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"CABOS" - A New Wastewater Treatment System for Vessels

Technology Development
Report EPS 4-WP-76-2

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"CABOS" - A NEW WASTEWATER TREATMENT SYSTEM FOR VESSELS

Developed under contract
for Task 7
Canada/United States Agreement on
Great Lakes Water Quality

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ABSTRACT

A system was designed for the treatment of black and grey water from commercial vessels to meet effluent quality requirements for undiluted discharge into the Great Lakes and other water bodies. Laboratory units and pilot plant models were constructed at the Ontario Research Foundation and tested under simulated shipboard conditions. The results of these tests were used in the design of a prototype unit which was constructed and installed aboard the SS John A. France, a bulk carrier owned and operated by Scott Misener Steamships Limited. The system incorporates flow equalization, carbon-adsorption bio-oxidation, clarification, multimedia filtration, and ozonation. It is conveniently called the CABOS system. Operations such as cleaning of the clarifier and backwashing of the filter are controlled automatically. Field testing and system evaluation under actual shipboard conditions will be undertaken during the 1975 sailing season.

RÉSUMÉ

Une unité de traitement des eaux usées de toilettes et des eaux usées totales des navires commerciaux a été conçue afin de satisfaire aux exigences de qualité des effluents non dilués, déversés dans les Grands lacs et autres étendues d'eau. Des unités de laboratoire et des unités pilotes ont été assemblées à l'Ontario Research Foundation et mises à l'essai dans des conditions simulant celles qui prévalent à bord des navires. Ces essais ont servi à la conception d'un prototype qui a été construit et installé à bord du SS John A. France, transporteur de marchandises en vrac appartenant à la Scott Misener Steamships Limited et exploité par celle-u. Cette unité, communément appelée CABOS, fait appel à la régularisation du débit, à l'adsorbtion sur charbon, à l'oxydation biologique, à la filtration sur milieux hétérogènes, et à l'ozonation. Certaines opérations comme le nettoyage du clarificateur et le lavage du filtre à contre courant sont commandées automatiquement. Les essais et l'évaluation du système en conditions réelles seront effectués pendant la saison de navigation de 1975.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

LIST OF FIGURES

LIST OF TABLES

SUMMARY AND CONCLUSIONS

1. Laboratory Studies - Two small sewage treatment units were built at the Ontario Research Foundation, and studies made to determine the best type of equipment for use on board ship. Tests were run with domestic sewage, with shock loadings of 4-6 times the biochemical oxygen demand (BOD) level of domestic sewage and, in the case of one unit, the clarifier was subjected to motion and vibration, simulating conditions on board ship.

Results showed that multizone horizontal aeration tanks charged with activated carbon would be expected to give the high treatment efficiency required in the removal of organics, suspended solids, turbidity and ammonia.

2. In-house Testing - Based on the results obtained with the small scale units a larger system (1.45 Igal/min. average flow) was designed, utilizing activated carbon. This is now called the carbon-adsorption biological-oxidation system (CABOS). Such a system is capable of handling variable food to microorganisms ratio (F/M) loadings for the following reasons:

(a) Organic compounds are adsorbed on activated carbon at high F/M loadings and released at low F/M loadings.
(b) When BOD levels are low the released organics and insoluble organics are biologically absorbed.

High conversion rates and low rates of solids build-up were obtained in the reactor even when raw sewage was used. Treatment efficiencies of over 99% for BOD and ammonia removal and 97% for suspended solids (SS) and turbidity removal were achieved once the process became stabilized. The amount of sludge wasted during 102 days of operation, with an applied BOD of 309 lb, was 41.24 lb (13.6%) and the total sludge production was 61.8 lb (20.02%).

The overall performance of the full scale pilot plant was achieved with an average F/M loading of 0.14/day at an average detention time of 4.6 hours. Since higher loadings and shorter detention times produced effluents with similar quality, it is felt that optimal conditions can be obtained with shorter detention times.

There was an apparently improved removal of refractory organics in the aeration tank with time, and this also occurred in the multimedia filter. After 3 months filter operation total organic carbon (TOC) and dissolved organic carbon (DOC) in the effluent dropped to 5 and 4 mg/1, respectively.

The use of an air-water backwashing technique reduced the volume of backwash water to 2/3 of that required when water alone was used.

Tests with additions of bleach and Pine-Sol showed that the latter had an adverse effect on performance, while the former had little effect at dosages which could be expected on board ship.

Some trouble with foaming in the clarifier indicated that modifications would be necessary in the design of the prototype.

Disinfection with ozone, using a vortex distribution system, gave an effluent with an average total coliform membrane filter count of 20/100 ml based on 12 tests.

3. Wastewater Survey - A preliminary survey of wastewater was carried out on board the SS John A. France, a bulk carrier (Figure 1) owned and operated by Scott Misener Steamships Limited, St. Catharines (SMSS). The data obtained showed that flow rates of wastewater were much lower than expected, but the concentration of pollutants was much higher and varied over a wide range. Toilet wastewater flow was 14 Igpcd and total combined wastewater flow was 36.5 Igpcd. The combined wastewater BOD_5 ranged from 1160 to 2200 mg/1 and 385 to 1400 mg/1, respectively, and suspended solids from 920 to 1300 mg/1 and 250 to 1160 mg/1, respectively.

4. Shipboard Unit - Based on the Results of the laboratory and in-house testing, a shipboard unit was designed by ORF. Process equipment was provided by the Crown, and the tanks and piping were supplied by Scott Misener (SMSS). The total system was installed on the SMSS ship, the SS John A. France.

Automatic controls for the surge tank, clarifier (cleaning, foam and scum removal) and multimedia filter (backwashing) were also provided.

FIGURE 1. THE SS JOHN A. FRANCE

Mechanical and hydraulic testing showed that the installed equipment was mechanically and hydraulically sound and that the automatic controls functioned satisfactorily. Noise from the blower necessitated the design and installation of additional noise abatement equipment.

1. INTRODUCTION

1.1 General

During the period August 1973-August 1974, a prototype Carbon Adsorption Bio-oxidation system (CABOS) for shipboard waste treatment was developed. The laboratory studies, in-house pilot plant testing, prototype design and installation on the SS John A. France were carried out under Contracts OSR-3-0123 and OSS-3-0303 awarded by the Department of Supply and Services on behalf of the Technology Development Branch, Water Pollution Control Directorate, Department of the Environment, Ottawa, as part of the Vessels Waste Program under the Canada-US Agreement on Great Lakes Water Quality.

The provision of self-contained sewage systems independent of shore facilities is one method of protecting our coastal waters (ocean and inland lakes) from shipboard sewage pollution. In designing such systems various unusual factors must be taken into account.

(a) BOD and suspended solids may vary over a wide range.
(b) The equipment should be capable of intermittent operation without extensive preparation and maintenance.
(c) The treatment processes must function effectively under conditions of ship motion and vibration.
(d) The available space may be limited.
(e) Dangerous gases, obnoxious odours, and noises should be absent.
(f) Most of the operations should be automatic and those which are not should be simple.

At the time of first discussions on the project, requirements for the effluent water were:

BOD_5	<50 mg/l
SS	<50 mg/l
Total Coliform Count	<240/100 ml

On this basis it was planned to develop a suitable unit for a 30-man crew to be installed on board a suitable ship.

1.2 Development Work Program

There were to be six major activities under the program: laboratory studies; in-house pilot plant testing; ship selection and survey; design of the CABOS prototype; installation; and, field testing.

(i) Laboratory studies including evaluation of over-all performance and efficiency, and investigation of those factors which would be liable to affect process stability and treatment efficiency of the units.

(ii) In-house pilot plant testing of a full scale unit including development work, installation, mechanical testing, and start-up of the process followed by short-run and long-run tests.

(iii) After selection of a suitable ship for installation and testing of a prototype unit, a survey of the vessel to provide data for use in the design of the prototype treatment unit.

(iv) Design and preparation of drawings of the final CABOS unit including design of the control system and automation.

(v) Installation of the prototype aboard the ship.

(vi) Field testing of the prototype in sufficient detail to facilitate marketing of the system.*

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* Mechanical and hydraulic testing were completed during the period covered by this report, but it was not possible to start functional testing before the end of the shipping season.

2. LABORATORY STUDIES

Laboratory studies of the biological oxidation-carbon adsorption process for shipboard application commenced in August 1973. They were directed to the development of a type of aeration tank and clarifier which would provide an effluent quality meeting proposed standards (BOD-50 mg/1, SS-50 mg/1) with reliable operation under shipboard conditions.

Two small scale units were constructed in the pilot plant facilities at the Ontario Research Foundation (ORF), and used to study the effects of variable loading, toxic effects, motion and vibration.

2.1 Equipment and Laboratory Treatment System

2.1.1 Equipment

Two types of aeration tank and two types of clarifier, both capable of several modifications, were developed and tested.

The first aeration tank (Unit A) was divided into 17 narrow chambers by plates arranged to provide plug flow of sewage. The second aeration tank (Unit B) was divided into six chambers. Both tanks had an operating volume of 85 litres (3 cu ft).

The first clarifier was of the inclined plate type and was capable of modification in shape, incline of plates, and feed location. The second was a vertical clarifier also with provision for either central or peripheral feed.

2.2.2 Treatment process

The two units described above were installed in parallel and tested on a continuous flow of domestic sewage. Each treatment system consisted of:

(a) screening of raw sewage to remove coarse suspended solids (later discontinued);

(b) biological oxidation combined with activated carbon adsorption; and,

(c) sludge separation by clarification.

Incoming raw sewage, after passing through the screen, entered the horizontal multizone aeration tanks where the organic matter in solution was adsorbed on activated carbon and activated sludge, and was degraded by microorganisms. The mixed liquor flowed continuously to the clarifiers and the separated sludge was returned by air lift to the aeration tanks in the ratio of 1:1 to 1:8 compared to the feed flow.

Polishing of the secondary effluent was not investigated under laboratory conditions. This was done later, however, in the provisional full scale unit in the pilot plant building at ORF.

2.2 Operational Procedure and Conditions

The design and operation of the two units, A and B, were based on the data supplied in Table 1.

TABLE 1 DESIGN BASIS FOR LABORATORY TEST UNITS

Parameter		Experimental Systems
Average Feed Rate	(Igpd)	83
Hydraulic Volume	(I gal)	18.5
Average Detention Time	(hr)	5.2
BOD/MLSS	(gr/gr/day)	0.25*
		0.1**

* Loading 0.25 designed for increased BOD in feed.
** Loading 0.1 designed for domestic sewage.

Each unit handled the equivalent of one man's waste load at an average flow rate of 0.27 l/min. Since the domestic sewage used in the investigations was much weaker than shipboard wastewater, BOD concentrations were increased by the addition of glucose and sodium glutamate (G and Na-G). During the test period sewage flows varied from 0.15 to 0.7 l/min. In 1973 screened sewage was used, but in 1974 the tests were continued with unscreened sewage. Detention times in the aeration tank averaged 5 hours, but varied from .2 to 9.4 hours during the test program.

Increased loadings and shock loadings were applied in November 1973. The dosages of G and Na-G were applied at two to four hour intervals, and the units were also operated separately under shock loading conditions.

The effect of complete interruption of feed for two to five day intervals, was studied. Such periods were folloeed by high loadings with additions of G and Na-G.

The effects of motion and vibration, simulating shipboard conditions, on the separation efficiency of the clarifier were also investigated.

Stability and performance of the two systems were studied in the presence of toxic materials in February 1974.

2.3 Sampling and Analysis

Sampling procedures for Units A and B are described in Appendix I and analytical procedures in Appendix II.

2.4 Results and Discussion (Laboratory Units A and B)

2.4.1 Overall performance of the laboratory system

Removals of organics, suspended solids, ammonia and Kjeldahl nitrogen were mostly above 90% and in some cases BOD_5 was reduced by over 98%. These high efficiencies were obtained throughout most of the test period, the only exceptions being when changes in the test program were made. It was found that Unit B gave consistently better results than Unit A, in which biological upsets occurred on several occasions. These upsets caused fine suspended solids to pass into the effluent and the concentrations of organic matter, nitrate, and phosphate in the effluent to increase. Phosphate removal in Unit B was better than in Unit A, improving after the first month's operation (see Table 2B).

Results for the whole period are summarized in Tables 2A, 2B and 3 and Figures 2 to 6. Particularly good quality effluent was obtained during December when toxicants were not applied to the system and the clarifier was under motion and vibration. Effluent of such quality is not usually obtained by the conventional activated sludge process without the addition of chemicals or the use of filtration.

TABLE 2 A TREATMENT EFFICIENCY AND MIXED LIQUOR CHARACTERISTICS Unit A

Component	Percentage (%) of Treatment Efficiency - Unit A																	
	September			October			November			December			January			February		
	Min.	Max.	Av .	Min.	Max.	Av .	Min.	Max.	Av .	Min.	Max.	Av .	Min.	Max.	Av .	Min.	Max.	Av .
Turbidity	94.9	97.6	96.6	91.6	97.8	95.3	26.8	97.2	76.8	74.4	93.8	88.2	83.7	97.3	93.4	91.0	95.2	93.4
SS	68.6	98.5	82.4	58.1	99.2	87.1	4.2	100	67.4	57.7	99.8	77.9	80.6	97.1	90.1	81.1	98.4	89.6
TOC	79.8	88.0	84.3	79.2	85.6	83.2	30.9	85.8	70.0	67.1	85.5	78.3	77.5	87.9	84.2	-60.5	91.6	70.5
DOC	56.7	75.8	68.2	63.8	78.6	70.4	42.1	82.8	72.7	72.6	80.1	75.9	60.7	80.4	72.3	-252.9	85.3	42.7
BOD_5	90.3	99.2	96.3	96.4	99.4	98.1	92.3	98.9	96.5	91.3	99.8	96.7	95.7	98.3	97.4	86.3	98.7	95.1
$N-NH_3$	89.3	98.7+	96.2	60.6	98+	90.4	96.6	98.3+	98.3+	94.3	97.6+	96.6	86.6	97+	96.9	88.1	97.2+	97.2
N-T. Kjeldahl	88.5	97.4	93.7	71.0	97.6	91.1	74.9	96.4	91.2	81.1	94.4	89.5	91.7	96.0	93.7	85.8	95.6	92.3
PO_4^{3-}	8.5	60.6	35.0	22.2	60.9	35.4	-73.9	54.9	23.6	23.8	63.4	44.3	-58.4	45.5	10.9	3.5	55.8	27.1
	Mixed Liquor Characteristics																	
MLSS mg/l	4,680	7,110	6,218	1,580	7,210	5,313	4,790	6,590	5,853	6,710	9,750	7,558	9,305	11,800	10,012	8,268	9,268	8,873
MLVSS mg/l	3,590	5,580	4,692	1,230	5,800	4,395	4,000	5,585	4,811	5,490	8,420	6,303	7,605	10,235	8,763	6,772	7,628	7,200
% MLVSS	65.2	79.9	75.4	77	98.1	82.6	80.3	84.7	82.2	80.6	86.4	83.1	79.1	98.2	87.5	81.9	84.2	83
Sludge Volume Index (SVI)	83	137	117	90	157	128	34	101	56	39.6	70.8	48.8	66	81	73	59	77	68
Return Sludge l/min	0.8	1.1	0.93	0.23	1.78	0.86	0.75	1.83	1.36	1.66	1.9	1.84	1.1	1.8	1.5	0.9	1.1	1.0
Feed - Sewage l/min	0.4	0.7	0.57	0.18	0.38	0.27	0.18	0.4	0.24	0.22	0.37	0.27	0.14	0.29	0.2	0.1	0.19	0.15
Number of samples tested	18			30			18			18			24			33		

TABLE 2 B TREATMENT EFFICIENCY AND MIXED LIQUOR CHARACTERISTICS Unit B

Component	Percentage (%) of Treatment Efficiency - Unit B														
	October			November			December			January			February		
	Min.	Max.	Av .	Min.	Max.	Av .	Min.	Max.	Av .	Min.	Max.	Av .	Min.	Max.	Av .
Turbidity	94.8	98.0	96.4	94.0	96.8	95.6	95.4	97.9	96.5	92.7	97.7	96.3	92.8	97.9	95.4
SS	79.8	94.2	88.4	82.2	100	82.2	89.4	100	96.4	82.3	98.5	94.4	84.6	98.4	92.8
TOC	75.9	89.6	82.5	78.3	88.5	84.8	69.4	86.9	82.1	84.1	90.7	87.3	66.4	95.8	88.4
DOC	53.9	81.9	70.1	79.1	85.2	81.3	77.6	81.3	78.9	76.4	80.4	78.5	23.5	93.1	76.7
BOD_5	97.3	99.4	98.2	93.6	99.4	97.7	98.7	99.6	99.3	95.9	99.1	97.8	86.3	99.0	95.8
$N-NH_3$	71.9	97.2	87.0	91.2	98.3+	96.3	97.6+	98.1+	97.6+	92.1	96.9+	96.9	97.2+	97.2+	97.2+
N-T. Kjeldahl	81.4	95.9	90.2	91.2	97.5	95.3	94.7	96.8	96.0	89.2	97.1	94.6	93.5	98.2	94.9
PO_4^{3-}	41.1	66.7	54.3	30.2	95.6+	60.7	30.2	92.8	71.7	5.4	90.6	53.0	76.9	95.0+	88.5
	Mixed Liquor Characteristics														
MLSS mg/l	1,470	6,950	3,883	3,680	6,890	5,577	6,000	8,830	7,330	3,950	11,770	7,845	9,132	11,208	9,882
MLVSS mg/l	1,360	5,800	3,261	2,880	5,920	4,598	4,870	7,370	5,997	3,270	8,790	6,246	7,132	8,910	8,018
% MLVSS	80.4	92.5	84.9	67.6	89.7	82.2	69.4	86.5	81.7	64.7	98.1	79.6	78.9	80.8	79.7
Sludge Volume Index (SVI)	51	194	124	139	178	160	13.3	153.3	108.9	83	168	120	84	105	96
Return Sludge l/min	0.59	1.46	1.08	0.52	1.22	0.88	0.75	1.64	1.26	1.1	1.8	1.34	1.45	1.86	1.58
Feed - Sewage l/min	0.26	0.48	0.36	0.15	0.44	0.28	0.2	0.3	0.26	0.18	0.41	0.27	0.14	0.19	0.16
Number of samples tested	20			20			18			18			33		

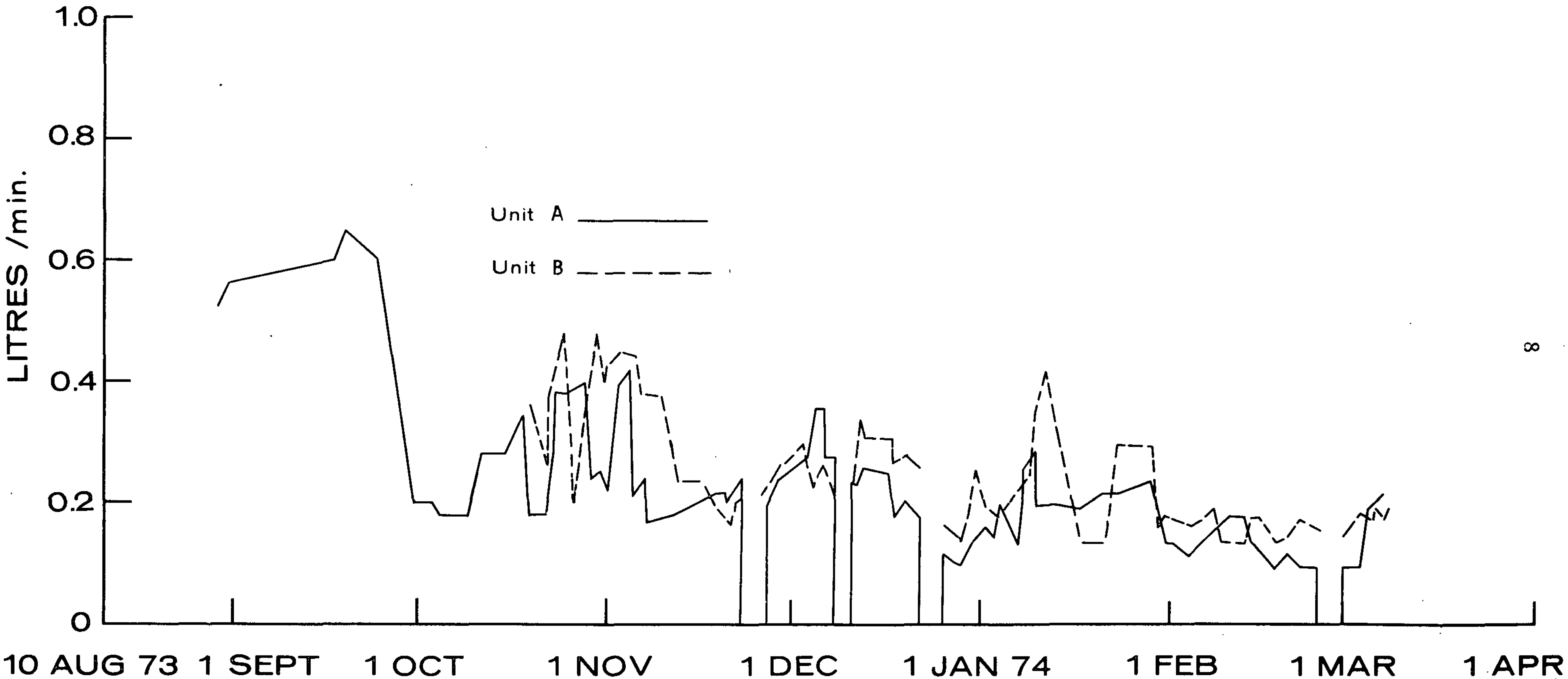


Figure 2 Flow of Sewage to Units A & B

2.4.2 Influence of various factors on treatment efficiency

2.4.2.1 Influence of loading and shock impacts on treatment efficiency.

The two test units were operated at flow rates of 0.15 to 0.7 l/min, which represent detention times of 2 to 9.4 hours. On November 16th, additions of G + Na-G (1 litre = 70 g BOD_5) were made to increase BOD loadings to values between 24 and 120 lb BOD_5/day/1000 cu ft and F/M ratios from 0.06 to 0.3/day, with shock loadings giving an F/M ratio of up to 0.6/day. As shown by the following table, shock durations were 2 to 4 hours, with total application times of 8 to 11 hours/day.

Phase I Nov. 17-Dec. 14, 1973		Phase II Dec. 14-Jan. 3, 1974	
Time of Dosage		Time of Dosage	
Time Period	Hours	Time Period	Hours
04-07	3	05-09	4
10-13	3	11-13	2
18-20	2	18-20	2
23-02	3		
Total/24 hr	11	Total/24 hr	8

The daily flows and loadings are shown in Table 3.

During this period, performance and efficiency of the units were not affected by the increased BOD. Although the activated sludge in Unit B (SVI[Sludge volume index] = 110-160) was finer and lighter than that in Unit A (SVI = 30-80), clarification of the sludge from Unit B was more effective.

2.4.2.2 Effect of interruption of food supply on treatment stability.

The possibility of the feed being interrupted for several days, due to the absence of most of the crew, made it necessary to determine if such an interruption had any effect on effluent quality.

TABLE 3. FEED (GLUCOSE + Na-GLUTAMATE) APPLIED TO UNITS A AND B

Date	Total Time* of Dosage (hr)	Unit A Dosage of Feed			Unit B Dosage of Feed			Notes
		ml/hr	ml/day	BOD_5 gr/day	ml/hr	ml/day	BOD_5 gr/day	
November 16	4	35	140	9.8	140	560	39.2	* Time (duration and daily program) is the same for Unit A and B.
" 17	11	35	385	27	140	1540	107.8	
" 20	8	43	345	24.1	140	1120	78.4	
" 21	11	43	475	33.2	140	1540	107.8	
" 22	6	43	260	18.2	140	840	58.8	
-----------Interruption in Food Supply------------								
" 28	8	43	345	24.1	140	1120	78.4	
" 29	11	43	475	33.2	140	1540	107.8	
" 30	11	43	475	33.2	140	1540	107.8	
December 1	11	43	475	33.2	140	1540	107.8	
" 2	11	43	475	33.2	140	1540	107.8	
" 3**	3	43	130	9.1	140	420	29.4	**For Unit A replaced tube in dosage pump. Capacity of pump decreased
" 3	8	90	720	50.4	90	720	50.4	
" 4	11	90	990	69.3	90	990	69.3	
" 5	11	90	990	69.3	90	990	69.3	
" 6	11	90	990	69.3	90	990	69.3	
" 7	6	90	540	37.8	90	540	37.8	
-----------Interruption in Food Supply------------								
" 12	5	90	450	31.1	90	450	31.1	
" 13	11	90	990	69.3	90	990	69.3	
" 14	11	90	990	69.3	90	990	69.3	
" 15	5	90	450	31.1	90	450	31.1	
" 15	3	140	420	29.4	140	420	78.4	
" 16	8	140	1120	78.4	140	1120	78.4	
" 17	8	140	1120	78.4	140	1120	78.4	
" 18	8	140	1120	78.4	140	1120	78.4	
" 19	8	140	1120	78.4	140	1120	78.4	
" 20	8	140	1120	78.4	140	1120	78.4	Cont'd .....

TABLE 3. (CONT'D)

Date	Total Time* of Dosage (hr)	Unit A Dosage of Feed			Unit B Dosage of Feed			Notes
		ml/hr	ml/day	BOD_5 gr/day	ml/hr	ml/day	BOD_5 gr/day	
December 21	6	140	840	58.8	140	840	58.8	*Time (duration and daily program) is the same for Unit A and B.
	-----------Interruption in Food Supply------------							
" 27	4	140	560	39.2	140	560	39.2	
" 28	6	140	840	58.8	140	840	58.8	
" 31	2	140	280	19.6	140	280	19.6	
January 2/74	4	140	560	39.2	140	560	39.2	
" 3	6	140	840	58.8	140	840	58.8	

When the feed to the units was stopped (November 23-27, December 8-11, December 22-26, 1973 and February 25-29, 1974 - see Table 3) effluent quality did not show any significant change. This is apparent from Figures 3, 4 and 5, particularly for Unit B.

Even when these interruptions were followed by applications of very high concentrations of BOD (sewage + G + Na-G to 1000 mg BOD/l) the effluents were of similar quality.

2.4.2.3 Effect of motion and vibration on effluent quality. The clarifier of Unit B was mounted on a platform capable of a rocking motion with a roll amplitude of 8-20^{o} at a frequency of 5-6 cycles/min. Vibration was supplied by attaching a small motor to the side of the clarifier. The vibration frequency was unknown, but could be characterized as even rather than intense. It was operated in this manner from the beginning of December.

Under these conditions sludge was released from the walls of the clarifier more effectively and the settled sludge appeared to be more compact than under static conditions. This was shown by the low SVI value of 139 compared to 159 for the static system.

The quality of the effluent from Unit B was at its best during December, indicating that motion and vibration did not affect treatment efficiency and reliability and may even result in some improvement.

2.4.2.4 Effect of toxic matter on the treatment process. Toxicant studies were carried out during the period January 29 - March 8, 1974. Additions of hypochlorite bleach and Pine-Sol detergent were made both separately and in combination: bleach from January 29 - February 6, Pine-Sol from February 11 - 15, and a 1:1 combination from March 1 to March 8. It should be noted that during part of this time (January 31, February 3-6 and February 11-15) the BOD loading was doubled by addition of G + Na-G.

Dosage of toxicants was equivalent to 0.2-0.5 gal per 30 men per day. One dose of Pine-Sol added approximately 94 mg TOC/l to the system.

Results of the tests are shown graphically in Figure 6.

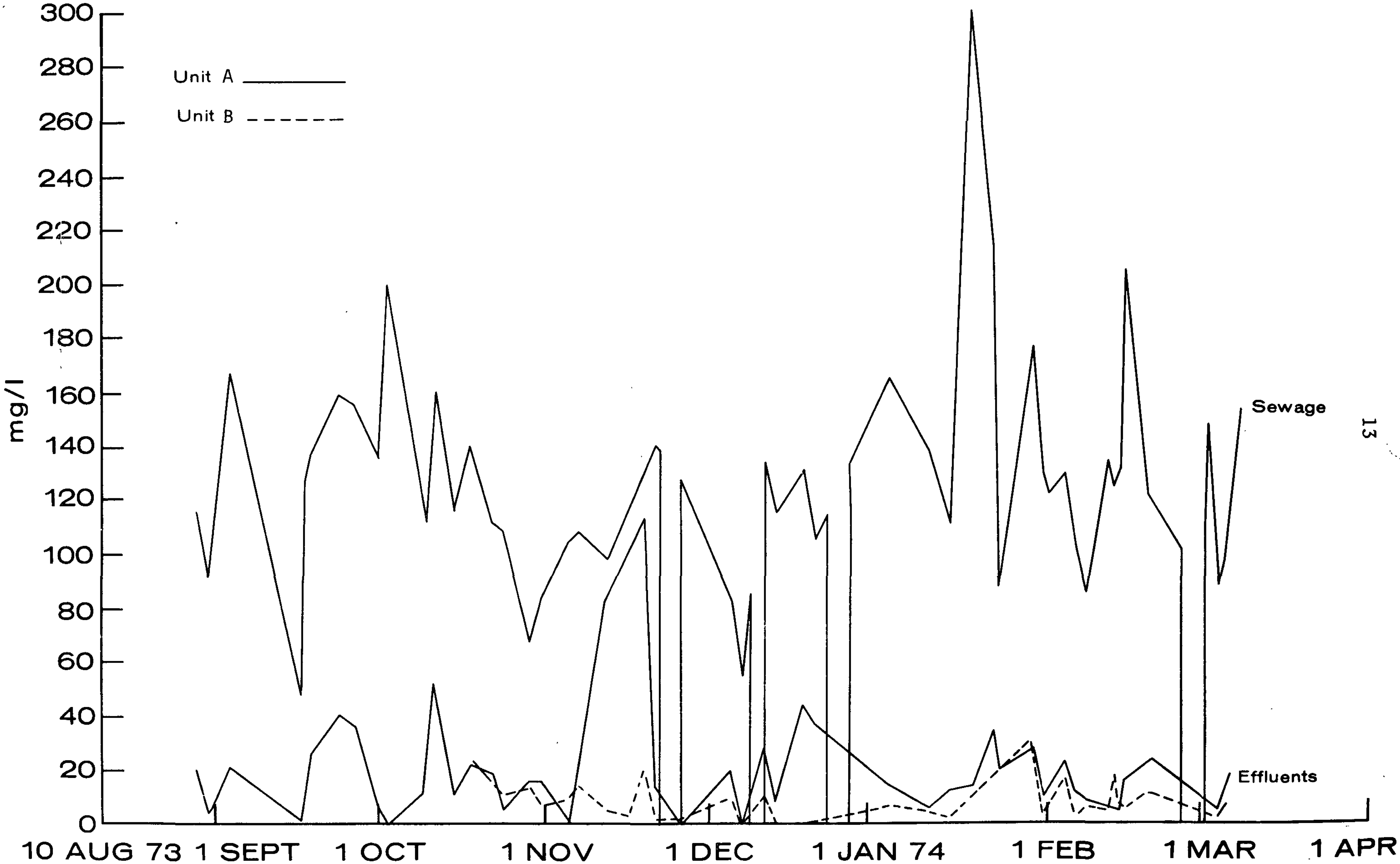
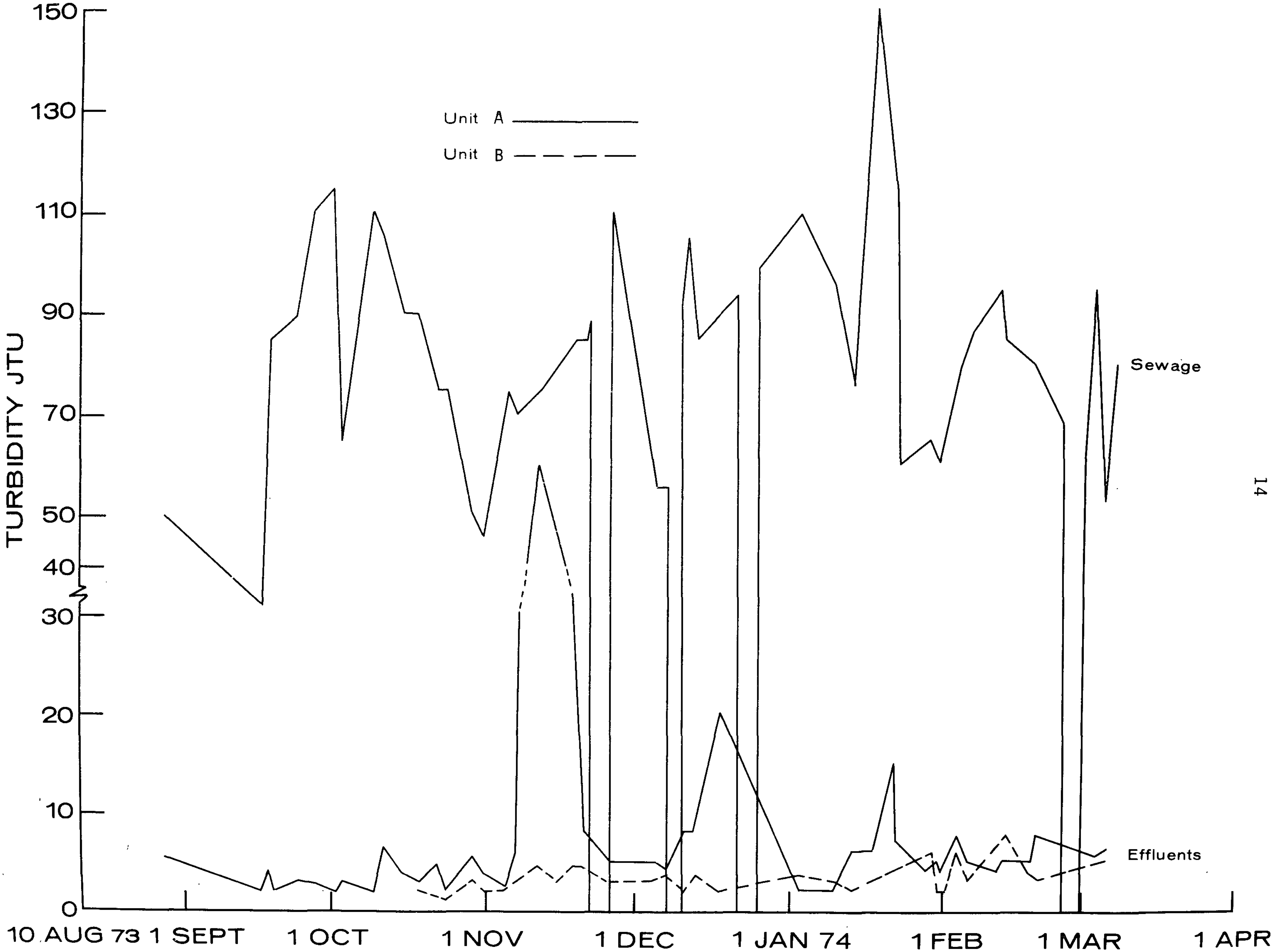


Figure 3 Suspended Solids in Sewage and Effluents- Units A & B


Unit A
Unit B
Sewage
Effluents
TURBIDITY JTU
150
130
110
90
70
50
40
30
20
10
0
10 AUG 73
1 SEPT
1 OCT
1 NOV
1 DEC
1 JAN 74
1 FEB
1 MAR
1 APR

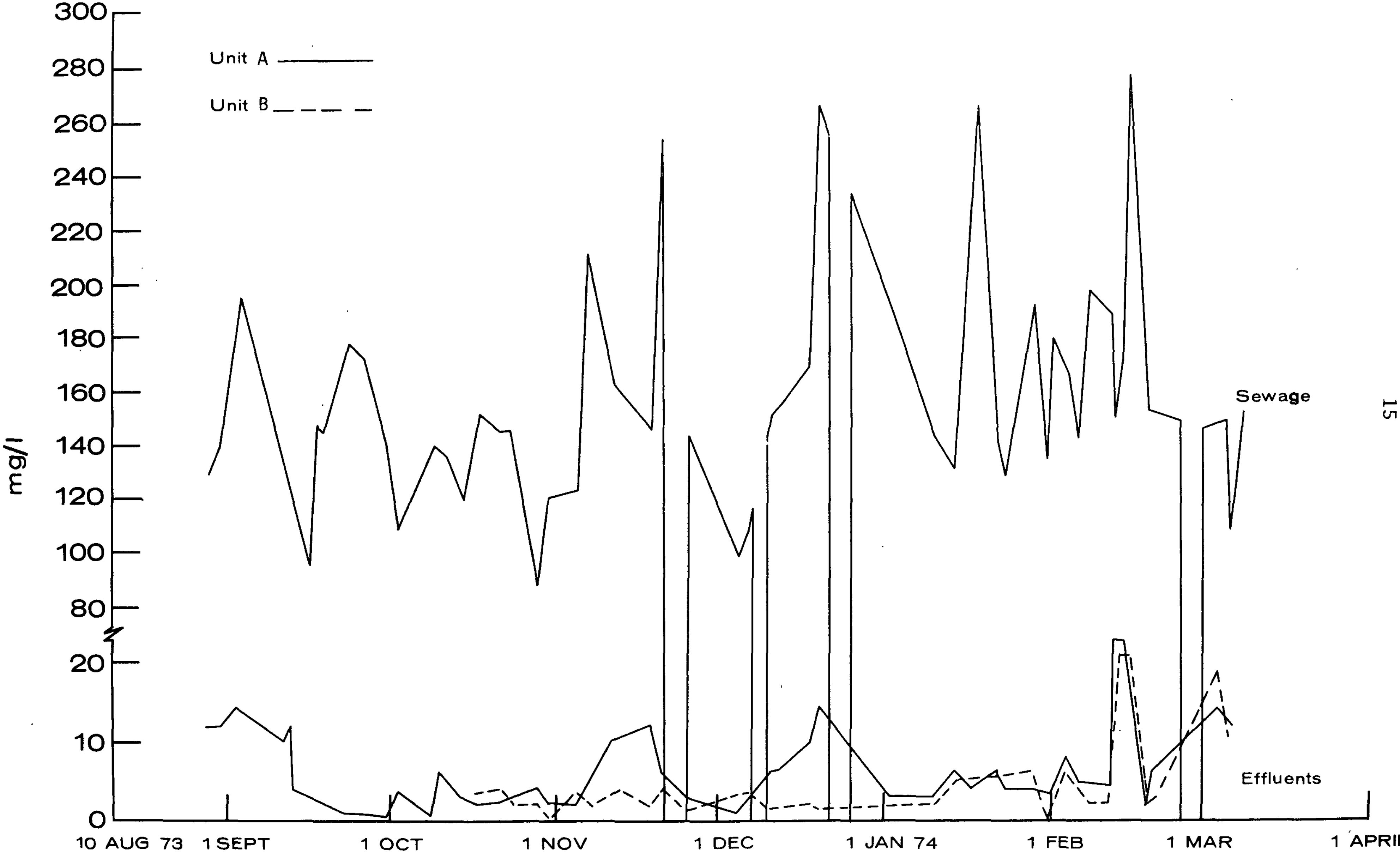


Figure 5 BOD$_5$ in Sewage and Effluents — Units A & B

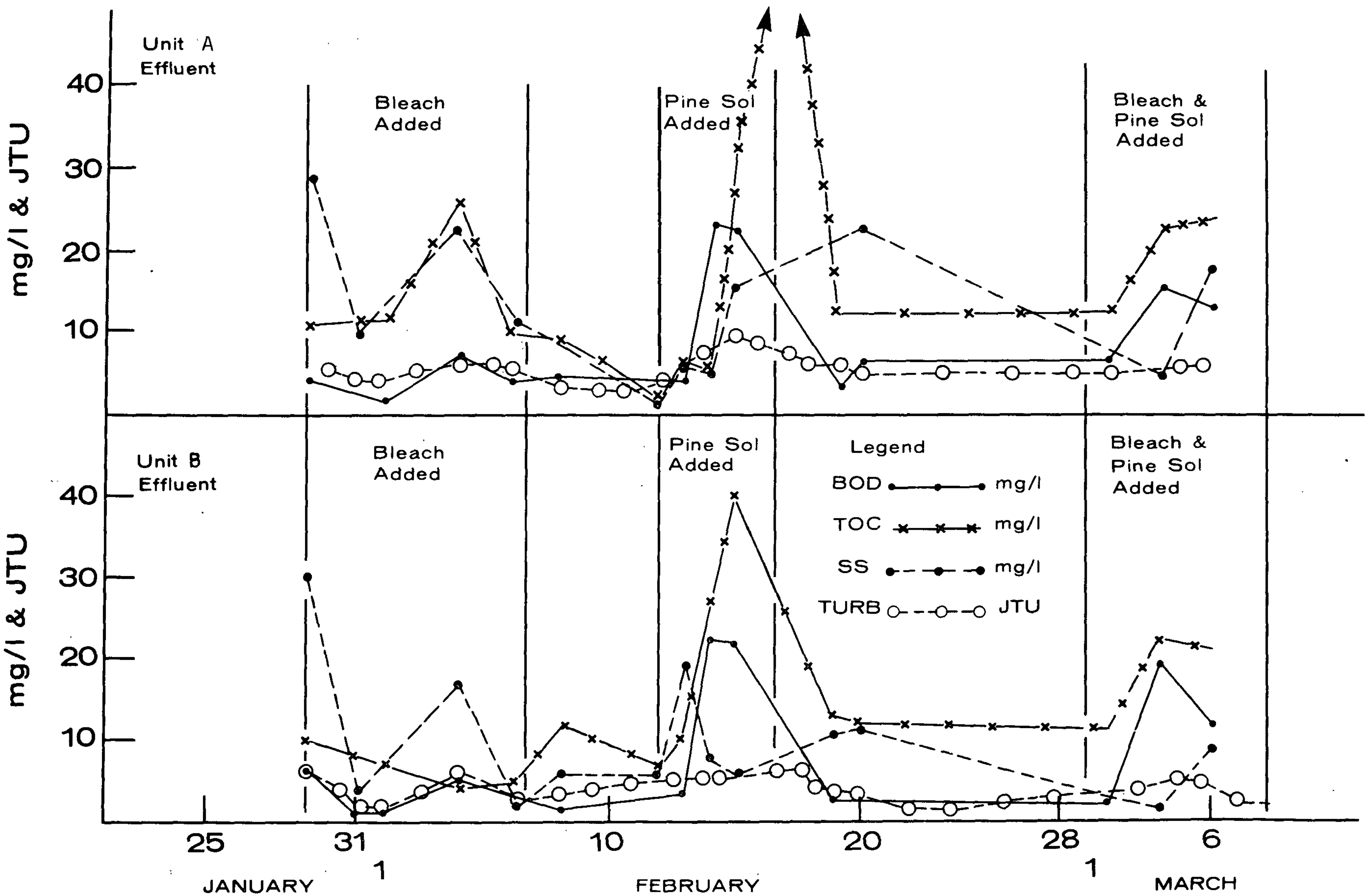


Figure 6 Effect of Toxicants on Treatment Process -Toxicity Test Units A & B

Bleach had no effect on efficiency at the 0.2-0.3 gal/30 men/day level, but slightly decreased the efficiency at the 0.6 gal/30 men/day level. Pine-Sol caused foaming for six hours after application and a substantial increase of TOC and BOD_5 in the effluent. Combinations of the two toxicants showed that bleach caused some reduction of the adverse effects of the Pine-Sol. As soon as additions were discontinued the system returned to normal.

2.5 Tank Selection for Pilot Plant Unit

In general the hydraulic conditions in Unit B allowed the system to reach a more stable adjustment than Unit A, particularly under adverse conditions, such as the presence of toxic materials, motion, and vibration. These differences are shown in Tables 2A, 2B and 3 and Figures 2 to 6 and led to the choice of Unit B as the basis for design of the pilot plant unit.

3. IN-HOUSE PILOT PLANT TESTING PROGRAM

As a result of the laboratory studies which showed that Unit B was superior to Unit A, the former type of system was used as a basis for the design of the full scale unit for pilot plant testing and for the prototype unit to be placed on board ship.

Work on the pilot plant took place in four stages:

(i) Design of the treatment system and individual units; preparation of drawing and equipment specifications.

(ii) Erection and installation of the system.

(iii) Start-up of the process without seeding to establish the system's stability under operating conditions.

(iv) Short-run and long-run testing programs.

Design of the clarifier was influenced by the need to withstand motion and vibration and to remove scum and foam before the secondary effluent entered the multimedia filter.

The filtration and disinfection units were designed to provide simple and reliable operation and storage of clean water for backwash of the filter, defoaming sprays, and cleaning of the clarifier.

3.1 Equipment and Pilot Plant Treatment System

3.1.1 Equipment

The provisional pilot plant unit was built using a PVC horizontal multizone aeration tank, a PVC circular clarifier, a fiberglas ozone contactor, and a fiberglas multimedia filter. Air to the system was provided by a blower and air for the ozone generator was provided by a separate compressor with dryer. Raw sewage was fed to the system by a progressive cavity pump, but flow of liquid from unit to unit and of return sludge were provided by airlifts. Filter effluent was delivered through a vortex device to the ozone contactor by a submersible pump which was also used to backwash the filter.

3.1.2 Treatment process description

The CABOS pilot plant is shown in Figure 7 and consists of:

(i) biological oxidation combined with activated carbon

FIGURE 7. VIEW OF PROVISIONAL CABOS UNIT - ORF PILOT PLANT.

adsorption of organic matter;

(ii) sludge separation by clarification;

(iii) multimedia filtration; and,

(iv) disinfection by ozonation.

In the pilot plant studies raw domestic sewage from a nearby residential housing subdivision of the City of Mississauga, Ontario was continuously pumped to the treatment system and the final effluent was allowed to flow back to the city sewer, together with occasionally wasted activated sludge and sludge from the filter backwash. The sewage, mixed with sludge returned from the clarifier by airlift, was aerated in the multizone horizontal aeration tank which had been charged with activated carbon. The carbon adsorbs organic matter from the mixed liquor when concentrations are high and is biologically regenerated when the concentrations are low. Mixed liquor flowed from the aeration tank to the specially designed clarifier and secondary effluent from the clarifier was polished in a downflow multimedia filter. The filter was backwashed with air and water, and the backwash water was returned to the system or discharged. Polished effluent was then disinfected by ozone in the ozone contactor. Ozone distribution was provided by a vortex device developed at ORF (6). The contactor had two zones, and ozone was injected into both of them. The effluent flowed up through the peripheral zone, then down through the central zone containing diffused ozone.

A simplified diagram of the CABOS system is shown in Figure 8. The comminutor and surge tank were not used in the pilot plant studies.

3.2 Operational Procedures and Conditions

The pilot plant unit was designed to handle 2500 I gal per day, based on 30 men, each producing 83 I gal per day of wastewater. This represents the maximum of the figures quoted in the literature.

Feed to the system was domestic sewage with the characteristics given in Table 4. Tests did not include a study of the effects of motion and vibration but were otherwise similar to those carried out in the laboratory tests. Backwashing of the filter was carried out with water only, and also with a mixture of water and air.

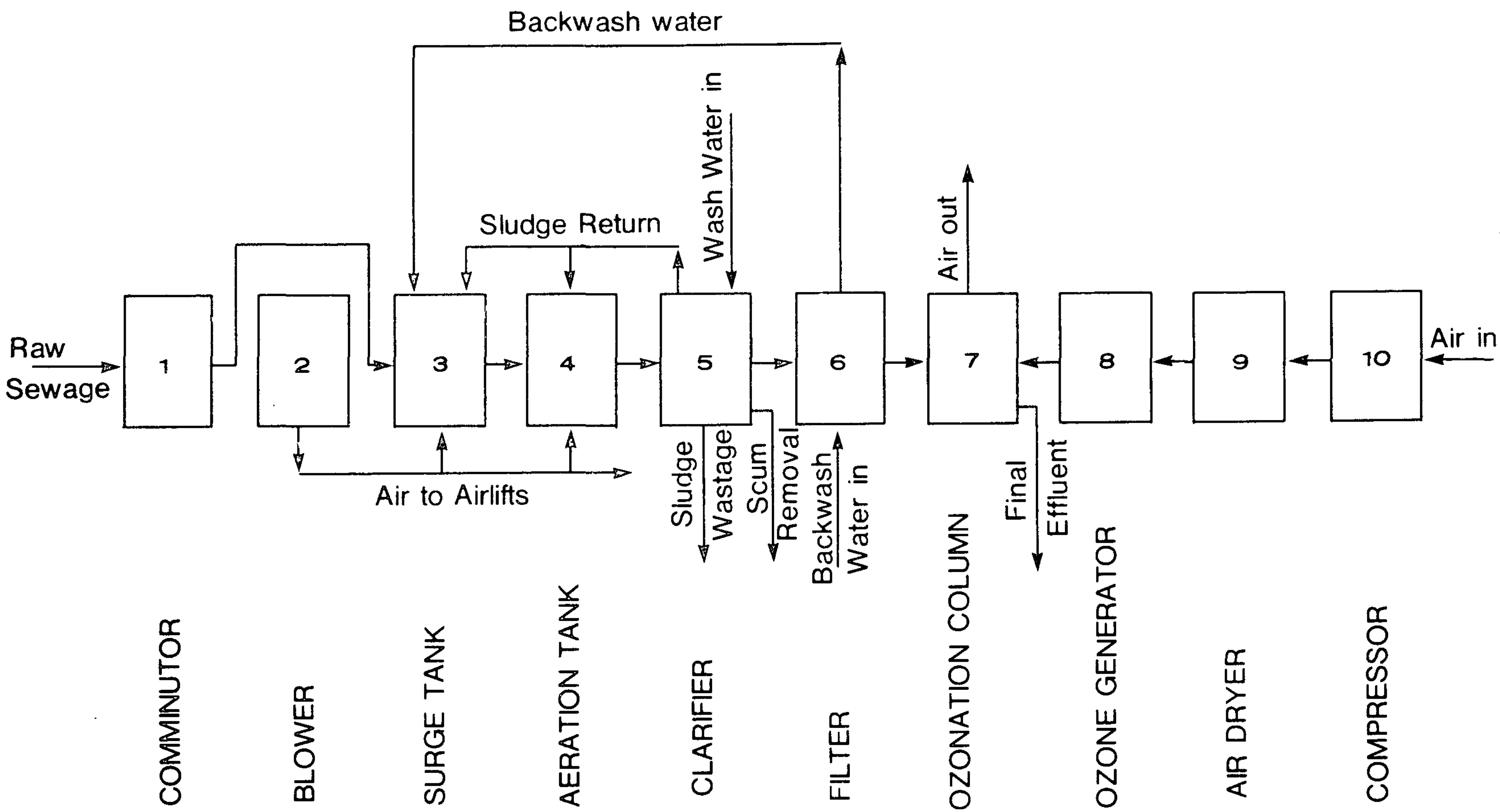


Figure 8 Flow Sheet of CABOS Unit With Comminutor

TABLE 4 CONCENTRATION OF PRIMARY CONTAMINANTS IN DOMESTIC SEWAGE AT ONTARIO RESEARCH FOUNDATION (5)

Constituents				
Total organic carbon (TOC)	(mg/l)	78	-	165
Soluble organic carbon (SOC)	"	20	-	52
BOD_5	"	100	-	400
PO_4	"	10	-	42
Total nitrogen - N	"	27	-	51
Ammonia - N	"	15	-	30
NO_2 & NO_3 - N	"	0.3	-	2.0
Organic nitrogen - N	"	12	-	21
Suspended solids	"	140	-	268
Volatile suspended solids	"	126	-	198
Dissolved solids	"	450	-	524
Chlorides	"	50	-	84
Sulphate	"	20	-	57
Total hardness	"	100	-	153
Calcium	"	30	-	50
Conductivity (μ mhos/cm)		700	-	925
pH		7.0	-	7.5

3.3 Sampling and Analytical Procedures

3.3.1 Sampling procedure

The sampling procedure and the preservation and storage of samples are described in Appendix I.

During the two start-up tests, composite samples were collected every day at the beginning of each test and the number of samples were gradually reduced to three per week and later to two per week.

During the toxicity tests, samples were taken every day except Saturday and Sunday.

For the total coliform counts, grab samples were taken in sterile glass containers with plugs (200-1000 ml).

Ozonated samples were collected in vessels containing excess sterile thiosulphate.

The following samples were taken:

(1) raw sewage feed;

(2) mixed liquor;

(3) clarifier effluent;

(4) filter effluent; and,

(5) ozonated effluent (final effluent).

3.3.2 Analytical procedures

Chemical analytical procedures are described in Appendix II.

Coliform counts were made by the standard total coliform membrane filter procedure (Standard Methods 408A) with the single step direct technique using agar based medium (LES Endo Agar).

3.4 Results and Discussion

3.4.1 Start-up of the process

There were two start-ups, February 19th and March 26th, 1974, which initiated the short-run test and the long-run test, respectively. The distributions of flow and BOD load per day are shown in Tables 5 and 6.

TABLE 5 CHARACTERISTIC DATA ON TREATMENT EFFICIENCY OF PROVISIONAL PILOT PLANT UNIT - START-UP I

Component	Raw Sewage - Feed			Clarifier Effluent			Removal Efficiency %
	Min.	Max.	Av.	Min.	Max.	Av.	Av.
Flow Rate IGPM	0.8	1.9	1.3	0.8	1.9	1.3	-
pH	7.5	8.3	7.9	7.3	8.1	7.7	-
Turbidity JTU	55	140	84	1.3	17.0	8.4	90.0
SS mg/l	88	218	124	1.2	43.0	11.9	90.4
TOC mg/l	90	156	119	10	31.5	16.1	86.4
DOC mg/l	32.5	65	42.6	5.5	21	11.5	73.1
BOD_5 mg/l	115	200	146	0.5	21.5	5.5	96.2
$N\text{-}NH_3$ mg/l	13.1	24.9	20.4	1.5	31.9	20.5	0
N-T Kjeldahl mg/l	21.9	51.5	27.4	1.45	36.9	24.6	10.4

TABLE 6 CHARACTERISTIC DATA ON TREATMENT EFFICIENCY OF PROVISIONAL PILOT PLANT UNIT - START-UP II

Component	Raw Sewage - Feed			Clarifier Effluent			Removal Efficiency %
	Min.	Max.	Av.	Min.	Max.	Av.	Av.
Flow Rate IGPM	0.7	1.8	1.3	0.7	1.8	1.3	-
pH	7.6	8.2	7.9	7.8	8.2	7.9	-
Turbidity JTU	55	120	94	3	18	6.3	93.3
SS mg/l	79	284	174	8.0	80	19.5	88.8
TOC mg/l	83	151	122	10.5	34	16.8	86.2
DOC mg/l	31	53	40.5	7.5	19.5	11.0	72.8
BOD_5 mg/l	102	250	172	1.4	19.0	8.5	95.1
$N\text{-}NH_3$ mg/l	17.3	33.4	22	8.6	39.9	23.9	0
N-T Kjeldahl mg/l	28.3	46.7	35.8	10.7	39.4	25.3	29.3

Results of these tests are shown in Tables 5 (Test I) and 6 (Test II) and indicate that treatment efficiencies were good. The first test gave average removals of BOD of 96%, SS of 90%, TOC of 86% and DOC of 73%. In the second test, treatment efficiencies were slightly lower, the BOD removal being below 90% for about 20 days but improving later to an average of 95%. Performance and reliability, however, were not completely satisfactory due to poor quality of the sludge and entrainment of the sludge in the top part of the clarifier. As the amount of entrained sludge slowly increased, anaerobic decomposition occurred.

3.4.2 Overall performance and treatment efficiency of the system

The overall performance and treatment efficiency of the CABOS process was evaluated for a period from April 21 - August 26, 1974. Operating conditions are shown in Figures 9 and 10.

Monthly characteristic data from the sampling points representing raw sewage, clarifier effluent, filter effluent, and ozonation effluent are summarized in Tables 7 and 8.

3.4.2.1 <u>Performance and treatment efficiency of the biological treatment and clarification</u>. Regardless of the flow rate (0.8 - 2.65 Igal/min) consistently high removals of organics and suspended solids were obtained. Ammonia removal became satisfactory only when the sludge problems, such as deposition and anaerobic conditions in the clarifier, were solved.

A drop in efficiency of the unit in the first half of June was due to clogging of the air diffusers. Modifications to these resulted in high BOD removal which was maintained to the end of the test. During this period BOD levels were 1.8-6.3 mg/l, averaging 4.3 mg/l; a treatment efficiency of 98%. At the same time TOC and DOC levels improved to 6.1-13.6 mg/l, averaging 9.6 mg/l, and 4.38 mg/l, averaging 6.7 mg/l, respectively.

Clarifier problems were solved by installation of stirring devices, first for manual operation, later for continuous operation and by installation of a positive means for removal of foam and scum. Suspended solids in the clarifier effluent varied from 0-29 mg/l (averaging 12 mg/l).

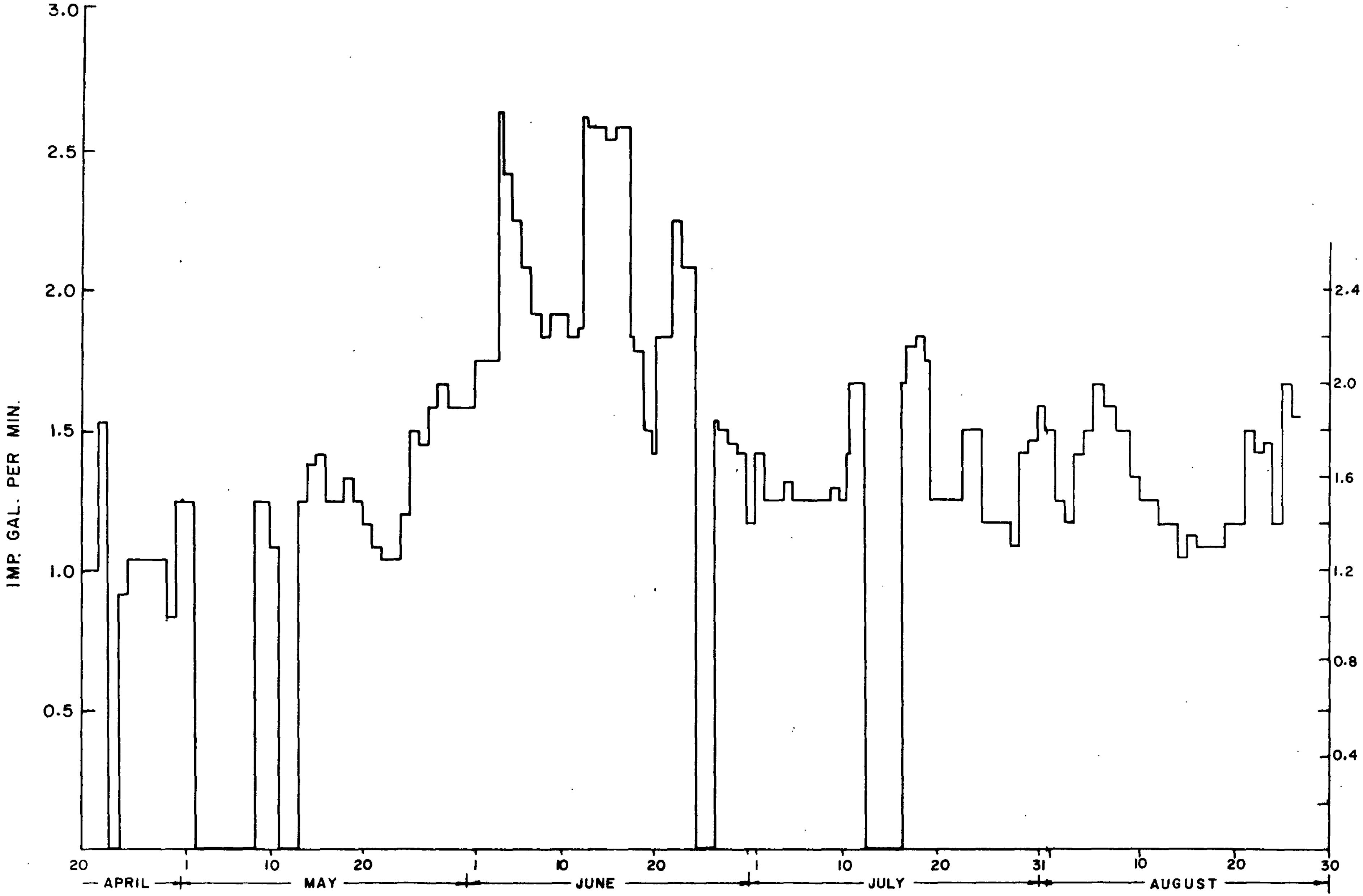


FIGURE. 9 FLOW RATE OF RAW SEWAGE TO THE CABOS UNIT (IGPM)

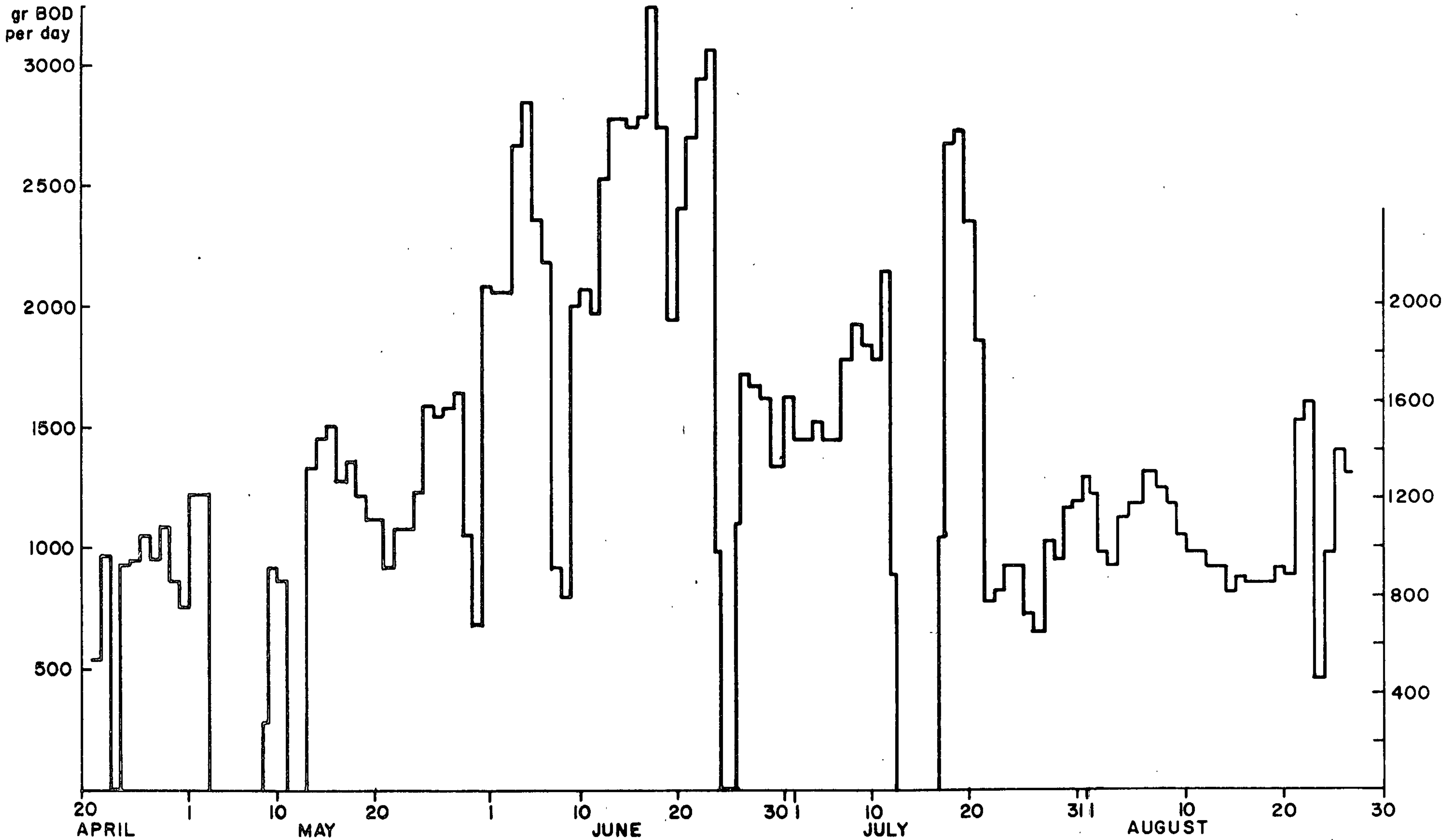


FIG. 10 DAILY BOD APPLIED TO CABOS UNIT (gr BOD/day)

TABLE 7 CHANGES IN TOC, DOC AND BOD OF FILTERED EFFLUENT WITH TIME OF OPERATION

Month	TOC mg/l	DOC mg/l	BOD_5 mg/l	Processed Sewage Volume Litres	Processed Sewage Applied BOD gr
May, '74	6.3	5.4	3.2	1.9×10^5	2.86×10^4
June, '74	8.5	6.7	2.6	3.44×10^5	6.31×10^4
July, '74	5.4	4.8	1.2	2.41×10^5	4.04×10^4
August, '74	5.4	4.8	4.0	2.48×10^5	3.08×10^4

TABLE 8 CHARACTERISTIC DATA FOR FEED (RAW SEWAGE) AND EFFLUENT QUALITY - PROVISIONAL CABOS UNIT

APRIL 21st - AUGUST 26th

Component	Raw Sewage - Feed (27 tests)			Effluent after Clarification (27 tests)			Effluent after Filtration (23 tests)			Effluent after Ozonation (13 tests)		
	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.	Min.	Max.	Av.
Flow rate IGPM	0.83	2.64	1.44	0.83	2.64	1.44	0.83	2.64	1.44	0.83	1.84	1.34
Temperature °C	13.7	21.5	16.8	13.7	21.5	16.8	15.0	21.5	18.2	15.0	21.5	18.2
pH	7.3	8.3	7.9	7.3	7.8	7.7	7.5	8.0	7.7	7.8	8.1	8.0
Conductivity μmhos	590	790	696	565	880	711	575	835	693.3	615	710	658
DS mg/l	372	622	512	387	600	513	378	576	502.1	324	608	504.9
Turbidity JTU	51	259	94	0.8	6.7	2.6	0.25	2.5	0.8	0.2	2.0	0.75
SS mg/l	63	207	157	0	28	12	0	16	2.3	0	10.0	4.0
VSS mg/l	30	176	126	-	-	-	-	-	-	-	-	-
TOC mg/l	62	152	110	6.1	28.5	15.1	3.9	10.1	6.9	4.5	13.2	7.05
DOC mg/l	23.1	52.5	40.4	4.3	17.0	11.5	3.5	8.9	5.5	3.8	9.3	6.18
BOD_5 mg/l	48	235	166.7	1.8	20.8	6.0	0.9	11.0	2.4	0.5	22	3.11
$N\text{-}NH_3$ mg/l	10.5	28.9	20.4	0.08	28.6	7.2	0.09	21.7	3.4	0	23.4	3.14
$N\text{-}NO_2$ mg/l	0.012	0.18	0.06	0.03	2.9	0.44	0.02	3.02	0.59	0.005	3.22	0.47
$N\text{-}NO_3$ mg/l	0.3	4.3	1.5	2	25	13.5	2.5	26	15.3	3.8	27	17.7
N-TKj mg/l	26.9	82.3	40.1	0.11	32.4	8.4	0	22.5	4.49	0	9.3	1.29
PO_4^{3-} mg/l	12.6	26.4	20.9	9.8	19.5	14.9	10.1	20.6	14.04	8.4	14.7	12.26
Coliforms Bact. TOTAL MPN/100 ml	2.2×10^7	6.4×10^7	4.2×10^7	3.1×10^5	1.7×10^6	7.7×10^5	7	4×10^5	1.4×10^5	0.4	70	20

It is known that high concentrations of aged sludge result in effluent quality deterioration. According to Eckenfelder (8) the concentration of non-biodegradable or refractory organic matter increases with the age of the sludge. Since the age of the sludge in the pilot plant reached 60 days, the concentration of refractory organics should have been high. Observations indicated that activated carbon assisted in the removal of these organics either by a catalytic action or by allowing development of acclimatized microorganisms capable of destroying adsorbed refractory material. This is supported by the fact that TOC levels in the effluent were high when activated carbon was accidentally lost from the aeration system.

3.4.2.2 Performance and treatment efficiency of the multimedia filter. Further improvement of the secondary effluent quality was achieved in the polishing stages involving multimedia filtration and ozonation.

As shown by data for the filtered effluent in Tables 7, 8 and 9, the performance and efficiency of the multimedia filter was excellent during the whole test period. Averages for BOD, TOC, DOC and SS were only 2.4, 6.9, 5.5 and 2.3 mg/l, respectively, and a gradual improvement was observed as the test run progressed. Even after backwashing the high quality of the filtered effluent was maintained.

3.4.2.3 Performance of the ozonation system. The quality of the effluent after ozonation is shown in Tables 8 and 9. From the physical-chemical point of view, ozonation did not contribute to further improvement of the effluent. The coliform count, however, was reduced from an average of 4.2×10^7/100 ml in the sewage to an average of 20/100 ml in the ozonated effluent. These results were obtained with a 50-75% ozone output at a flow rate of 30 scf/hour of ozone to the ozone column, and a contact time of 13-27 minutes.

3.4.2.4 Activated sludge accumulation and wastage. To maximize the conversion of influent organic matter to CO_2, H_2O and inorganic salts a high concentration of activated sludge was maintained in the presence of activated carbon. Such a condition was also necessary to cope with shock loadings and food-limiting situations.

TABLE 9 TREATMENT EFFICIENCY AND CONTRIBUTION OF SEPARATE UNITS OF CABOS PROCESS

Component		Raw Sewage Feed (Average)	Secondary Effluent after Clarifier		Effluent after Filtration		Contribution to Overall Efficiency (%)	Effluent after Ozonation		Contribution to Overal Efficiency (%)
			Average Value	% Removal	Average Value	% Removal		Average Value	% Removal	
Turbidity	JTU	94	2.6	97.2	0.8	99.2	2.0	0.75	99.2	< 0.1
Susp. Solids	mg/l	157	12	92.4	2.3	98.6	6.2	4.0	97.5	-1.1
TOC	mg/l	110	15.1	86.3	6.9	93.7	7.4	7.05	93.6	-1.1
DOC	mg/l	40.4	11.5	71.5	5.5	86.4	14.9	6.2	84.7	-1.7
BOD_5	mg/l	166.7	6.0	96.4	2.4	98.6	2.2	3.1	98.1	-0.5
$N-NH_3$	mg/l	20.4	7.2	64.7	3.4	83.3	18.6	3.1	84.8	1.5
PO_4^{3-}	mg/l	20.9	14.9	28.7	14.04	32.8	4.1	12.26	41.3	8.5
Coliform Bact.	N/100 ml	$4.2X10^7$	$7.7X10^5$	98.2	$1.4X10^5$	99.6	-	20	99.99+	

The total amount of solids entering the system over the testing period included 363.4 lb suspended solids, 288 lb volatile suspended solids and 376 lb BOD.

It was assumed that biological equilibrium was reached in mid-May when the concentration of SS in the mixed liquor reached the average value of 8000 mg/l.

Sludge with a volume of 40-70 Igal was wasted every 2-3 weeks. The total wasted sludge and its percentage of applied BOD were as follows:

		Sludge weight	
(i)	Sludge wastage (regular)	38.4 lb	(10.2%)
(ii)	Sludge discharged from filter backwashing	3.5 lb	(0.95%)
(iii)	Losses (SS in effluent)	14.1 lb	(3.75%)
(iv)	Accumulation of SS in aeration tank	13.2 lb	(3.5%)
		69.2 lb	(18.4%)

The activated sludge had good properties with an SVI of 110-120 when dissolved oxygen in the MLSS was above 2 mg/l. The exception was in June when the SVI averaged 183 with a maximum of 278 due to lack of oxygen in the system.

3.4.2.5 Carbon usage. The amounts of wasted sludge, discussed above, include part of the activated carbon used in the system. Due to accidental losses (April 10-21, 1974) amounting to 30 lb or more of carbon, the exact amounts remaining in the system were unknown. Additions to the system were as follows:

To April 21, 1974	60 lb
May 29, 1974	10 lb
July 1, 1974	6 lb
July 21, 1974	4 lb
August 20, 1974	1 lb
	81 lb

Since accidental losses amounted to 30+ lb of carbon it is estimated that a system of this type would need about 50 lb of carbon during a comparable period with no abnormal loss of carbon.

3.4.2.6 Oxygen uptake. Data showing the distribution of oxygen and oxygen uptake in the system (mg oxygen/gr MLVSS/hr) are given in Table 10. These figures do not include the low June levels which resulted from clogged air diffusers. Redesign of these diffusers corrected the situation.

3.4.2.7 Performance and backwashing of the multimedia filter. Performance and frequency of backwashing are dependent on the quality of the secondary effluent. During the tests the length of filter runs between backwashing varied from 48 to 380 hr (av. 139 hr) at an average flow rate of 1.5 Igpm and a surface load of 0.9 Igpm/sq ft.

Two methods were used:

(i) Backwashing with water only.
(ii) Backwashing with air and water.

The first method was unsatisfactory. The time for one cycle was 30-45 minutes and the volume of water was 150-170 gal (100 gal per sq ft per cycle).

The second method, using air and water, was completed in 10-15 minutes and the volume of water used was 100-120 gal (70 gal per sq ft per cycle).

Data obtained from these tests are given in Figure 11.

3.4.3 Effect of interruption of food supply and toxic materials on the stability and treatment efficiency

3.4.3.1 Effect of interruption of food supply on treatment stability. Interruptions of food supply lasted 1-7 days and after each interruption the test was continued at the same hydraulic loading.

Results of tests showed that the interruption in food supply had negligible effect on the effluent quality.

TABLE 10 OXYGEN LEVEL AND OXYGEN UPTAKE IN AERATION TANK

Location	Minimum		Maximum		Average	
	O_2 mg/l	O_2-uptake mg/gr MLVSS/hr	O_2 mg/l	O_2-uptake mg/gr MLVSS/hr	O_2 mg/l	O_2-uptake mg/gr MLVSS/hr
First Compartment - Second chamber of 6	0.8	3.9	6.4	16.2	3.6	9.4
Second compartment - Fourth chamber of 6	1.0	3.4	7.0	13.5	4.6	6.9
Third compartment - Sixth chamber	3.3	3.4	7.6	7.9	5.6	5.2

3.4.3.2 Effect of toxic matter on the treatment process. On August 20, 1974 0.1 gal Pine-Sol was added to the system. This resulted in foaming in the aeration tank. To overcome this, one lb of powdered activated carbon was added and the air supply decreased.

Additions of bleach were then made during the period August 21-27, 1974 in two doses: 1150 ml (August 21-23), and 1980 ml (August 25-26). On the first day the poor effluent quality resulting from the Pine-Sol addition rapidly improved.

Analyses of the clarifier, filter, and ozonation effluents during these periods showed that there were no adverse effects of bleach on the system. Results of these tests are given in Table 11.

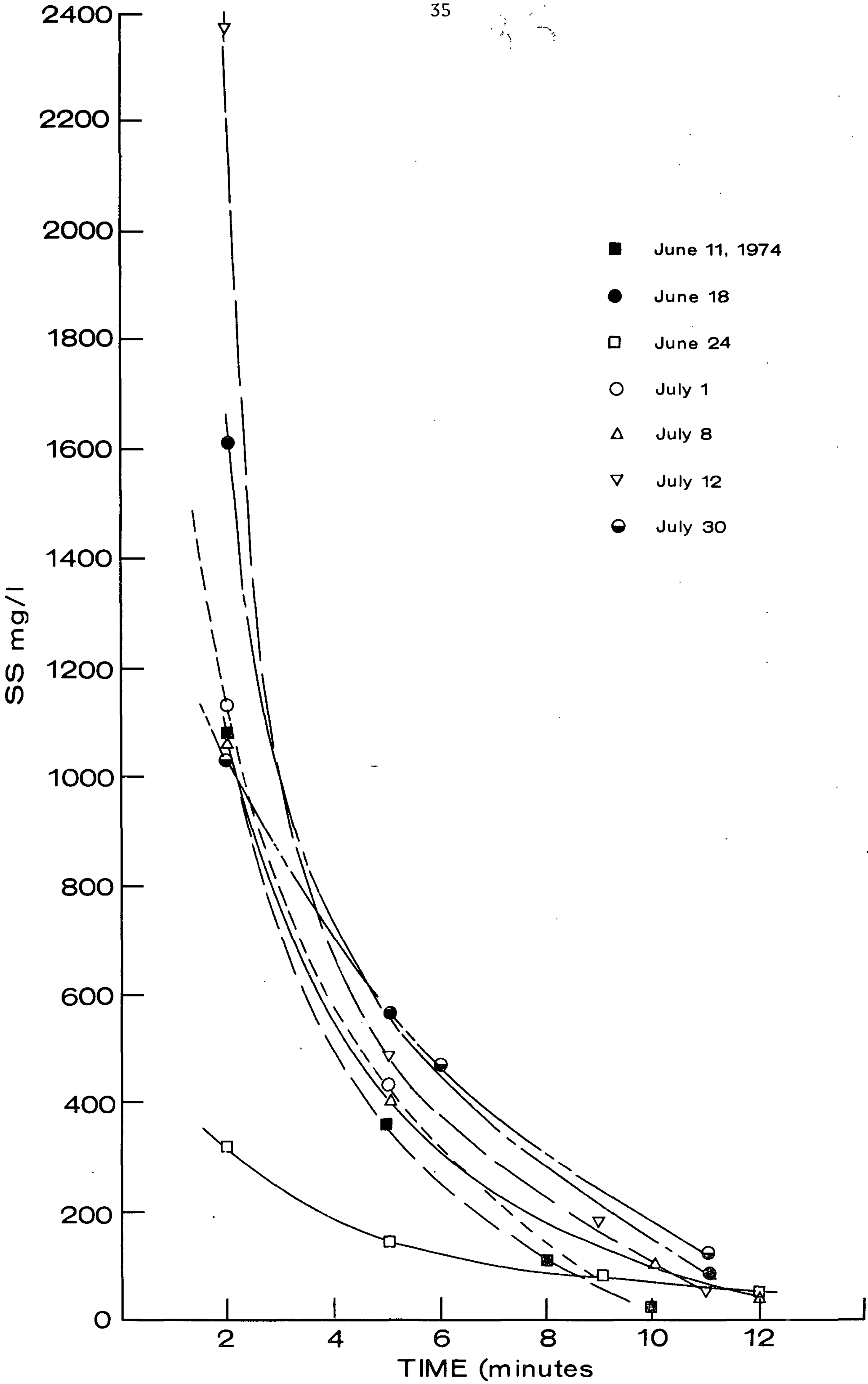


Figure 11 SS in Backwash Water vs Time

TABLE 11 EFFECT OF TOXIC MATTER ON THE TREATMENT PROCESS

Volume of Bleach added:

August 21-23 1150 ml
August 25-26 1980 ml

Components	Raw Sewage (Feed)	Clarifier Effluent		Filter Effluent		Ozonated Effluent	
	Av.	Av.	% Removal	Av.	% Removal	Av.	% Removal
Flow Rate - Feed - IGPM	1.48	1.48	-	1.48	-	1.43*	-
pH	7.5	7.5	-	7.75	-	8.0	-
Turbidity - JTU	87	2.9	96.7	0.81	99.1	0.67	99.2
SS - mg/1	143	7.0	95.1	<1	>99	<1	>99
TOC - mg/1	82.2	8.1	90.2	4.5	94.5	4.5	94.5
DOC - mg/1	30.3	6.1	79.9	3.8	87.5	3.9	87.1
BOD_5 - mg/1	144	4.75	96.7	4.0	97.2	-	-
NH_3 - mg	16.2	0.74	95.4	0.89	94.5	0.86	94.7

* Ozone subsystem was operated till August 24, 1974.

4. SHIP SELECTION AND MODIFICATION

4.1 Ship Selection

To demonstrate the prototype treatment system it was necessary to select a ship having an available space approximately 10 ft long by 8 ft wide by 10 ft high and the capability to run the treatment unit with various sources of wastewater (toilet, galley, showers, and combinations of these).

Through the Dominion Marine Association, four companies offered ships for installation and demonstration of a prototype treatment unit. They were:

Algoma Central Railway Limited
Algoma Steel Corporation
Canada Steamship Lines Limited
Scott Misener Steamships Limited

The SS John A. France of SMSS was selected, based on a formal evaluation of proposals submitted to the Department of Supply and Services (DSS). The ship is 700 ft long, has a crew of 29-31 men with crew quarters fore and aft, and had approximately 12' x 9' x 12' space available.

It was already equipped with sewage treatment units which could serve as stand-by units during the test period. It was proposed to locate the CABOS unit forward and to pump wastewater from aft to the treatment unit through an existing pipe.

Ample power was available at 550V, 3 phase, and 110V, single phase.

4.2 Modifications and Piping

The following modifications were necessary to accommodate and provide service to the CABOS unit on board ship:

(i) Installation of 2 sewage tanks and grinder pumping units aft in parallel with the existing sewage treatment units to provide delivery of wastewater to the CABOS unit located forward.

(ii) Installation of tees and valves to each pipeline carrying wastewater, to make it possible to use different sources and combinations of wastewater.

(iii) Installation of pipes to connect the above valves with the installed pumping units and the CABOS unit.

These modifications allowed the hook-up of each source of wastewater to the CABOS unit independently and in any combination. Wastewater not being processed, could be pumped to the existing stand-by sewage disposal units.

5. PRELIMINARY WASTEWATER SURVEY ON THE SS JOHN A. FRANCE

5.1 General Information

To obtain parameters for use in the design of the prototype CABOS unit a survey was made from June 7-10, 1974 on board the SS John A. France.

Thirty persons were on board during the survey period. Distribution of their work and meal times were as follows:

Work Distribution

12 persons - day time only (8 hr)
5 persons - on each of 3 shifts
1 person - night time only
2 persons - irregular

Meal Times

7.30 - 8.30 hr
11.30 - 12.30 hr
17.00 - 18.00 hr
23.30 - 0.30 hr
3.30 - 4.30 hr

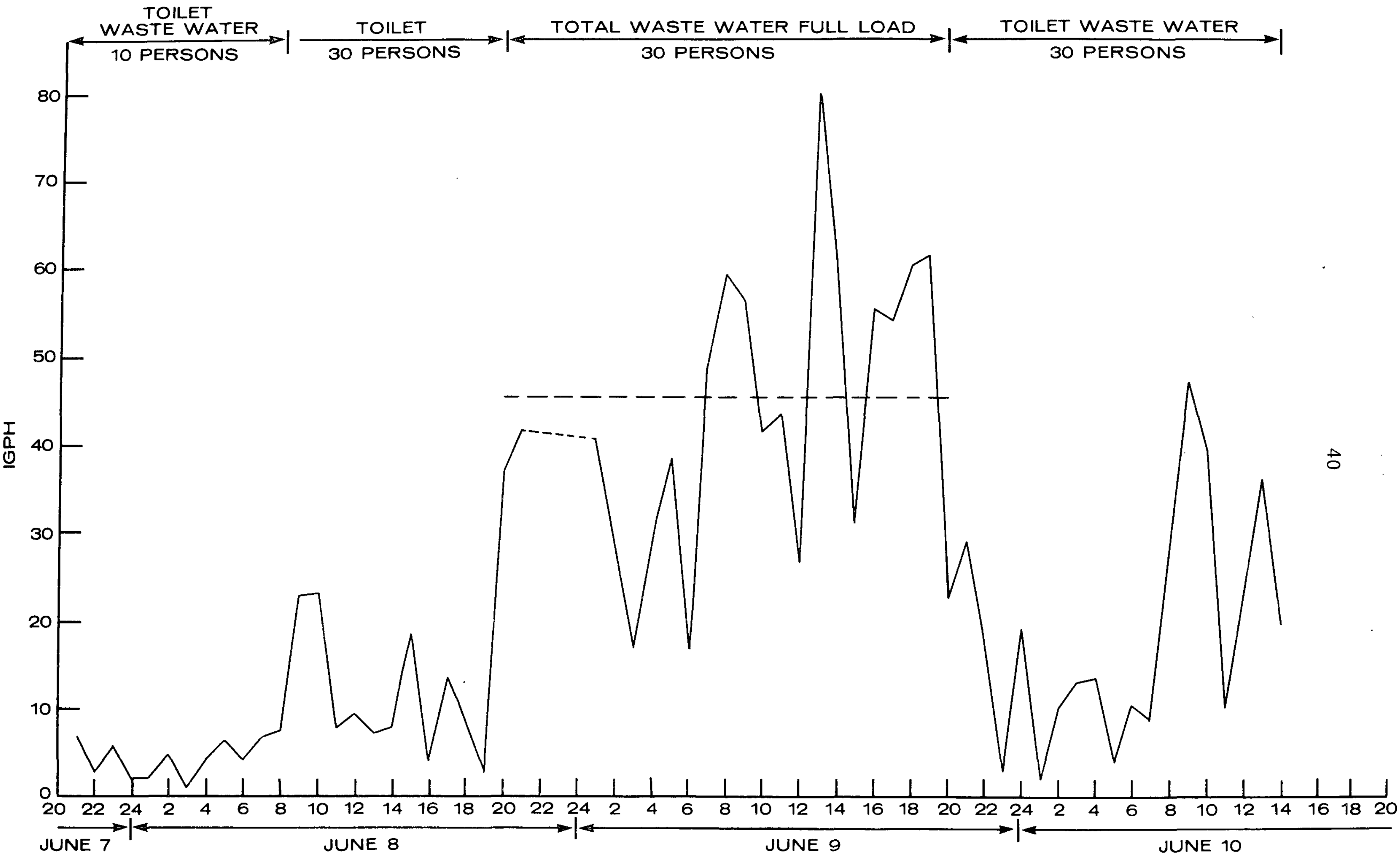
5.2 Wastewater Flow

Flow measurements were made between 20.10, June 7, and 14.30, June 10, 1974. They were obtained by timing a calibrated positive displacement pump.

The measuring periods were as follows:

June 7, 20.10 - June 8, 8.00	10 persons toilet water (forward only)
June 8, 8.00 - June 8, 20.00	30 persons toilet water
June 8, 20.00 - June 9, 20.00	30 persons full load (toilet, shower and galley waste)
June 9, 20.00 - June 10, 14.30	30 persons toilet water

A profile of the flow rates is presented in Figure 12. The volume of total wastewater was estimated at 1074 I gal/day and of toilet wastewater 421 I gal/day. This represents 14 I gal per capita per day of toilet wastewater and 37 I gal per capita per day of total wastewater.


TOILET
WASTE WATER
10 PERSONS
TOILET
30 PERSONS
TOTAL WASTE WATER FULL LOAD
30 PERSONS
TOILET WASTE WATER
30 PERSONS
IGPH
0
10
20
30
40
50
60
70
80
20 22 24 2 4 6 8 10 12 14 16 18 20 22 24 2 4 6 8 10 12 14 16 18 20 22 24 2 4 6 8 10 12 14 16 18 20
JUNE 7
JUNE 8
JUNE 9
JUNE 10

Three major peaks were recorded and, as expected, they appeared at 8.00-10.00, 13.00-14.00 and 16.00-.9.00, corresponding to the periods following the main meals.

The ratio of maximum peak to average flow was higher for toilet wastewater than for total wastewater but the duration of the latter was greater. See Tables 12 and 13.

5.3 Composition of Shipboard Wastewater

The sampling program was organized to cover day and night periods and the three peak periods at meal times. Composite samples were taken every hour, day and night, and every half-hour during the three hours of the expected peak periods.

Determinations made included temperature, conductivity, SS, VSS, BOD_5, TOC, DOC and NH_3. Since the grease trap had not yet been installed, all the grease was present in the samples of total wastewater.

Results are listed in Table 14. The second and third series of tests show a much higher level of contaminants than the first series. Wide variations in levels are apparent: BOD_5, 313-2200 mg/l; TOC, 212-1503 mg/l; SS, 252-1280 mg/l; VSS, 228-1108 mg/l; and, ammonia, 47-225 mg/l (Table 15).

BOD figures on a per capita per day basis were 0.286 lb for toilet wastewater and 0.434 lb for total wastewater.

TABLE 12 RATIO OF MAXIMUM FLOW TO AVERAGE FLOW OF TOTAL WASTEWATER

Time		Av. Flow Igal/hr	Full Load		
			Duration of Peaks hr	Max. Flow (Average in time) Igal/hr	Ratio Max. Flow / Av. Flow
Lunch Time	12:30-13:30	44.7	1	81	1.76
Lunch Time	12:30-14:30		2	71	1.55
Evening	16:30-19:30		3	59	1.29
Evening	15:30-19:30		4	58	1.27
Morning	6:30-11:30		5	50	1.01

TABLE 13 RATIO OF MAXIMUM FLOW TO AVERAGE FLOW OF TOILET WASTEWATER

Time		Av. Flow Igal/hr	Toilet Wastewater		
			Duration of Peaks hr	Max. Flow (Average in time) Igal/hr	Ratio Max. Flow / Av. Flow
Morning	8:30- 9:30	17.5	1	47	2.70
Morning	8:30-10:30		2	42	2.42
Morning	7:30-10:30		3	38	2.18

TABLE 14 COMPOSITION OF TOILET AND TOTAL WASTEWATER (SS JOHN A. FRANCE)

Sample No.	Sample Type	Temperature oC	Conductivity µmhos	SS mg/l	VSS mg/l	% VSS	BOD mg/l	TOC mg/l	DOC mg/l	NH_3 mg/l
1	Toilet w.w. - Night composite	20.4	1933	256	228	89.1	-	282	158	225
2	" - Morning peak	18.8	1915	284	256	90.1	-	336	176	222
3	" - Lunch peak	18.7	1650	400	320	80.0	353	339	137	138.1
4	" - Evening peak	19.7	1725	348	268	77.0	363	347	188	162.7
5	" - Day composite	19.0	1656	368	288	78.3	313	336	154	176
6	Total w.w. - Night composite	22.4	968	252	228	90.5	385	212	113	81.3
7	" - Morning peak	20.9	983	452	384	84.9	488	327	158	84.8
8	" - Lunch peak	27.8	970	560	492	87.8	1170	820	285	86.1
9	" - Evening peak	26.2	1027	1156	1060	91.7	>1400	1476	128	47.5
10	" - Day Composite	25.8	1070	552	464	84.0	>1400	654	167	75.7
11	Toilet w.w. - Night composite	24.5	1755	1056	940	89.0	2140	1344	494	131.9
12	" - Morning peak	23.1	1812	1168	1048	89.7	2200	1503	277	173.3
13	" - Lunch peak	24.2	2307	924	784	84.8	1160	806	234	174.5
14	" - Day composite	23.9	2123	1280	1108	86.6	1400	1046	229	184.5

TABLE 15 VARIATION OF COMPOSITION OF TOILET AND TOTAL WASTEWATER (SS John A. France)

	Total Wastewater			Toilet Water		
	Min.	Max.	Ave.	Min.	Max.	Ave.
BOD_5	385	> 1400	-	313	2200	1818
TOC	212	1476	527	282	1503	1220
SS	252	1156	466	256	1280	1173
VSS	228	1060	396	228	1108	1029
NH_3	47.5	86.1	77.3	131.9	225	158
Conductivity	968	1070	1041	1650	2307	1947

6. FINAL DESIGN OF PROTOTYPE CABOS UNIT

The final design was made by ORF based on the laboratory and pilot plant data, as well as on the wastewater survey results.

6.1 Final Concept of the Treatment System

The laboratory studies and in-house testing program of the provisional full scale treatment system proved that the combined process of adsorption and bio-oxidation using activated carbon was efficient and reliable. Since the performance of the other treatment steps was also good, the design of the prototype unit was based on this concept. It consists of a grinder, surge tank, multizone aeration reactor, clarifier, multimedia filter, ozone generator, ozone contactor and sludge holding tank. Sludge disposal is by incineration in the ship's boiler.

6.2 Functional Description of the On-Board CABOS Prototype

Incoming wastewater (galley, toilet, wash and shower water) enters the surge tank via a grinder which disintegrates coarse solids and fibres. The surge tank accommodates peak flows and also provides the first step of the bio-oxidation and activated carbon adsorption process.

The wastewater, mixed with return sludge from the clarifier in the surge tank, is then pumped to the horizontal multizone aeration tank at constant flow rate by one of two progressive cavity pumps, and aerated. The aeration tank is charged with activated carbon, which adsorbs organic matter from the mixed liquor while concentrations of organic matter are high and is biologically regenerated when concentrations are low.

Zone growth of microorganisms and disintegration of bioflocs and suspended solids increase the decomposition rate, leading to a high treatment efficiency.

Mixed liquor from the aeration tank flows to the clarifier, which has arrangements for foam and scum removal by air lift. Activated sludge, separated in the gravity clarifier, is returned to the surge tank and/or multizone aeration tank by air lifts. Excess sludge is stored in a separate holding tank for thickening before incineration in the ship's boiler.

Secondary effluent from the clarifier is polished in a downflow multimedia filter which is periodically cleaned by backwash water stored in the ozone tank and under the settling zone of the clarifier. Used backwash water is returned to the surge tank.

The polished effluent is disinfected by ozone in a specially designed contactor in which ozone distribution is provided by a vortex system developed at ORF (7). The mixture of polished effluent and ozone flows up through the packed peripheral part of the contactor and down through the central part.

Air for the ozone generator is supplied by a compressor and air dryer, while air for the surge tank, aeration tank, sludge holding tank, and air lifts is provided by one of two blowers.

To provide reliable and self-sustaining operation of the treatment system, automatic controls were designed to control the feed pump by levels in the surge tank, wash-out of the clarifier, foam and scum removal, and backwash of the multimedia filter.

6.3 Design of Prototype CABOS Unit

The final design of the prototype CABOS unit commenced soon after completion of the wastewater survey on the SS John A. France. Based on the results of the pilot plant testing program and from the survey, design parameters were established as follows:

Parameter		Value from Survey or Pilot Plant Testing	Design Value
Average flow rate (total wastewater)	- Igpd	1,070	1,606
Average BOD	- mg/l	1,210	807
MLSS	- mg/l	8,000	8,000
F/M ratio	- gr BOD/gr MLSS	0.4	0.4
Detention time	- hr	9.0	6.0

Note: A safety factor of 1.5 was used for hydraulic loading.

The final design of each unit, the layout, and the schematic piping diagram for the prototype CABOS unit were done by ORF staff.

The final manufacturing drawings were prepared by SMSS. After these had been verified by ORF, manufacturing of the unit was carried out by SMSS.

7. AUTOMATIC CONTROL OF THE PROCESS

Automation of some of the functions of the CABOS unit is necessary to provide safe, reliable, self-sustained and unattended operation. The automatic control system was designed and built at ORF.

Controls were designed for surge tank levels, constant flow for the process, foam and scum removal, clarifier wash-out, and backwashing of the multimedia filter. Wastage of excess sludge will not be automatic in the prototype unit, since it is anticipated that sludge will be wasted once or twice a week and this can be done manually in a few minutes during inspection.

7.1 Surge Tank

Pressure sensors located at four points control pump operation, and high and low level sensors operate the alarm system.

7.2 Clarifier

The cleaning procedure for the clarifier is initiated by level indicators in the clarifier, which control valves to the water supply. When the liquid level is low, the upper part of the clarifier and the foam-removing lines are cleaned and flushed by sprays which operate for predetermined times.

7.3 Filter

The filter is automatically backwashed by a mixture of air and water stored under the clarifier and in the ozone contactor. By the use of solenoid valves and timers, different rates of flow are used to flush out the system and to allow the filter media to settle back into position. The used backwash water is automatically returned to the surge tank.

8. MANUFACTURE, INSTALLATION AND TESTING OF PROTOTYPE CABOS UNIT ON BOARD SS JOHN A. FRANCE

8.1 Manufacture

During the months of June through August, final construction drawings of the tanks to be manufactured were prepared by SMSS. Manufacture of the tanks was also arranged by SMSS. ORF personnel visited the production facilities several times to inspect the tanks. Most of the required equipment items were purchased by ORF on behalf of the Crown. Piping and hand operated valves were purchased by SMSS.

8.2 Installation

By the end of October, 1974 all tanks, pumps and most auxiliary equipment were located on board the SS John A. France. The tanks and equipment were lowered into the first cargo hold and there they were lifted through a hole cut in the deck, to be installed one deck below the main deck level. This procedure was followed because doors and hallways did not allow passage of the tanks.

The deck was then reinforced by U channels to support the equipment. The CABOS units were located so that there was reasonable access to each tank and associated equipment.

The air blowers, exhaust silencer, pressure relief valve and main air flow meter were located in the winch room above. Piping was installed after all tankage and auxiliary equipment had been fixed. All water lines and most air lines are PVC Schedule 80. Pressurized air from the air preparation unit and the ozone mixture are carried in 1/4" copper tubing.

The automatic control panel, blower motors, feed panel, and other electrical connections were completed. Braided, marine type cable was used for these connections.

Sewage and wastewater lines were completed except for the connections to and from the grinder. The missing grinder, flow meter for the surge tank and a blower inlet silencer are to be installed in time for process testing.

8.3 Testing and Corrective Action

When the piping and electrical connections were completed, mechanical and hydraulic tests were conducted.

For testing purposes, the aeration tank, clarifier, sludge holding tank and ozone contactor were filled with water. All was satisfactory except:

(a) The foam control in the aeration tank had one nozzle missing. This is to be installed by SMSS before process testing.

(b) The clarifier wash cycle was tested but the pressure switches could not be adjusted. The pressure switches for the clarifier wash cycle were subsequently adjusted by ORF's electrician and gave satisfactory action.

(c) The clarifier collection troughs were not adjusted. Two of them leaked. These have since been sealed.

(d) A few leaks found in the air and water lines are to be fixed by SMSS.

(e) The air blowers were noisy and corrective action was necessary. In the suction line an inlet silencer was installed between the intake filter and the blowers. Both blowers were enclosed in a wooden box covered on the inside by embossed acoustic foam liner. This enclosure gave a satisfactory reduction in noise level.

9. SUMMARY OF PROPOSED 1975 SEASON PROCESS EVALUATION PROGRAM

During 1975 it is planned to determine the treatment efficiency and treatment stability of the CABOS unit for a variety of loading conditions under real conditions on board ship during the shipping season.

The results of this program will be presented in a second report, and a manual will be written on the operation and maintenance of the CABOS system.

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REFERENCES

1. APHA, AWWA, WPCF. Standard Methods for the Examination of Water and Wastewater. 13th Edition, 1971.

2. Antonic, M. Progress Report on Development of Shipboard Wastewater Treatment System; DOE Contract No. OSR-3-0123. Report ORF 74-1 January 1974.

3. Antonic, M. Report on Development of Shipboard Wastewater Treatment System; DOE Contract No. OSR-3-0123. Report ORF 74-7 April 1974.

4. Antonic, M. and Pancuska, V. Carbon Adsorption Bio-oxidation System (CABOS) for Shipboard Wastewater Treatment; ORF Record of Invention #493, 1974.

5. Besik, F. "High Rate Adsorption Bio-oxidation Process". Presented at the 9th Can. Symp. on Water Poll., Feb. 7, 1974, London, Canada.

6. Besik, F. Summary of Data for CMHC. ORF Report. August 1974.

7. Smith, D.K. and Method and Apparatus for Fail-Safe Introduction of a Bactericidal Gas into Liquid Sewage Canadian Patent No. 880, 759 U.S. Patent No. 3, 531, 406

8. Eckenfelder, W.W. "Recent Developments in the Technology of Wastewater Treatment". Presented at the Environment 72 Int. Conf. in London. Printed by: William Cowes and Sons, Ltd., London.

9. Metcalf and Eddy Wastewater Engineering: Collection, Treatment, Disposal. McGraw-Hill Book Co., 1972.

APPENDIX I

SAMPLING PROCEDURES

SAMPLING PROCEDURES

Sampling Procedure for Laboratory Scale Units A and B

Composite samples were taken, usually twice a week. For the special program (feed concentration, toxicity tests) samples were taken more often, sometimes daily.

Samples were collected and marked as follows:

#1 - Raw sewage - common to both units, A and B
#2a - Mixed liquor of the unit A
#2b - Mixed liquor of the unit B
#3a - Effluent from unit A
#3b - Effluent from unit B

Samples #1, #3a and #3b were taken every hour between 9 a.m. and 5 p.m. and composited. These samples were then divided into two portions: a smaller one, ∿ 500 ml which was preserved by sulphuric acid and used for nitrogen analysis; a larger one ∿ 3 litres which was without any preservative and used for all analyses other then nitrogen.

Samples #2a and #2b were taken three times a day and composited.

During the sampling period and overnight, samples were refrigerated and analyses commenced next day.

Sampling Procedure for Full Scale CABOS Unit

From the full scale CABOS unit composite samples were collected and marked as follows:

#1 - Raw sewage
#2 - Mixed liquor
#3 - Clarifier (secondary) effluent
#4 - Filter effluent
#5 - Final (ozonated, disinfected) effluent

The frequency of sampling was as follows:

a) Start ups - daily sampling gradually decreased to twice a week sampling
b) Long run test - twice a week sampling
c) Toxicity test - four times a week sampling

For the total coliform count, the grab samples were collected in sterile glass containers with plugs and testing commenced within 1/2 hour after sampling. The frequency of sampling for this purpose was once a week.

Collection of samples #1, 2, 3, 4 and 5 during one sampling day proceeded as follows:

a) Sampling time was 10 a.m., 12 a.m., 2 p.m., 4 p.m.
b) At sampling time, two portions of each sample were taken: a smaller one $\sim$ 100 ml into a small bottle in which sulphuric acid preservative was present; and, a larger one $\sim$ 800 ml into a large bottle with no preservative.
c) Sampling bottles were kept in a refrigerator during the sampling period as well as overnight.
d) Analyses commenced next day.

APPENDIX II

ANALYTICAL PROCEDURES

ANALYTICAL PROCEDURES

Chemical analyses of composite samples were done mostly by staff in the central laboratory at ORF, using the following methods:

Temperature - Mercury glass thermometer or YSI oxygen meter - BOD probe.

pH - pH meter

Conductivity - Conductivity Meter YSI Model 31

DS - Gravimetric method after filtration through a Whatman filter GF/C

Procedure

The sample is well mixed and filtered through a glass fibre filter. Known volumes of the filtered sample are transferred to tared evaporating dishes and the water evaporated at 103°C for 24 hr. The dishes are allowed to cool briefly in air before placing in a desiccator containing Drierite. The residues in the evaporating dishes are weighed when cool.

$$\text{mg/l} \quad \text{TDS} = \frac{\text{mg residue x 1,000}}{\text{ml filtrate used}}$$

Turbidity - Hach laboratory Turbidimeter Model 1860 and Hach Turbidimeter Model 2100 A

Procedure

Allow instrument to warm up for 5 minutes. Check zero and adjust if necessary. Insert the standard turbidity rod and place light shield over holder and adjust standardization on the appropriate JTU scale for a reading equal to that stamped on the rod. (Periodic standard turbidity checks using formazin are conducted to insure reliability of the rod. Provided adequate warm-up time is allowed, the instrument is reasonably free from drift on all ranges.)

SS - Gravimetric standard method using glass fibre filter (Reeve Angel 934AH or Qhatman GF/C) dried at 103°-105°C

VSS - Gravimetric method after burning of SS at 600°C

Procedure

Wash the filters with distilled water and dry at 103°C overnight. Cool in desiccator and weigh. Filter the selected volume of sample through the pre-weighed filter, using suction, and wash the funnel with three 10 ml volumes of distilled water. Discontinue suction, remove the filter and dry it overnight at 103°C. Cool in desiccator and re-weigh. Suspended solids are found by the difference in weight in milligrams, multiplied by 1,000 and divided by ml of sample used, to give ppm suspended solids.
After ignition of the weighed filter and SS, the loss in weight in mg times 1,000 divided by ml sample gives ppm VSS.

BOD - Dilution method - samples were pasteurized.

Procedure

To obtain the required oxygen depletions, the following dilutions are suggested: 0.1-1% for strong trade wastes, 1-5% for raw and settled sewage, 5-25% for oxidized effluents and 25-100% for polluted river waters. It should be noted that these are only very rough guidelines. About 1000 ml of each dilution should be prepared. Fill three BOD bottles with the diluted sample, one for determination of the initial DO, the other two for incubation. Stopper the latter two tightly, leaving a water seal, and seal them with parafilm. Incubate at 20°C for five days and determine the remaining DO.

ppm BOD = Initial DO - (Final DO + Seed Corr) x (Dilution Factor)

$N\text{-}NH_3$ - Distillation method - using Nessler reagent and measured by spectrophotometer at 410 nm. In the ORF pilot plant building, the Hach Technique was used (Nessler ization technique).

The sample is preserved with 1 ml of 1 + 9 H_2SO_4 per litre. The acid is neutralized with NaOH immediately before the determination is undertaken.

Procedure

Place 250 ml of sample into a 1000 ml boiling flask along with boiling beads. Add 40 ml of phosphate buffer, pH 7.4 (14.3 g KH_2PO_4 + 68.8 g K_2HPO_4 → 1000 ml water) and 110 ml of distilled water. Note: For samples containing >500 mg Ca, check the pH and adjust, if necessary, to 7.4 with acid or base. Distil over 250 ml into a 250 ml graduated cylinder. Note: The sample should not contain more than 5 ppm of ammonia as NH_4. For higher concentrations, use less sample and more distilled water to give 400 ml in the boiling flask.

Go through the distillation step with sample and standards. Using 50 ml aliquots of sample, standards and a distilled water blank, add 3 drops of Rochelle salt solution and mix. Add 1 ml of Nessler reagent and mix. After 10 minutes, read standards and sample against the (distilled water + reagent) blank. The ammonia in the sample is found from a calibration curve of the absorbance vs. ppm standard.

$N\text{-}NO_2$ - Hach NitriVer Powder Pillows

Procedure

Take a water sample by filling a clean 25-ml graduated cylinder to the 25-ml mark. Pour the sample into a clean sample cell.

Add the contents of one NitriVer Powder Pillow and swirl to mix. A pink color will develop if nitrite nitrogen is present. Allow at least 3 minutes, but not more than 25 minutes for the colour to fully develop and proceed. Fill another sample cell with about 25 ml of the original water sample and place it in the cell holder. Insert the Nitrogen, Nitrite (NitriVer Method) Meter Scale in the meter and adjust the Wavelength Dial to 520 nm. Adjust the LIGHT CONTROL for a meter reading of zero mg/l.

Place the prepared sample in the cell holder and read the mg/l nitrite nitrogen (N).

$N\text{-}NO_3$ - Hach NitraVer V Powder Pillows - method modified at ORF.

Procedure

One powder pillow is added to a 25 ml sample on a magnetic stirrer. The stirrer is turned on at fixed speed for precisely 1 minute. At the end of 1 minute the sample is filtered immediately through Whatman #41 filter paper. The filtrate collected during the exact first minute after stopping the stirrer is used to read the colour intensity against a reagent blank at 500 nm after a further 3 minutes (5 minutes for complete test).

N-T Kjeldahl - Microkjeldahl apparatus is used for digestion and distillation. Ammonia in distillate is determined by the Nessler method.

Procedure

The sample to be analyzed is placed in a Kjeldahl digester flask. To this are added 1 g of potassium sulphite, one Hengar granule (Selenized) and 2 - 5 ml concentrated H_2SO_4. The mixture is digested for 2 1/2 hr or longer until the digest is clear. The samples are then allowed to cool before distillation.

A microkjeldahl distillation apparatus is used. The digested sample, after dilution with about 5 ml distilled water, is poured into the distilling chamber via the funnel. The digestor flack is rinsed and the rinsings are added to the distillation chamber. Sodium hydroxide - sodium thiosulphate solution is added and approximately 25 ml of distillate condensed and collected in 0.02 N H_2SO_4 in an Erlenmeyer flask.

Volume of the distillate is adjusted and diluted if necessary according to values expected and the ammonia determined by the Nessler method.

PO_4 - Total phosphates were determined by ammonium molybdatestannous chloride method with preliminary sample treatment or digestion of sample using strong acid technique.

Procedure

(a) If the sample is alkaline, add phenolphthalein, then strong acid dropwise to discharge the pink colour. Turbid samples should be filtered through glass fibre filters (Whatman GF/C or equivalent). The samples should be diluted with distilled water to contain less than 3 ppm phosphate. If the sample is coloured a blank reading of the acidified sample against acidified distilled water should be done, and the value obtained should be subtracted from the optical density obtained after colour development.

(b) Place 50 ml of sample into a 125 ml Erlenmeyer. Add 2.0 ml of molybdate reagent and mix. Add 5 drops of stannous chloride reagent and mix thoroughly. Read after 10 minutes at 690 nm against a reagent blank.

Settling test - Recorded volume of sludge through 30 minutes and volume after 30 minutes of sedimentation - performed in the ORF pilot plant building.

O_2 - Used YSI Oxygen Meter Model 54 with BOD probe.

O_2-uptake rate - Determined in sample (0.5-3 minutes reaction time) and expressed in mg O_2 per 1 g of VSS per hour.