l for UCAR de-icer and 9,200 mg/l for Dow de-icer. Insufficient partial responses were available to calculate the 96-hr LC50 with confidence limits using the procedure specified by Litchfield and Wilcoxon (5). For the purposes of this study, it is sufficient to indicate that the 96-hr LC50 for UCAR de-icer lies between 5,700 and 6,750 mg/l; for Dow de-icer the 96-hr LC50 lies between 8,900 and 12,000 mg/l. The toxicity curves indicate that no incipient lethal level can be found in a routine 96-hr bioassay. The incipient lethal level is defined by Sprague (3) as "that level of the environmental entity beyond which fifty percent of the population cannot live for an indefinite time".

Fish exposed to Dow and UCAR de-icer suffered equilibrium loss before they died. In many cases, the loss of equilibrium persisted for days before death. Logarithmic plots of time to median equilibrium loss versus de-icer concentration for Dow and UCAR de-icers are presented in Figures 25 and 26. The results show that the effects of the de-icing materials on rainbow trout are more severe than indicated by the toxicity curves. The 96-hr equilibrium loss concentration is approximately 3,500 mg/l and 4,600 mg/l for UCAR and Dow de-icers, respectively. In both cases, the 96-hr equilibrium loss concentration is about one-half the 96-hr LC50.

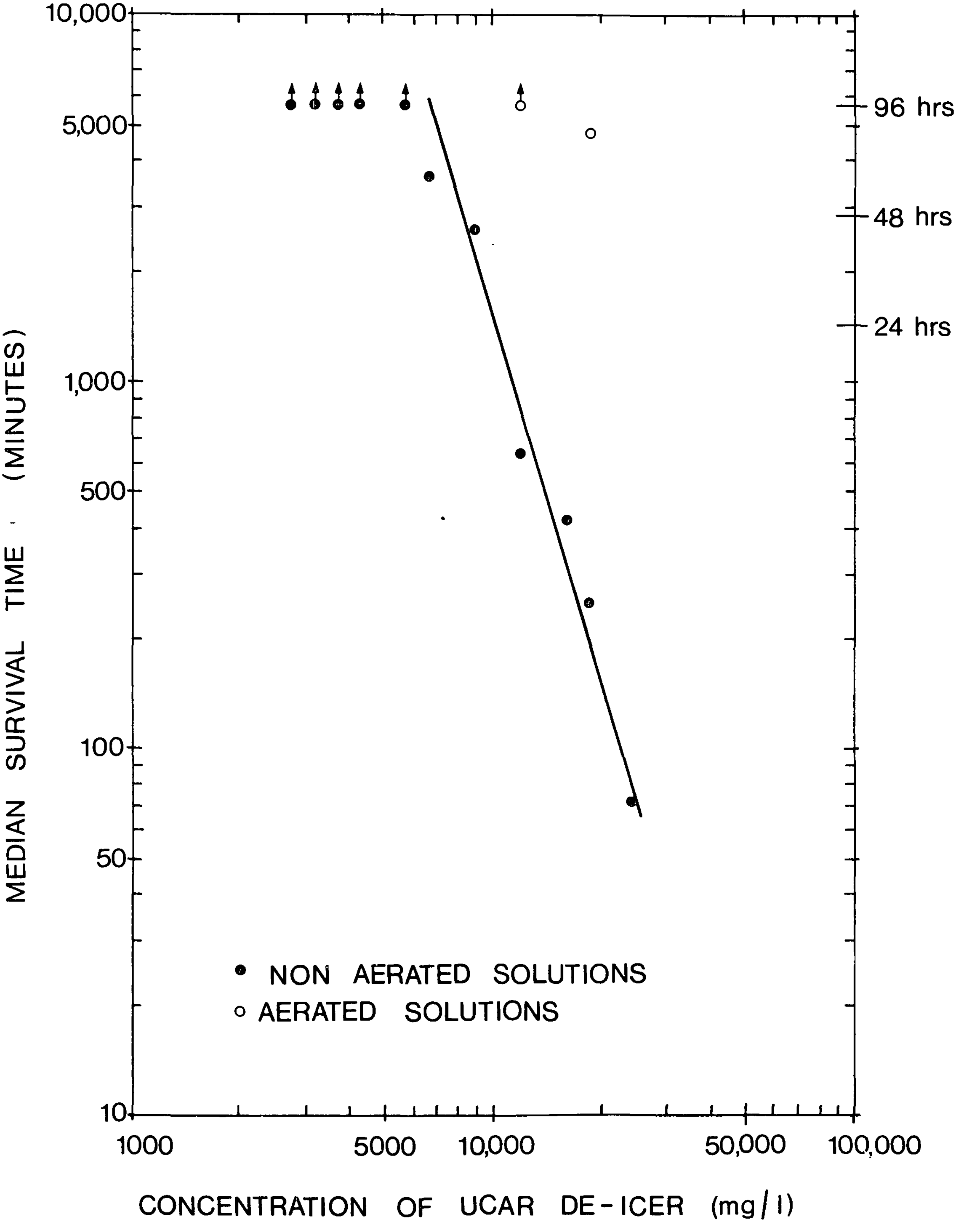


FIG. 23 MEDIAN SURVIVAL TIME FOR RAINBOW TROUT EXPOSED TO UCAR DE-ICER

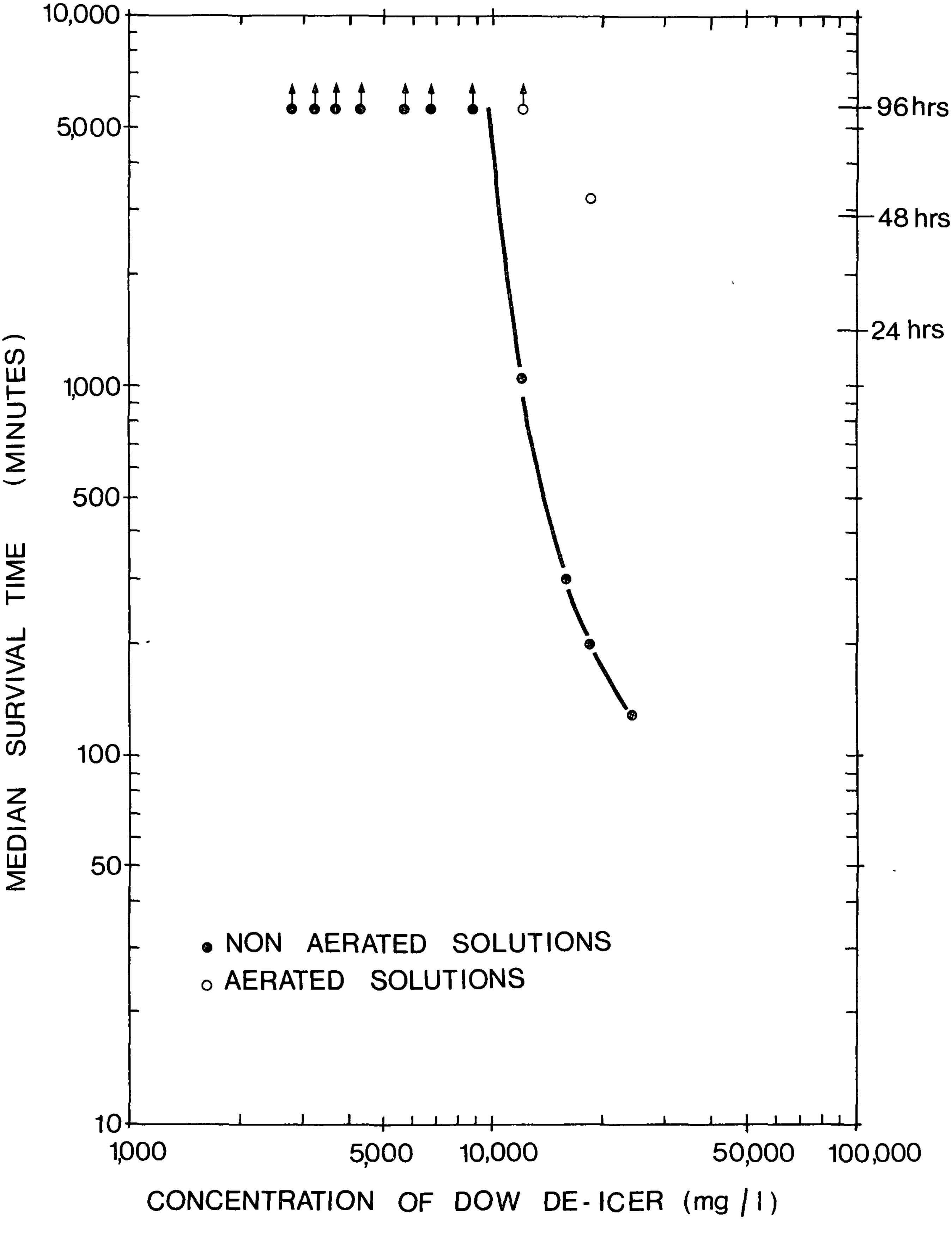


FIG. 24 MEDIAN SURVIVAL TIME FOR RAINBOW TROUT EXPOSED TO DOW DE-ICER

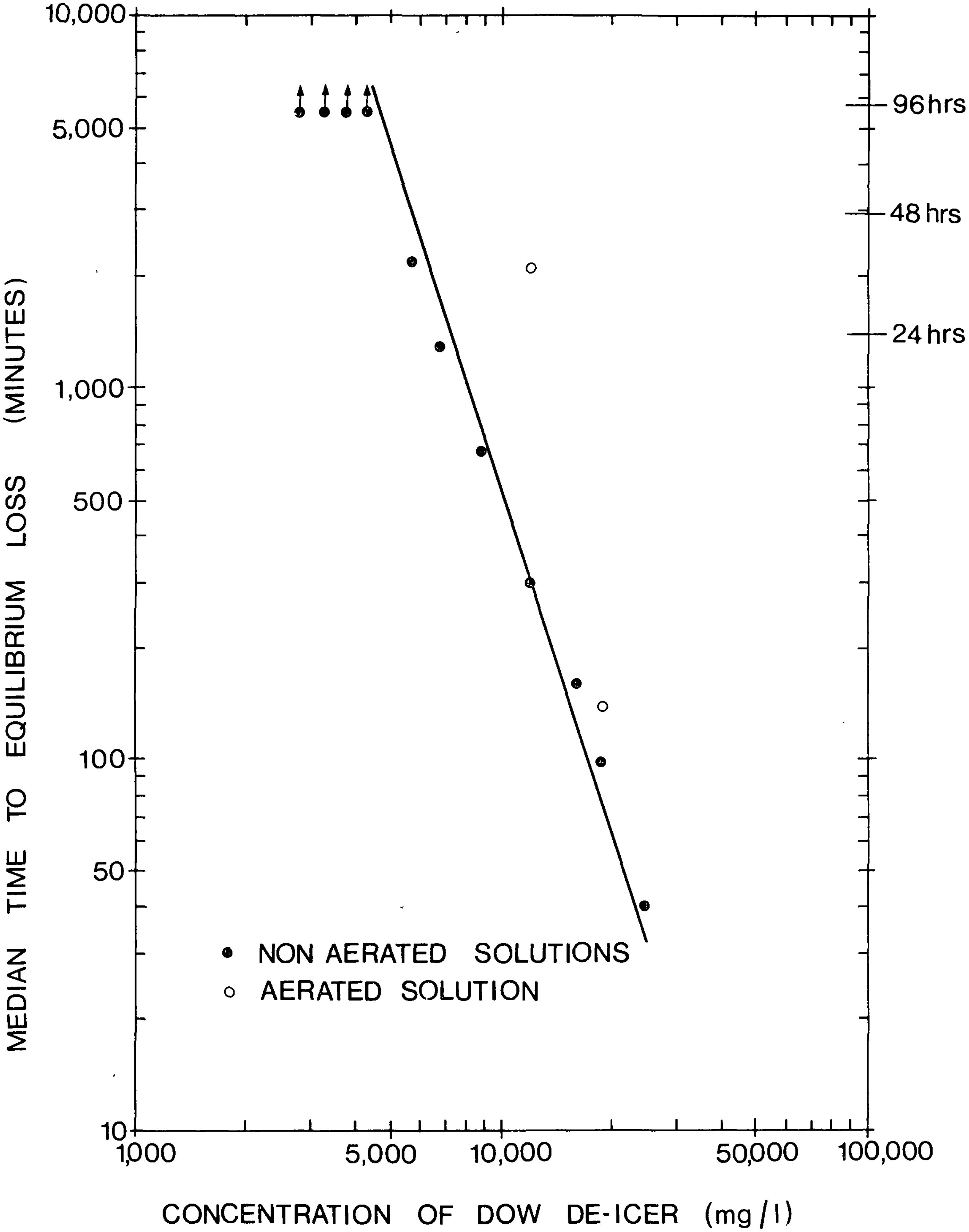


FIG. 25 TIME TO MEDIAN EQUILIBRIUM LOSS FOR RAINBOW TROUT EXPOSED TO DOW DE-ICER

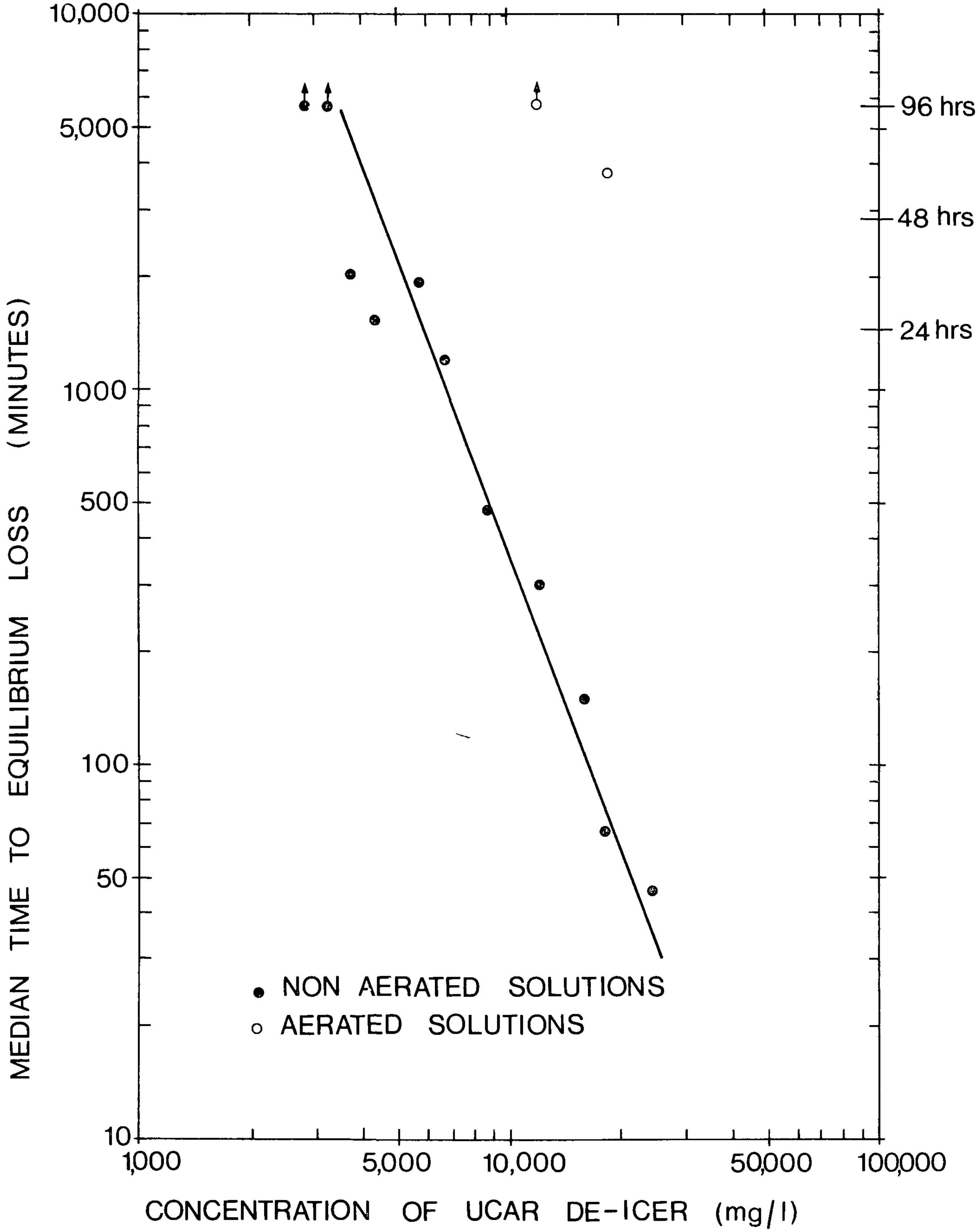


FIG. 26 TIME TO MEDIAN EQUILIBRIUM LOSS FOR RAINBOW TROUT EXPOSED TO UCAR DE-ICER

For comparison purposes, bioassays were conducted using reagent grade ethylene glycol. The bioassays indicated that the 96-hr LC50 for ethylene glycol was greater than 18,500 mg/l.

Toxicity of Dow and UCAR de-icers was greatly reduced by aerating at a rate of 10 cc/l/min. Experimental results are presented in Table 30 and Figures 23 to 26, inclusive. The reduction in acute toxicity could not be attributed to glycol removal as there was no measurable reduction in the glycol concentration. During aeration, a layer of foam was formed on the surface of the solution with the amount of foam generated by the UCAR de-icer greater than by the Dow de-icer. The results presented in Figures 23 to 26 show that aeration removed the toxicity from UCAR de-icer much more rapidly than from Dow de-icer.

7.2 Results for the Effluent from Activated Sludge Processes

The results of the bioassay tests conducted on undiluted effluents from the temperature-controlled single-stage reactor are presented in Table 31. A portion of the effluents from the reactors treating Dow de-icer at 5°C were toxic at the high loading conditions (700 and 1000 mg/l of de-icer). Mortality occurred within 24 hours after introducing the fish to the effluent. The results of a third bioassay on a similar effluent indicated no mortality even though loading conditions were identical.

Fish exposed to effluent from a reactor treating Dow de-icer at 2°C experienced no mortality. The results of this test are questionable as solutions were not renewed every 24 hours and the volume to fish weight ratio was 0.5 l/g/day.

TABLE 30

EFFECT OF AERATION ON DEGRADATION AND TOXICITY REDUCTION OF DOW AND UCAR DE-ICERS

Type of De-icer	Estimated Glycol Concentration (mg/l)	Measured Glycol Concentration (mg/l)		ET50 (min)	
		Before Aeration	After 24 hrs. Aeration	Unaerated Solution	Aerated Solution*
Dow	18,500	19,300	18,900	200	3,000
UCAR	18,500	17,900	18,100	250	4,800

Aeration rate, 10 cc/l/min.

Difference between estimated and measured glycol concentrations are within the limits of error of the analytical test procedure.

ET50, median effective time; values were taken from Figures 23 and 24.

* -- The fish were placed in an unaerated solution and aerated for 24 hours; the solution was replaced and the procedure repeated to the end of the test.

TABLE 31

PERCENT SURVIVAL OF RAINBOW TROUT EXPOSED TO 100 PERCENT EFFLUENT FROM THE TEMPERATURE-CONTROLLED SINGLE-STAGE REACTORS

Treatment Period	De-icer Conc. in feed (mg/l)	Temp. °C	De-icer	Percent Survival at 24 hrs	48 hrs	96 hrs	144 hrs	Bioassay Type
Jan. 4-23	100	5	Dow	100	100	100	100	Static
	300	5	Dow	100	100	100	100	
	500	5	Dow	100	100	100	100	
	700	5	Dow	80	80	80	80	
	1000	5	Dow	80	80	80	60	
Jan. 4-23	100	5	Dow	100	100	100		Static
	300	5	Dow	100	100	100		
	500	5	Dow	100	100	100		
	700	5	Dow	100	100	0		
	1000	5	Dow	0	0	0		
	1000 (R)	5	Dow	80	0	0		
Jan. 24-28	100	2	Dow	100	100	100		Static
	300	2	Dow	100	100	100		
	500	2	Dow	100	100	100		
	700	2	Dow	100	100	100		
	1000	2	Dow	100	100	100		
Jan. 29-Feb. 6	100	5	Dow	100	100	100		Static
	300	5	Dow	100	100	100		
	500	5	Dow	100	100	100		
	700	5	Dow	100	100	100		
	1000	5	Dow	100	100	100		
Feb. 8-21	100	10	UCAR	100	100	100	40	Static
	300	10	UCAR	80	80	80	40	
	500	10	UCAR	100	100	60	60	
	700	10	UCAR	100	100	100	100	
	1000	10	UCAR	100	100	100	100	

TABLE 31

(cont'd.)

PERCENT SURVIVAL OF RAINBOW TROUT EXPOSED TO 100 PERCENT EFFLUENT FROM THE TEMPERATURE-CONTROLLED SINGLE-STAGE REACTORS

Treatment Period	De-icer Conc. in feed (mg/l)	Temp. °C	De-icer	Percent Survival at				Bioassay Type
				24 hrs	48 hrs	96 hrs	144 hrs	
Feb. 22-Mar.9	100	5	UCAR	100	100	100		Static
	300	5	UCAR	100	100	100		
	500	5	UCAR	100	100	100		
	700	5	UCAR	0	0	0		
	700 (R)	5	UCAR	0	0	0		
	700 (R)	5	UCAR	100	100	100		
	1000	5	UCAR	100	100	100		

R -- indicates that test was being repeated.

There was no mortality in any of the control tests.

* -- Due to operational problems at the low temperature, solutions were not renewed every 24 hours; volume to fish weight ratio was only 0.5 l/g/day.

Bioassays on effluents from reactors treating UCAR de-icer at 10°C indicated mortality at the three lowest loading conditions. Tests on effluents from reactors treating UCAR de-icer at 5°C resulted in mortality at the second highest loading condition (700 mg/l as de-icer). As shown in Table 31, the particular test was repeated twice with one producing a toxic effluent and the other a non-toxic effluent.

Results from bioassays conducted on effluents from the two-stage and single-stage extended aeration units are presented in Table 32. The two-stage biological treatment of Dow de-icer and raw sewage produced a non-toxic effluent for ten consecutive days. Biological treatment of Dow and UCAR de-icers in the extended aeration reactors consistently produced a toxic effluent at the feed rate of 70 ml/min. Some toxicity was also evident in the reactor treating UCAR at 10°C at a feed rate of 35 ml/min. Bioassays on effluents from the 10°C operation were carried out three times with the response being approximately the same each time. The effluent from the extended aeration reactors treating Dow and UCAR de-icers at 5°C produced a non-toxic effluent for a four-day period (Table 32).

Because of the random nature of the bioassay results, samples were collected and analyzed to establish the concentration of certain metals in the test solutions. Samples were collected from a complete set of test containers when mortality occurred in one or more of the solutions. The analytical results for the laboratory-scale extended aeration reactors are presented in Table B-2, Appendix B.

According to the results presented in Table 33, effluent from the extended aeration pilot plant during de-icer addition was toxic for

TABLE 32

PERCENT SURVIVAL OF RAINBOW TROUT EXPOSED TO 100 PERCENT EFFLUENT FROM THE TWO-STAGE AND EXTENDED AERATION REACTORS

Reactor and Test Period	De-icer Conc. in feed (mg/l)	Temp (°C)	De-icer	Flow Rate ml/min	Percent Survival at			Bioassay Type
					24 hrs	48 hrs	96 hrs	
Two-stage	440	10	Dow	22	100% survival at 10 days			Continuous
Mar. 8-30	880	10	Dow	22	100% survival at 10 days			
Single-stage	358	10	Dow	35	100	100	100	Continuous
Apr. 5-20	358	10	Dow	70	100	100	40	
	358	10	UCAR	35	100	100	60	
	358	10	UCAR	70	100	100	0	
Single-stage (R)	358	10	Dow	35	100	100	Test	Continuous
Apr. 5-20	358	10	Dow	70	100	40	Dis-cont'd.	
	358	10	UCAR	35	100	100		
	358	10	UCAR	70	100	0		
Single-stage (R)	358	10	Dow	35	100	100	90	Continuous
Apr. 5-20	358	10	Dow	70	100	70	30	
	358	10	UCAR	35	100	100	100	
	358	10	UCAR	70	90	70	30	
Single-stage	358	5	Dow	35	100	100	100	Continuous
May 2	358	5	Dow	70	100	100	100	
	358	5	UCAR	35	100	100	100	
	358	5	UCAR	70	100	100	100	

No mortality occurred in the controls.

R -- indicates that the test was being repeated.

TABLE 33

PERCENT SURVIVAL OF RAINBOW TROUT EXPOSED TO 100 PERCENT EFFLUENT

FROM THE EXTENDED AERATION PILOT PLANT

Date	De-icer Conc. in feed (mg/1)	Temp (°C)	De-icer	Flow Rate IGPM	Percent Survival at			Bioassay Type
					24 hrs	48 hrs	96 hrs	
March 15	460	9	Dow	20	100	100	100	Continuous 75 ml/min
May 2	460	10	Dow	20	100	100	20	Continuous 75 ml/min
May 10	460	10	Dow	20	100	20	20	Continuous 75 ml/min
May 17	460	10	Dow	20	100	90	10	Continuous 75 ml/min
May 21	460	10	Dow	20	100	70	0	Continuous 75 ml/min
May 25	--	11	None	20	0	--	--	Continuous 75 ml/min
May 29	--	11	None	20	100	0	--	Continuous 75 ml/min
May 31	--	11	None	20	70	0	--	Continuous 75 ml/min

four of the five bioassays. The elapsed time to mortality varied from 5 to 80 hours. No relationship existed between the exposure time and percent mortality. In all cases, fish died quickly. At no time did a fish which had lost equilibrium live more than thirty minutes. Effluent from the extended aeration pilot plant during periods when de-icer addition was discontinued was toxic in each of the three bioassays. Samples for heavy metals were collected daily and the results have been presented in Table B-3, Appendix B.

Control tanks containing only dilution water were operated in parallel with tanks containing the test solutions throughout the study. There was no mortality in any of the control tanks. In addition, results from the bioassays on DSS indicated consistent tolerance of the test fish. The test results are summarized in Table 34.

7.3 Discussion of Results

The bioassay results were used to determine which components of the Dow and UCAR de-icers contributed to the toxicity. Twenty-four hours of aeration of Dow and UCAR de-icer greatly reduced toxicity but did not appreciably alter the glycol concentration. An unaerated solution of Dow de-icer having a glycol concentration of 19,000 mg/l had a median survival time (ET50) of 200 minutes; when a solution of the same concentration was continuously aerated, the ET50 was 3000 minutes. These results indicate that extremely toxic substances were removed during the first 200 minutes of aeration. As the glycol concentration was not reduced during aeration, the assumption was made that the toxic components associated with the inhibitor package were being stripped from the solution during aeration. Ethylene glycol, the major component

TABLE 34

APPROXIMATE 96-HR LC50'S FOR RAINBOW TROUT

EXPOSED TO DSS

DATE	APPROXIMATE 96-HR LC50
Feb. 13	5.6 mg/1
Feb. 27	5.1 mg/1
March 19	5.4 mg/1
April 10*	4.2 mg/1
April 27	5.0 mg/1

* -- This group of fish was exposed to reagent grade sodium lauryl sulphate while all other groups were exposed to technical grade dodecyl sodium sulphate. Subsequent laboratory tests revealed that the reagent grade sodium lauryl sulphate was more toxic than technical grade dodecyl sodium sulphate.

of the de-icing fluid, was much less toxic than either of the de-icing fluids, verifying the fact that the major contributor of toxicity was the inhibitor package.

In an activated sludge process treating de-icing fluids, mixed liquor aeration would greatly reduce the toxicity. In addition, there may be biological degradation of the specific components contributing to the toxicity. As a result the extended aeration process required to treat the de-icer and sewage mixture at low temperatures should provide exceptionally good toxicity removal.

The bioassay results for the Dow and UCAR de-icer can be used to show that the mortality which occurred in the effluents from the laboratory or pilot-scale reactors could not have resulted from the de-icing fluids. This can be accomplished by comparing the toxic units contributed by the de-icing fluids in the reactor effluent with presently accepted safe levels for a range of other toxicants. A toxic unit represents the concentration of toxicant divided by its 96-hr LC50. As the wastewater was aerated during treatment, the 96-hr LC50 for Dow and UCAR de-icer would be at least 12,000 mg/l (Figures 23 and 24). For the worst condition, it is necessary to assume that during treatment, there is no biological degradation of the components responsible for the toxicity. As a result, for the pilot plant treating an influent de-icer concentration of 460 mg/l, 0.04 toxic units would be the maximum level that the de-icer would contribute. Similar calculations were made for the laboratory-scale reactors discharging toxic effluents. Since various influent de-icer fluid concentrations were used for the bench-scale biological treatment program, the range of toxic units contributed by the de-icer alone for the untreated waste was 0.02 to 0.08.

Although various pollutants have different characteristics, Sprague (6) reported that the safe level tends to fall within the range of 0.01 to 0.05 of the lethal level based on chronic, sublethal and cumulative toxicity. The majority of the results from the laboratory and pilot-scale reactors are well within this range of safe levels, and thus, it was considered that the de-icing fluids were not responsible for the toxicity which existed in many of the reactor effluents.

Following the previous reasoning it is concluded that the only other toxicity source was the raw sewage from the Burlington Skyway Treatment Plant which contained considerable quantities of industrial wastes. This was verified during the period of May 29 to June 15 when the pilot plant was operated without de-icer addition. The results of the three bioassays (Table 33) conducted during this period proved that the effluent was extremely toxic.

Information has been presented in the literature which verifies that the effluent from sewage treatment plants receiving mixtures of domestic and industrial wastewater can be toxic. Lloyd et al (7) conducted bioassays to determine the toxicity of eight sewage treatment plants and found each effluent to be toxic. It was demonstrated that low levels of ammonia, phenol, heavy metals and perhaps cyanide were responsible for most of the toxicity in these sewage plant effluents.

During laboratory and pilot-scale operation, effluent samples which were both toxic and non-toxic were analyzed for heavy metals. The results presented in Tables B-2 and B-3 show that there is a considerable fluctuation in the metal content of the treated wastewater. Toxicity of the mixed domestic-industrial sewage could not be related to the variable metal concentrations. In many instances, the metal levels were higher in non-toxic effluents than in toxic effluents.

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APPENDIX A

ANALYTICAL RESULTS FROM LABORATORY
AND
PILOT-SCALE ACTIVATED SLUDGE SYSTEMS

TABLE A-1

ANALYTICAL RESULTS, EXTENDED AERATION (10°C)

DATE	Inf. BOD (mg/l)	Loading: 0.13 kg BOD/kg MLSS.day				Loading: 0.06 kg BOD/kg MLSS.day			
		Eff. BOD (mg/l)	Eff. S.S. (mg/l)	MLSS (mg/l)	SVI (ml/g)	Eff. BOD (mg/l)	Eff. S.S. (mg/l)	MLSS (mg/l)	SVI (ml/g)
DOW DE-ICER									
pril 5	359	--	17	6100	165	--	12	5900	170
" 6	332	--	8	5500	84	<15	5	5400	80
" 7	--	--	--	5600	--	--	--	5400	--
" 8	--	--	--	5600	--	--	--	5400	--
" 9	291	22	23	5600	133	24	25	4800	90
" 10	382	16	9	5600	131	13	15	5200	98
" 11	339	10	18	5700	112	12	30	4800	124
" 12	469	12	11	4900	110	13	27	5300	97
" 13	361	7	48	6000	131	5	27	5300	101
" 14	193	13	--	5000	--	13	--	5700	--
" 15	--	--	--	5100	--	--	--	5100	--
" 16	--	--	39	4900	127	--	54	5000	100
" 17	369	17	47	4600	138	9	34	5300	105
" 18	311	7	29	4300	140	10	48	5300	106
" 19	313	9	26	4000	148	8	25	5100	110
" 20	304	13	--	--	--	7	--	--	--
UCAR DE-ICER									
pril 5	380	--	18	5400	184	--	12	5500	211
" 6	333	--	9	4600	89	--	6	5600	70
" 7	--	--	--	5100	--	--	--	4800	--
" 8	--	--	--	5100	--	--	--	5000	--
" 9	311	24	12	5300	129	24	9	4600	87
" 10	340	16	10	5400	132	13	6	4600	99
" 11	363	10	19	6000	107	14	42	4700	--
" 12	454	16	41	4900	110	62	19	4800	96
" 13	335	6	39	5200	119	6	51	4900	99
" 14	171	14	--	5100	--	12	--	5000	--
" 15	--	--	--	5000	--	--	--	5000	--
" 16	--	--	35	5600	137	--	11	5300	95
" 17	312	15	27	4800	133	5	9	5400	97
" 18	296	5	37	5000	137	10	17	5700	102
" 19	338	10	28	4900	148	9	25	5400	97
" 20	239	12	--	--	--	5	--	--	--

TABLE A-3

ANALYTICAL RESULTS, EXTENDED AERATION (2°C)

DOW DE-ICER

DATE	Inf. BOD (mg/l)	Loading: 0.16 kg BOD/kg MLSS.day Eff. BOD (mg/l)	Eff. S.S. (mg/l)	MLSS (mg/l)	SVI (ml/g)	Loading: 0.07 kg BOD/kg MLSS.day Eff. BOD mg/l	Eff. S.S. (mg/l)	MLSS (mg/l)	SVI (ml/g)
May 7	402	8	14	4000	207	8	23	5700	106
" 8	284	10	23	4200	181	11	30	5800	129
" 9	345	10	16	5400	181	31	40	5200	131
" 10	298	8	15	4900	--	11	28	4700	--
" 11	346	29	46	4100	160	13	15	4600	116
" 14	319	6	8	4000	188	8	17	4900	153
" 15	399	7	11	4300	302	4	14	4800	117
" 16	391	9	18	4100	174	7	12	4500	147
" 17	325	11	21	4300	167	10	29	4800	141
" 18	354	19	24	4300	178	18	20	4800	162

UCAR DE-ICER

DATE	Inf. BOD (mg/l)	Loading: 0.16 kg BOD/kg MLSS.day Eff. BOD (mg/l)	Eff. S.S. (mg/l)	MLSS (mg/l)	SVI (ml/g)	Loading: 0.07 kg BOD/kg MLSS.day Eff. BOD mg/l	Eff. S.S. (mg/l)	MLSS (mg/l)	SVI (ml/g)
May 7	402	12	28	4500	149	13	38	5500	94
" 8	261	8	22	4700	171	19	--	5100	179
" 9	330	18	44	5800	150	15	24	5500	145
" 10	377	18	--	5300	--	11	21	4900	--
" 11	350	11	19	4800	164	13	33	5000	136
" 14	414	7	17	4700	158	8	19	3900	188
" 15	319	6	23	5100	160	8	16	4200	180
" 16	312	6	12	4800	146	9	22	3900	170
" 17	308	9	19	4800	148	8	21	3700	174
" 18	300	19	26	4800	161	17	23	3800	176

TABLE A-4

ANALYTICAL RESULTS, SINGLE-STAGE REACTOR OPERATED AT 20°C

DATE	Inf. BOD (mg/l)	Loading: 0.76 kg BOD/kg MLSS.day				Loading: 0.29 kg BOD/kg MLSS.day				Loading: 0.12 kg BOD/kg MLSS.day			
		Eff. BOD (mg/l)	Eff. S.S. (mg/l)	MLSS (mg/l)	SVI (ml/g)	Eff. BOD (mg/l)	Eff. S.S. (mg/l)	MLSS (mg/l)	SVI (ml/g)	Eff. BOD (mg/l)	Eff. S.S. (mg/l)	MLSS (mg/l)	SVI (ml/g)
Apr. 24	391	80	15	3600	--	12	14	6100	135	8	17	3200	94
" 25	384	--	--	--	--	6	3	6200	174	6	9	3100	103
" 26	374	162	30	2000	104	7	8	5300	229	6	9	3100	107
" 27	435	16	11	4100	239	4	4	4300	171	5	18	3000	107
" 30	369	141	35	4900	205	4	13	5200	149	7	10	3100	106
May 1	392	34	24	4500	411	6	1	5300	165	5	8	3500	110
" 2	280	27	24	3100	426	5	6	3800	188	5	4	2400	119
" 3	494	25	24	5000	1250	23	10	4100	152	4	4	3400	105
" 4	441	22	22	2300	312	3	--	4000	137	4	1	3300	106

TABLE A-5

ANALYTICAL RESULTS*, EXTENDED AERATION PILOT PLANT

DATE	DAY NO.	AERATION TANK				BOD_5		TOC		SS		SVI	NOTES***
		MLSS	pH	TEMP	DO**	INF	EFF	INF	EFF	INF	EFF		
Mar. 7	1	3200	7.3	10	3.1/5.6							41	
" 8	2	4500	7.0	10	1.2/1.2	410	80	204	61		18	86	
" 9	3	3900	7.4	10	1.6/4.0	372	33	221	67.4	136	8	96	
" 10	4							190	13.8				
" 11	5							145	10.1				(1)
" 12	6	5600	7.0	10	0.8/0.8	840	11	357	77	121	10	177	
" 13	7	5800	7.3	10	0.0/0.0	530	6	288	12.1	188	4	143	(2)
" 14	8	5400	7.3	10	0.3/2.1					66	10	339	(3)
" 15	9	5400	7.2	10	0.0/1.9	357	9	93	9.9		9	259	
" 16	10	5000	7.3	10	0.0/2.9			730	8.0		8	268	
" 17	11							198	14				
" 18	12												
" 19	13	4500	7.3	7.5	0.1/2.0	398	9	234	9.0			176	
" 20	14	4300	7.2	7.5	0.0/2.6	52	6	226	10	121	10	162	
" 21	15	4300	7.1	8	0.1/2.4	375	7	186	8.1	642	4	195	
" 22	16		7.0	9	1.0/2.9	581	6	217	8.4	314	3		
" 23	17	4000		9	4.9/7.4			226	116	230	3	214	(4)
" 24	18							232	10.0				
" 25	19					458	7	215	8.6				
" 26	20									316	3		
" 27	21					768	73						(5)
" 28	22	3900	7.0	11	0.0/0.1	512	42	330	31	320	9	269	(6)
" 29	23									210	6		
" 30	24							432	9.3				(7)
" 31	25							394	12.1				(8)
Apr. 1	26					1019	12	543	9.2				
" 2	27	4000	7.0	12	0.0/3.7			467	17	162	9	343	
" 3	28	3700				829	30	417	20.8	490	47	359	
" 4	29	3300	7.3	12	0.2/2.2	790	76	437	14.5	118	25	364	(9)
" 5	30	3200	6.5	9.5	1.7/4.6	588	11	308	11	112	4	365	
" 6	31	3100	7.2	10	4.1/6.8			60	10.5	126	8	539	(10)
" 7	32							225	10.8				
" 8	33					446	7	157	11.6				
" 9	34	2800	7.1	10	4.4/7.6					174	5	545	
" 10	35	3000	7.2	11	3.4/8.1	577	13	244	15.6			402	
" 11	36	3100	7.2	10	4.8/8.1					344	14	291	
" 12	37	3400	7.2	10	3.2/6.9	638	11	249	11.3	296	14	280	
" 13	38	3500	7.3	10	3.2/7.4	517	8	234	14.5	206	9	320	
" 14	39							237	13				
" 15	40					475	8	207	13				
" 16	41	3800	7.1	12.5	1.0/4.9	483	9	225	15	240	10	206	
" 17	42	3900	7.1	13	1.2/5.6	502	7	216	13.6	534	11	199	
" 18	43	4000	7.1	13	1.6/5.9	426	9	196	13.1	428	13	134	
" 19	44	3600	7.2	13.5	1.0/4.6			257	13.1	372	18	162	
" 20	45							130	32.5				

(cont'd.)

TABLE A-5

(cont'd.)

ANALYTICAL RESULTS*, EXTENDED AERATION PILOT PLANT

DATE	DAY NO.	AERATION TANK				BOD_5*		TOC*		SS*		SVI	NOTES***
		MLSS	pH	TEMP	DO**	INF	EFF	INF	EFF	INF	EFF		
Apr. 21	46							243	14.9				
" 22	47					407	15	479	24.2				
" 23	48					521	13	212	13.7				
" 24	49	3300	7.1	13	3.2/7.4	593	10	211	12.7	324	22	183	
" 25	50	3400	7.1	13	2.8/6.6	395	11	219	13.2	854	14	138	
" 26	51	3200	7.2	12.5	3.3/7.2	456	23	214	14.3	152	18	121	
" 27	52	2800	7.1	13	3.8/7.4					452	58		
" 28	53							219	12.6				
" 29	54					392	9	212	9.7				
" 30	55	3400	7.1	13	1.6/3.2	447	22	210	11.0	194	25	118	
May 1	56	3100	7.1	13	2.0/3.8	449	12	212	9.0	204	71	115	
" 2	57	3200	7.1	13.5	2.8/7.4	434	14	150	9.9	208	42	110	
" 3	58	3000	7.2	13	4.2/7.4	593	16	205	10.3	176	36	102	
" 4	59	3200	7.1	13	2.6/7.2					188	22	99	
" 5	60							240	10.1				
" 6	61					466	9	194	9.7				

* -- Units for BOD_5, DO, TOC, SS & MLSS are mg/1, for SVI ml/g and Temp °C.

** -- Dissolved oxygen measurements recorded were measured once a day with the first reading from the first aeration tank compartment and the second from the final compartment of the six-compartment aeration tank.

*** -- Notes (1) to (10) --

(1) - Raw sewage pump off for 15 hrs.;de-icer pump in operation.

(2) - Insufficient DO; compressor operating at maximum output.

(3) - De-icer pump failed during night; unit re-started at noon.

(4) - Two air compressors placed in operation to increase DO.

(5) - De-icer feed rate doubled.

(6) - Two air compressors would not operate on a common header; units cut out on motor over load.

(7) - Air supply header re-piped so each compressor supplies air to one-half of the aeration tank.

(8) - Supplementary nutrient addition initiated.

(9) - De-icer feed rate decreased to .74 ml/min.

(10) - Nutrient addition terminated.

APPENDIX B

CHEMICAL AND PHYSICAL CHARACTERISTICS OF MUNICIPAL WATER AND PROCESS EFFLUENTS

TABLE B-1

CHEMICAL AND PHYSICAL CHARACTERISTICS of DECHLORINATED MUNICIPAL WATER*

Temperature	10 ± 1°C
pH	7.4
Total Chlorine	10 μg/l
Ca	62 mg/l
Mg	7.8 mg/l
Al	124 μg/l
Cd	<1 μg/l
Cr	2.5 μg/l
Cu	11.9 μg/l
Fe	43.5 μg/l
Pb	5.7 μg/l
Ni	6.5 μg/l
Zn	47.4 μg/l
Total Hardness	190 mg/l as $CaCO_3$

* -- Results are an average of 30 samples collected over the 6-month experimental period.

TABLE B-2

CONCENTRATION OF METALS IN EFFLUENT FROM EXTENDED AERATION REACTORS

TEST NO.	RATE (ml/min)	DE-ICER	TEMP °C	Al (μg/l)	Ca (mg/l)	Cd (μg/l)	Cr (μg/l)	Cu (μg/l)	Fe (μg/l)	Mn (μg/l)	Ni (μg/l)	Pb (μg/l)	Zn (μg/l)	Mg (μg/l)
1a*	70	Dow	10	545	--	<1	<30	37	380	37	<10	180	390	--
1b	35	Dow	10	382	--	<1	380	37	6,500	35	310	50	100	--
1c*	70	UCAR	10	263	--	<1	110	18	1,440	15	90	140	81	--
1d	35	UCAR	10	100	--	<1	50	23	260	13	20	95	152	--
2a*	70	Dow	10	1,670	--	<1	50	--	590	112	10	15	--	--
2b	35	Dow	10	382	--	<1	<30	--	70	14	10	<10	--	--
2c*	70	UCAR	10	220	--	<1	<30	--	90	14	<10	<10	--	--
2d	35	UCAR	10	100	--	<1	<30	--	50	10	<10	<10	--	--
3a	70	Dow	5	30	87	<10	<10	13	70	<5	<10	110	60	20
3b	35	Dow	5	30	80	<10	<10	16	60	<5	<10	140	35	21
3c	70	UCAR	5	100	90	<10	<10	11	55	<5	<10	80	59	20
3d	35	UCAR	5	305	93	<10	<10	12	210	40	<10	190	236	22

Toxic effluents marked with * ; other samples non-toxic.

Test No. 1 -- Samples collected 19/4/73

Test No. 2 -- Samples collected 16/4/73

Test No. 3 -- Samples collected 7/5/73

Samples were filtered through 0.45 micron filter paper.

TABLE B-3

CONCENTRATION OF METALS IN EFFLUENT FROM EXTENDED AERATION PILOT PLANT

DATE	Al µg/1	Ca mg/1	Cd µg/1	Cr µg/1	Cu µg/1	Fe µg/1	Mn µg/1	Ni µg/1	Pb µg/1	Zn µg/1	Mg µg/1
May 10	30	72	<10	<10	14	70	15	<10	<20	132	15.7
May 11	35	63.9	<10	<10	11	70	15	<10	<20	96	15.9
May 16	135	72.5	12	25	21	207	60	20	63	563	16.2
May 17	205	79.6	<10	25	39	307	30	25	68	310	15.6
May 18	130	69.8	<10	90	16	1630	12	35	<20	139	15.1
May 19	25	55	<10	20	6	92	<5	<10	<20	123	15.3
May 20	<20	76.8	20	<10	6	115	<5	15	<20	160	15.7
May 21	<20	74	12	<10	11	65	7	<10	<20	135	16.2
May 22	65	83.9	<10	<10	8	40	<5	<10	<20	89	16.2
May 23	65	82.8	25	30	24	231	70	20	40	565	16.5
May 25	65	68.0	20	<10	104	363	58	200	<20	214	15.9
May 29	63	72.6	20	<10	35	164	30	170	36	184	15.5
May 30	65	70	38	25	23	297	30	45	56	560	15.6
May 31	35	69	25	20	33	280	30	130	<20	172	15.5
June 1	80	72	20	<10	32	264	26	100	<20	247	16.2

Total hardness - 250 mg/1 as $CaCO_3$

pH - 7.3 to 7.9

De-icer added from May 10 to May 23

No de-icer added from May 25 to June 1

Samples were filtered through 0.45 micron filter paper.