THE UNIVERSITY OF MANITOBA

Treatability Study of the Wastewater From Freshwater Fish Processing Plants

by

G. MAZZA

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ADDENDUM

RE: THE M.SC. THESIS OF GIUSEPPE MAZZA - OCTOBER 1973

Please by advised that the Supervisor of this student's M.Sc. program was R. A. Gallop.

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(Food Science)

University of Manitoba
Winnipeg, Manitoba,
Canada

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Author: G. MAZZA

Supervisor: Dr. F. A. HENNING

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SCOPE AND CONTENTS

The rapid increase in the nation's already vast output of industrial wastes, together with progressively higher environmental standards, have resulted in increasing demands for economical and reliable methods of liquid waste treatment. An evaluation of the problems, means, and costs of treating the total wastewater from a freshwater fish processing plant was made. The plant processed whitefish, pickerel, trout, sauger, northern pike, tullibee, sturgeon, perch and goldeye. The wastewaters from receiving, filleting, freezing and storage areas after screening, were disposed of into the city of Winnipeg sewage system. The City charged the Corporation mainly on the basis of C. O. D., suspended solids, and flow.

Preliminary investigations with flocculants, peat moss, coal, vacuum flotation, dissolved air flotation and dispersed air flotation, showed that the only potentially economically feasible method of attacking the problem was dispersed air flotation. Batch and continuous dispersed air flotation studies were undertaken to ascertain the feasibility of the treatment process. It was determined that for the continuous dispersed-air flotation process, organic compounds measured by C.O.D. and suspended solids measured by turbidity, can be removed up to approximately 58 percent and 80 percent respectively. The requirements are an air rate of 3000 ml/min, a retention time of 60 minutes, and an air to liquid feed ratio of approximately 91, and no chemicals. In the batch experiments, the effect of air flow rate, initial volume, liquid height, initial concentration, temperature, foam height, column diameter, air diffuser porosity and sampling height were identified and optimized.

Continuous experiments were carried out using feed rates of 33, 40, 67 and 133 cc/min, air rate of 3 litres/min, and initial wastewater volume of 2 litres. The effect of retention time was investigated with simulated and real wastewaters. Because gross organic removal was the parameter of prime interest in these laboratory-scale studies, no attempt was made to distinguish between soluble and insoluble contaminant removals. Likewise, no determinations of the readily biodegradable portion of the organic material removed were made, a portion which would exert a biochemical oxygen demand (BOD) in the receiving body of water.

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NOMENCLATURE

Symbol	Significance
V	initial volume of wastewater, batch process, ml
G	air flow rate, ml/min
H_L	height of wastewater in column above base of column, cm
H_F	height of column of foam between foam-liquid interface and foam collector, cm
H_S	height of sampling above air diffuser, batch process, cm
T	temperature, °C
I.D.	internal diameter
O.D.	outside diameter

CHAPTER I

INTRODUCTION

The large numbers of water bodies in Canada's interior produces a large supply of freshwater fish. The annual catch from these waters averages approximately 120 million pounds, worth 13.5 million dollars at the shore, and 20 million dollars in the food market (Anon., 1971). The processing represents a sizable food industry, and requires the use of considerable quantities of water for operations such as cleaning the fish, transporting the waste material, equipment cleaning and plant clean-up.

The discharge of these wastewaters directly into adjacent lakes and rivers has solved the disposal problem of fish processors for many years. The improvement of the by-product recovery techniques achieved in the last decade had made it economical to remove the large solid materials from the wastewater by screening. The screenings have been utilized for animal feed, but the wastewaters have continued to be discharged into the rivers and lakes. This has been so, mainly because no economical means of treating this type of effluent has been developed.

During the last few years, the increased awareness of the public on matters concerning pollution has led the governments to put pressure on the fish industry to treat their wastewaters before discharge. The Freshwater Fish Marketing Corporation, the largest freshwater fish processing plant in Manitoba, has chosen to have its wastewater treated by The Metropolitan Corporation of Winnipeg. The City applies a surcharge on the basis of flow, suspended solids, and C.O.D. The effluent from The Freshwater Fish Marketing Corporation is large, diluted, subject to wide variation throughout the year, and expensive to treat in-plant by available means. Because of these conditions, the present study was concentrated on dispersed-air flotation, also called foam separation, as a possible wastewater treatment process for this plant. The process has the following advantages:

a) Reduces and eliminates costly surcharges
b) Recovers valuable material presently discharged
c) Does not require chemicals
d) Simple to adapt to automatic control
e) Allows good clarification
f) Existing tanks can be utilized for the installation
g) Economic
h) Simple to operate

An economical treatment method for the wastewater from freshwater fish processing plants was sought, and the variables important for design purposes were investigated.

CHAPTER 2

LITERATURE REVIEW

2.1 Treatability Studies of Wastewater From Fish Processing Plants

Wastewaters from fish processing plants are difficult to treat because of the following:

1. high flows
2. low concentration
3. variation in the type of effluent
4. high odour

Saltwater fish processing wastes have been the object of several studies. The results of these studies have been promising, but the degree to which these results can be applied to the liquid wastes from freshwater fish processing remains to be tested.

Claggett and Wong (1969) studied the effectiveness of screening salmon wastes. Two specific screen types were tested: rotary and tangential. The rotary screen, made of stainless steel 34-mesh screen, was 4 ft. long and operated at 100 U.S. gallons per minute. Solids were removed by a screw-conveyor and the screen was cleaned by high pressure water sprays. The tangential screens, one 20 and the other 35-mesh, had capacities of 20 and 35 gallons per minute. Both screens were judged successful for salmon canning wastewaters. A screen with a capacity 500 U.S. gallons per minute costs approximately $10,000 (Clagget, 1970).

Table 2.1 indicates that with relatively low capital and operating cost of screening, a processor could expect removal of over 50 percent of the total solids in his wastewater.

Table 2.1

Solids Removal from Salmon Wastewater by Screening

(Claggett and Wong, 1969)

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

Shaffner (1970) studied the effectiveness of screening the waste from a groundfish plant, and reported BOD_5 removal up to 60 percent for both 10 and 40 mesh screens. The author was careful however, to point out that the removal was variable, and 20 percent of the BOD_5 and 16 percent of the suspended solids removal would have to be expected for a 20 mesh screen.

Centrifugation is undoubtably effective in removing solids from waste streams. Fats and proteins can also be removed with this method. Kato and Ishikawa (1969), working with horse mackerel (Trachurus japanicas), scabbard fish (Trichiurus Lepturus) and yellow croaker (Pseudosciaena Manchiurica), used a centrifuge to concentrate the solids present in the wastewater stream. They also developed a method by which fish oil and edible protein could be successfully and economically recovered from the centrifuge effluent. Separation of oil from the effluent was conducted by skimming of the frothy surface layer which was subsequently purified. Heating the frothy oil gave an excellent separation of contaminants, water and suspended solids, from pure oil. Protein recovery was achieved by chemical coagulation with high molecular weight synthetic coagulant aid, "Meat Floc", and separations of the floc from the liquid by pressurized flotation. The centrifuge effluent with which the authors were working, had a crude oil content of 2 percent.

Claggett and Wong (1969) studied flocculation for treatment of wastewaters from salmon-canning plants. The flocculants tested were: alum, ferric chloride, F-Flok, alum hydroxide, retanol-A (trade name of an animal glue) and lime. Aluminum hydroxide ($Al(OH)_3$), and F-Flok gave the best results. F-Flok is a commercial coagulant marketed by the Georgia Pacific Corp. and is derived from lignosulfonic acid. A summary of the results achieved in large-scale test with F-Flok is given below in table 2. 2.

Table 2. 2

Classification of Salmon Wastewater by Flocculation with F-Flok (Claggett and Wong, 1969)

F-Flok concentration mg/l	Total solid recovery %	Protein recovery %	Overflow BOD_5
5020	68	92	100
4710	60	80	100
2390	47	69	100

The settling rate was about 4 ft. per hour. The authors also found that the F-Flok gave good results only when used in the range of 8 to 12 percent of the total solids present in the wastewater, when the solids were about 50 percent protein.

Matusky et al (1965), in a preliminary process design and treatability study of fish processing wastes, encountered no unusual problems in a digester operation. They obtained better results when coarse solids and oils were removed before treatment. Without this pretreatment, the oil and grease may interfere with oxygen transfer in the activated sludge process. These authors used grease traps to remove the grease and oils. The digester loading rates used by these investigators varied from 0. 1 to 0. 5 lbs. of volatile solids per cubic ft. per day.

Pearson et al (1970), working with a fairly concentrated synthetic tuna waste, found that 90 percent reduction of BOD and C. O. D. can be obtained in two hours when an activated sludge process is used. Both C. O. D. and BOD reduction to 80 percent are immediate when the waste is mixed with activated sludge. A further reduction of 10 percent is observed in the first two hours; three percent reduction is shown in the next two hours. Settlement of the sludge is rapid; the supernatant is often turbid. They also found that oxygen uptake and BOD reductions increase as mixed liquor suspended solids increase up to a limit of 6, 800 mg/l. The composition of the synthetic waste with which these investigators were working is given in Table 2. 3

Table 2. 3

Synthetic Tuna Waste Composition (Pearson et al, 1970)

Parameter	Unit	Value
C. O. D.	mg/l	2, 280
Chlorides	mg/l	500
Grease	mg/l	295
Nitrogen	mg/l	20
S S	mg/l	825
BOD to C. O. D. ratio		0. 4

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

Dazai et al (1970) reported that treatment of wastes from fish meat paste processing with an activated sludge acclimatized in the waste for one week significantly reduced its BOD. The crude protein and phosphorous contents expressed as P_2O_5 of the precitated sludge were 57 and 5 percent, respectively.

Tsuchiya (1971) also investigated activated sludge treatment of wastes from fish and meat processing plants. A combined aeration and sedimentation system gave BOD and suspended solids removals of greater than 95 and 90 percent respectively at a loading of 0. 3 Kg BOD/cu m/day.

Borchardt and Pohland (1970) found in laboratory-scale studies that two-stage anaerobic digestion could be used for treating alewife processing stick liquor alone or in combination with fresh primary domestic wastewater sludge if the volatile solids loading rates did not exceed 0. 05 lb/day/cu. ft. of digester capacity with respective first or second stage retention time of 10 to 15 days.

Tonseth and Berridge (1968) proposed to remove the proteinaceous material from wastewater by chemical means. The authors tested a number of protein precipitants on a wide range of waste material, including a fish filleting waste. They found that pure lignin sulfonic acid gave the best results. The waste from the fish filleting plant had an original BOD_5 of 1, 240 mg/l, but following treatment with pure lignin sulfonic acid the BOD_5 was reduced to 110 mg/l, a 91 percent removal of BOD_5. It was also found that the ratio of lignin sulfonic acid to soluble protein present in the waste was critical if the maximum degree of purification is to be achieved.

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

Claggett has done considerable work in the treatment of wastes from fish processing plants in British Columbia. Claggett and Wong (1968) reported the results of preliminary studies on treatment of wastewater from a salmon canning operation by dissolved-air flotation. The experimental work was carried outin a continuous 50 U. S. gallons per minute, total flow pressurization flotation cell. The authors suggest that flotation should follow a screening operating which would recover large solid particles. The remaining solids in the wastewater could then be removed by flotation either with or without a chemical flotation aid. Alum can be used as a flotation aid where the primary consideration is the reduction of the insoluble solids load of the wastewater.

Claggett and Wong (1969) continued their study on dissolved air flotation using a more flexible unit than that used in their initial study reported above. It was a "Favair" unit supplied by Permutit of Canada, and had the following advantages over their original unit:

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

The authors tested 34 mesh rotary screens together with 20 and 40 mesh tangential screens as a pretreatment to dissolved-air flotation. They also tested several flotation aids. Precipitated aluminum hydroxide and a modified form of F-Flok, called F-Flok 98 yielded the best results. The precipitate aluminum hydroxide system worked well physically with little floc carried over, a problem when using F-Flok. The effluent water was clear, with only a slight yellowish tinge remaining. The dosage level over the test period averaged at 375 mg/l aluminum sulphate and 75 mg/l of sodium hydroxide. The system on the average removed 73 percent BOD (from 1775 to 475), 44 percent total solids (from 2685 to 1505 p. p. m.), 38 percent soluble solids (from 2045 to 1305 p. p. m.) and 65 percent protein (from 1440 to 485 p. p. m.). This work led to the installation of a full-scale 500 U. S. gallons per minute demonstration treatment plant at Steveston B. C. fish processing plant (Claggett, 1970; 1971). The unit basically involving screening to 0.7 mm or 1.0 mm using tangential screens, storage in a 60,000 gallon surge tank, addition of caustic-alum or alum - polyelectrolyte combination, and removal of the resultant floc by dissolved air flotation in a Model 1250 Pacific Flotation cell. Claggett (1971) reported that the unit required 85 ± 12 mg/l sodium hydroxide and 235 ± 40 mg/l aluminum sulphate. It cost (using some used equipment) $85,000 to install, and $10.50 per hour or 26¢ per thousand gallons to operate. The cost of operation excludes sludge recovery or disposal. The unit removed over 80 percent BOD, over 60 percent protein, over 95 percent fish oil, and over 25 percent soluble solids. A typical analysis of the unit's effluent is shown in Table 2.4.

Table 2.4

Characterization of Dissolved-Air Flotation cell Effluent

Parameter	Unit	Value
Insoluble solids	mg/l	75
Soluble solids	mg/l	1,000
C. O. D.	mg/l	800
BOD	mg/l	500
pH	-	5.4
Fish oil	mg/l	20
Turbidity	J.T.U.	2,000

Very recently, Claggett (1973) reported on an investigation concerned with the treatment of the above flotation cell effluent by means of a biological treatment unit called a Rotating Biological Contactor (RBC).

The 12,000 g. p. d. biomodule consisted of a wet well and rotating bucket feed system, a three-stage treatment system with each section containing twenty-four 6 foot diameter polystyrene discs, and a secondary clarifier with a rotating sludge scoop. The stages are divided by bulkhead and connected in series by troughs. The clarifier is a 5 foot section of the trough with an overflow area of 25 square feet, and an operating volume of 300 gallons. The clarified water overflows a weir mounted on the end of the unit. Settled sludge is removed by the rotating scoop, driven at 4 or 6 r. p. m. The rotating speed of the discs was set at 4 or 6 r. p. m.

The unit performed quite well at loadings up to 20 lbs. C. O. D. per 1,000 square feet per day, showing good stability with fluctuating loads. Little advantage appeared to be gained at higher r. p. m. as far as sludge removal was concerned, and some disc damage occured at the higher r. p. m. About 80 percent removal of applied C. O. D. was reported for loadings of up to 20 pounds C. O. D. per 1,000 square feet per day. The treatment cost appears relatively high. For a 1. 0 m. g. d. unit, Claggett (1973) estimated the installed cost to roughly $250,000. However, the unit was reported to be flexible, easy to start and operate, and attractive as far as operating costs are concerned.

Dreosti (1967) reported on a study concerned with flotation on fish waste. The authors commented on the drawbacks of dissolved-air flotation and suggested that it might be possible to whip air into the wastewater without the need of any air or water pressure system. This technique was tried with "spectacular results" on fish factory effluent, presumably due to the foaming characteristic of the waste. Air can be entrained by surface mixing equipment given sufficiently vigorous beating of air into the liquid. For instance, in the laboratory, good results were obtained by means of high speed (20,000 r.p.m.) rotary blade blender or a centrifugal pump (4,550 r.p.m.) with a suitable air leak at or near the intake. This paper contained little quantitative information on the process. The author did state, however, that good results were obtained with fish effluents containing solid concentrations up to 8,000 mg/l.

2.2 Wastewater Treatment by Foaming

Foaming of wastewater has classically been regarded as a nuisance. In the past, prevention or destruction studies have always had priority over beneficial use studies of the foams.

In recent years however, interest in foaming has been on the rise (Lemlich 1968).

Hansen and Gotaas (1943) were among the first to apply foaming to wastewater treatment. They demonstrated that a "heteropolar lauryl amine hydrochloride, DP243" was an effective "flotation coagulant" agent for the flotation of raw domestic sewage. They succeeded in reducing suspended solids by 95 to 99 percent, bacteria by 99 to 99. 9 percent, BOD by 50 to 80 percent, and dissolved solids, either organic or inorganic, by 25-40 percent. The cost of the additive was thought, however, to be too high and apparently the work was not continued.

With the commercial introduction in the middle 1940s of synthetic detergents based on aryl alkyl sulfonates, foaming in sewage treatment plants, especially on activated sludge aeration basins, in secondary effluents, and on the watercourses into which sewage and sewage effluents were discharged, became a problem of major magnitude (Degens, 1954). Alkyl benzene sulfonate (ABS) residues began to appear, and foaming began to occur in some well waters, indicating the presence of water of sewage origin. This problem stimulated the development of foaming processes for ABS removal.

McGauhey and Klein (1959) in a paper representing a progress report of studies of the removal of ABS by sewage treatment processes, presented perhaps the first data supporting foaming of sewage effluents. They found that 83.2 percent removal of ABS from settled sewage could be achieved by aeration alone, and that with an added frothing agent this overall reduction was increased to more than 90 percent. These positive results led the Sanitary Engineering Research Department of the University of California to undertake laboratory and pilot-scale studies in ABS removal as an intermediate or tertiary sewage treatment process, involving aeration to concentrate ABS in froth, followed by froth removal and disposal by incineration (Klein and McGauhey, 1963). Water solutions of ABS, settled raw sewage (sterilized), and activated sludge effluent were used in these studies. Foam was produced by dropping the wastewater upon a splash plate in a receiving chamber (cascade aeration) and by bubble aeration. The latter method was found to be the most effective of the two. It removed more than 80 percent of the normal ABS content of the sewage. The air requirements for the process ranged from 0.83 to 1.0 cu. ft/gal of sewage treated.

Klein and McGauhey (1963) tested the commercial foaming agent called 2 - octanol and found that its addition increased the percentage removal of ABS by inducing frothing, but resulted in a large volume of net froth. The authors also investigated removal and various disposal methods for the foamate. They found removal a simple matter, requiring only a skimming weir outlet at an end of the covered trough foamer, and continuous incineration of froth, technically feasible with from 3 to 5 cu. ft. of gas per 100 gal., when activated sludge effluent was treated.

Rubin and Everett (1963) studied the foam separation of ABS and of organics analyzed as C. O. D. from secondary sewage effluents. For their experiments, the authors used a column type foamer, 55 cm. high and 7. 5 cm. in diameter. Batch experiments with filtered effluents gave an average ABS removal of 86 percent with a range of 67 to 92 percent. For continuous experiments of both filtered and unfiltered secondary effluent, ABS removal was found to depend primarily on gas-to-feed flow ratio and concentration in the feed. A volume of 1. 5 liters of air per mg. of ABS in the feed produced a foamer effluent concentration of 0. 4 p. p. m. ABS. C. O. D. removal on the other hand, was found to depend on ABS concentration in the feed, and on the air-to-feed flow rate ratio. The highest removal, 40 percent, was obtained when the feed ABS and C. O. D. values were 2. 9 and 118 p. p. m. and the air-to-feed flow ratio was 3. 7.

Brunner and Stephen (1965) constructed the first pilot-size foaming unit. It was a trough foamer 15 ft. long by 9. 8

ft. deep, operating on a feed rate of about 325 gal. of secondary effluent per minute, a gas to liquid volume ratio of 5, and a liquid residence time of about 5 minutes. The unit reduced the ABS concentration of the effluent stream to nearly 1 p. p. m., and achieved gross organic removals of 30 to 35 percent. The foamate flow varied from 1 percent of the feed volume at a foam height of 2. 5 ft. to 10 percent at a foam height of 1. 5 ft.

At about the same time, two additional foaming units were constructed. A 12 million gal/day plant-scale unit at the Whittier Narrows Water Reclamation Plant, and a 0. 5 million gal/day unit at the Valley Community Services District (V. C. S. D.) San Ramon, California Water Reclamation Plant (Stephen, 1965; Jenkins, 1966). The Whittier Narrows foamer was a full-scale longitudial flow unit, 50 ft. (15 m.) in length, 14. 5 ft. (4. 4 m.) wide, and 11 ft. (3. 4 m.) deep treating about 12. 5 m. g. d. (47,000 cu. m/day) of activated sludge effluent. Two rows of "saran" tube diffusers were located 4 ft. (1. 2 m.) and 11 ft. (3. 4 m.) below the liquid surface. The top of the unit was enclosed by a flexible air-tight plastic cover and the foam produced, spilled over a free board into a well, where it was collapsed by spraying with secondary effluent. Activated sludge effluent detention varied between 6. 5 and 7. 3 minutes. According to Jenkins (1966) the unit removed 48 percent of ABS, 26 percent total C. O. D., 43 percent total suspended solids, and 50 percent volatile suspended solids. Total solids, volatile dissolved solids, total phosphate, soluble phosphate and all forms of nitrogen of the secondary effluent were not effected by the process. The Valley Community Service District (V. C. S. D.) unit consisted of a metal hood 8 ft. long by 9 ft. wide by 13 ft. deep, that sat on the surface of a chlorine contact chamber. Air was supplied through cylindrical carborundum diffuser located at the bottom of the unit. At the liquid surface, a layer of "Hexel expanded metal", separated the liquid from the foam layer. Foam spilled over a weir, running the width of the unit and was collapsed by spraying with already collapsed foam. At this unit, Jenkins (1966) found that ABS was decreased from 2 to 0.79 p.p.m., total C.O.D. from 49 to 37 p.p.m., suspended C.O.D. from 8 to 4 p.p.m., and suspended solids from 9 to 3 p.p.m.

With the change-over from nondegradable to degradable detergents in the late 1960 s, removal of ABS was no longer a pressing problem (Anon., 1967). Nevertheless, foaming still offered potential in certain specific problems related to the clean up of wastewaters. Interest thus turned to the removal of non-surface-active species, such as dichromate (Grieves and Wilson, 1965), phosphate (Grieves and Bhattacharyya, 1966) phenolate (Grieves and Aronica, 1966) and cyanide (Grieves and

Bhattacharyya, 1969). Grieves has discussed his extensive work in this area in a recent article (Grieves, 1970) and has indicated that successful removals of the above species and others are possible in the p. p. m. range.

Also, studies were undertaken for removal of microorganisms (Rubin et al, 1966; Grieves and Wong, 1967; Rubin, 1968) and clay (Grieves, 1966) for wastewater clarification. Rubin et al (1966) successfully floated E. Coli and several species of algae. They used low gas flow rates for more efficient removal. Flocculants such as alum, and frothers, such as ethanol, were also found to aid removal.

Grieves and Wong (1967) floated six species of bacteria: Escherichia coli, Serratia marcescens, Proteus vulgaris, Pseudomonas fluorescens, Bacillus cereus and Bacillus subtilis var. niger, all with cationic surfactant ethylhexadecylmethylammonium bromine (EHDA-Br). The authors evaluated the results in terms of total cell count, and found that from neutral water suspensions of pure cultures, (approximately 10^7 cells/ml), the ratios of cell concentrations in the residual suspensions to those in the initial suspensions ranged from 0. 0013 for Bacillus subtilis var. niger to 0. 25 for Serratia marcescens.

Rubin (1968) examined the effect of lauric acid and laurylamine with and without aluminum sulfate upon the flotation of Aerobacter aerogenes. He found that at constant gas flow rate, collector (lauric acid or laurylamine) and alum (when used) concentrations, and frother doses, A. aerogenes removals were improved after coagulation.

Grieves (1966) investigated the effects of pH, mono-, di-, and trivalent cations and anions, and organics upon the flotation of turbidity from synthetic suspensions. The turbidity consisted of illite clay, of natural dirt and sand (soil origin), and Fuller's earth; excellent removals were achieved for waters containing high concentrations of a variety of inorganics and organics, but interferences to the process were provided by the presence of iron, aluminum and phosphate.

In the nuclear waste field, a good deal of interest was shown several years ago in the removal of trace radioactive metals by foaming (Lemlich, 1968). Effective removals of such isotopes as Cs^+, Cs^{2+}, ^{89}Sr, and ^{90}Sr were achieved. Hydrogen sulfide has been removed from sour water by foaming utilizing a surface-active oxidizing agent (Bheda and Wilson, 1969). Schoen et al, (1962) successfully removed radium from uranium wastewater.

A fairly recent and interesting development in the foaming of industrial wastewaters is the electro-air foaming process described by Ellwood (1968). Apparently, the method works by electrolyzing water in the stream, and using the resultant air bubbles to float particles to the surface. According to Ellwood, the air bubbles are produced on a pair of electrodes, with a porosity of 60-75 percent, and subjected to a potential difference of between 8 and 10 volts.

This literature review gives an indication of the current knowledge of treatment of wastewaters from fish processing plants, and also provides information on a number of studies concerned with application of foaming (dispersed air flotation or foam separation) to wastewater treatment. The treatment of wastewater from fish processing plants has been the subject of a number of investigations, but in all the studies, seafood processing wastewater as opposed to freshwater fish processing wastewater, has been the subject of investigation. There is no available information of any kind on the treatment of wastewater from freshwater fish processing operations, and the foaming process, while considered applicable to ABS, microorganisms and clay removal, has never been investigated or even proposed for the treatment of wastewater from fish processing plants. The present study was undertaken to seek an economical treatment method for the wastewater from Freshwater fish processing plants, to set forth the process, and to generate information for its application.

CHAPTER 3

TREATABILITY STUDIES

3. 1 Experimental Apparatus and Procedure

Schematic flow diagrams of the apparatus used for the batch studies is shown in Figure 1. In the continuous studies, feed was pumped through an additional inlet at the bottom, and effluent was withdrawn continuously from the sample tube. The most important part of the equipment was the foam column, which was constructed for versatility so that liquid height and foam height could be changed conveniently and the same column could be used with different air diffusers, with more than one sampling tube, and with or without a feeding tube. The foaming column assembly, consisting of a foaming section, foam collector and the air diffuser, was put together in the laboratory. An acrylic plate formed the bottom of the column. Unless otherwise indicated, all the experiments were conducted at room temperature and with 53 inch (132. 6 cm.) long, 3 1/2 inch (8. 9 cm.) O. D. , 3 1/4 inch (8. 3 cm.) I. D. acrylic column, distributed by Johnson Industrial Plastics (Western) Ltd. (Winnipeg, Manitoba, Canada). The foam collector, also shown in Figure 1, was made of a circular plate 8 cm. in diameter and 1 cm. in thickness. It contained six 1. 5 cm. in diameter holes, in which

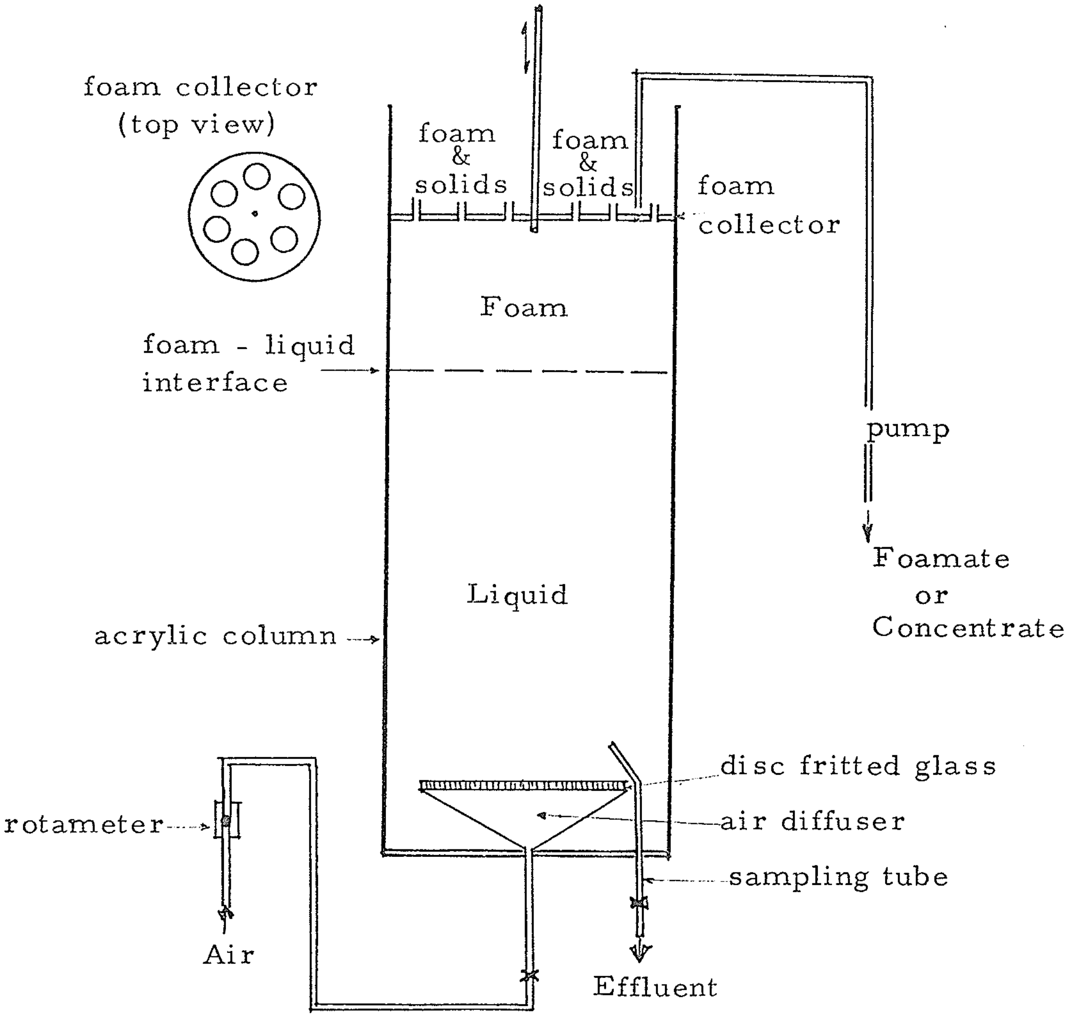

Fig. 1 Apparatus used for Batch Dispersed - Air Flotation Studies

were inserted six 0.9 cm. I. D. vinyl tubes. The vinyl tubes were 6.0 cm. long projecting 5 cm. above the plate. By placing an O-ring around the plate, the foam collector was made watertight. The compressed air from the laboratory supply first passed through a pressure regulator, then was metered with a calilbrated rotometer and diffused through a 6.5 cm. diameter fritted glass disc, Kimax Brand, distributed by Canadian Laboratory Supply Ltd. (Winnipeg, Manitoba). The fritted glass disc was held in place by a funnel-shaped glass casing, 1 inch (2.54 cm.) in depth. This will be referred to as the air diffuser. The air diffuser was attached at the bottom of the column through a 3/8 inch (0.95 cm.) I. D. nylon Swagelok tube fitting.

Air and feed to and effluent and foamate from column assembly, were carried into Jayflex 180 non-toxic vinyl tubings made and distributed by Johnson Industrial Plastics Ltd. The sampling and feeding tubes were glass tubes, and were attached at the bottom of the column by means of Swagelok tube fittings.

Unless otherwise indicated, one sampling tube was used, and the samples or effluent were taken 3-5 cm. above the air diffuser. The foamate (solids-liquid mixture) was continuously removed from the top of the foam collector by means of a Masterflex tubing pump, made by Cole-Palmer Instrument Co. (Chicago Ill.). An identical pump was used to pump the feed into the column. For most of the runs, an air diffuser of medium porosity was used.

Simulated freshwater fish processing wastewater was used for the batch studies. The use of simulated wastewater provided a continuity of waste characteristics, while studying selected parameters under variable conditions. The simulated wastewater was synthesized to the average values determined by a characterization of the real wastewater from the Freshwater Fish Marketing Corporation Plant. Details concerning the preparation are given in Appendix 1. Simulated and real freshwater fish processing wastewaters were used for the continuous studies.

The effect of column diameter was studied by assembling a 53 inch (132. 6 cm.) long, 6 inch (15. 24 cm.) O. D. , and 5 3/4 inch (14. 6 cm.) I. D. acrylic column. The foam collector for the wider column, had eighteen 1. 5 cm. in diameter holes, each containing a 0. 9 cm. I. D. and 6 cm. long vinyl tube.

In the batch experiments, simulated wastewater was placed into the column, and a predetermined air flow was introduced to the column by setting the appropriate rotameter reading. Pumping out of the foam was then initiated, and samples of the treated water were taken and analyzed for C. O. D. and Turbidity. The foam height, that is, the distance between the foam-liquid interface and the foam collector was adjusted by lowering the foam collector to a predetermined distance every five minutes. The volume of collapsed foam or liquid reflux was also measured.

For the continuous experiments, 3000 ml. of simulated or real wastewater was placed into the column and foamed for 1.0 hr. as for the batch studies. After 1.0 hour, feed was introduced to the column at a predetermined rate. The drain rate was adjusted to maintain a constant volume of liquid (2000 ml.) in the column and the foam height was adjusted to 10 cm. The feed rate to the column and the drain rate from the bottom of the column, were controlled by rotameters. After 10-15 minutes, the first sample of the drain or effluent stream was taken for analysis and the volume of collapsed foam measured. Sampling and foamate or collapsed foam measurements were continued for several hours. C. O. D. analyses were carried out according to the procedure outlined in Standard Methods for Examination of Water and Wastewater, 13th edition (1971). Turbidities were determined by a nephlometer made by Evans Electroselemium Ltd. (Halstead, Essex).

3.2 Batch Dispersed Air Flotation Studies

In the batch experiments, wastewater of given initial volume and concentration was subjected to aeration by an air stream for a specific period of time, with simultaneous removal of foam.

3. 2. 1 Effect of Air Flow Rate and Initial Volume of Wastewater or Liquid Height

The first series of experiments were conducted to establish the influences of air rate (G), and initial volume of wastewater (V), or liquid height (H_L) upon the foam separation characteristics of pollutants present in freshwater fish processing wastewater.

The experiments were conducted at air rates of 2000, 3000 and 4000 ml/min and 2, 3 and 4 litres of initial wastewater volumes. The initial liquid heights in the 8. 3 cm. I. D. foaming column were 39, 57 and 75 cm. The freshly made simulated wastewater used for each experiment had approximately the same pollution load. The original C. O. D. and turbidity were 660 mg/l and 71 turbidity units respectively. A foam height of 20 cm. was chosen, and was maintained at 20 ± 1 cm. by adjusting the foam collector. The C. O. D. and turbidity were followed by analysing samples of foamed water after 5, 10, 15, 25, 35, 45 and 60 minutes of foaming. The samples were taken 5 cm. above the air diffuser. The volume of collapsed foam was also measured.

3. 2. 2 Effect of Original Concentration Variations

In an effort to determine whether the original concentration of the wastewater had any effect upon the treatment process, fresh simulated wastewaters varying in C. O. D. and turbidity were subjected to foaming. The experiments were designed to demonstrate the effect of original concentration on the range of operable concentrations, holding constant other experimental variables. An air flow rate to simulated wastewater volume ratio of 1 and 20 cm. foam height was employed.

3. 2. 3 Effect of Temperature

Several experiments were conducted at temperatures of 10, 25 and 41°C and at an air rate of 4000 ml/min. The original volumes of wastewater were 3000 and 4000 ml and the foam height above the interface was held constant at 25 cm. Each volume of simulated wastewater of various concentrations, was foamed at the said air rate and removal height, and at three different temperatures. The C. O. D. and turbidity removal were sampled 3 - 5 cm. above the air diffuser after 5, 10, 15, 25, 35, 45 and 60 minutes of foaming.

3.2.4 Effect of Air Diffuser Porosity

Sparging, or blowing a gas through a body of liquid is certainly one of the simplest methods of foam generation. Preliminary experiments indicated that the uniformity of the foam bubbles was important to the foam stability and to avoid channeling. To investigate the effect of air diffuser porosity, three fritted glass discs of fine, medium and coarse porosity of equal diameter and thickness were sealed to three identical funnel shaped glass casings. Holding constant other experimental variables 3 liters of simulated wastewater were foamed with each air diffuser. The air rate was 3000 ml/min. The foam height was 20 cm. and the original C. O. D. and turbidity of the freshly made simulated wastewater were 629 mgl/l and 49 turbidity units respectively.

While using each air diffuser, the C. O. D. and turbidity removal were followed for 40 minutes. The volume of collapsed foam was also measured.

3.2.5 Effect of Foam Height

Foam height (H_F) appeared to effect the degree of treatment achieved in a foaming operation. In order to determine the extent of the effect, a series of experiments to this end were conducted. Two and 4 liters of simulated wastewater were foamed using air rates of 4000 and 2000 ml/min, and 20 and 40 cm. foam heights for each volume air rate combination. A medium porosity air diffuser was employed. The C. O. D. and turbidity removal and the liquid reflux were followed for 45 minutes.

3. 2. 6 Effect of Column Diameter

Of those variables governing the performance of a batch dispersed air flotation system such as air rate, concentration, foam height, volume of liquid and others, only the column diameter was considered in this series of experiments.

Two foaming columns of 8. 26 cm. and 14. 5 cm. I. D. (inside diameter) provided with the arrangements for aeration, foam removal and sampling were used. In each column, 2, 3, and 4 liters of simulated wastewater were aerated for 1 hour using a 3000 ml/min air flow rate. For both columns, the foam height was 20 cm. The air was dispersed in the wastewater by means of the same medium porosity air diffuser. The percent C. O. D. and turbidity removal and the liquid reflux were followed for 1 hour.

It is important to note that in order to keep the column areas to foam collector apertures area ratio constant for both columns, the foam collector used for the wider column had eighteen 0. 9 cm. I. D. vinyl tubes, while the narrow foam column had only six.

3.2.7 Effect of Sampling Height (H_S)

As the bubbles from the air diffuser rise through the wastewater, they adsorb part of the solute and carry it to the top of the column where it may migrate to the air liquid interfaces associated with the bubbles and become part of the foam phase or may be released back to the liquid if the bubbles pass out. After several minutes of bubbling a vertical gradient in concentration is expected increasing from bottom to top. In order to demonstrate that such a gradient did in fact exist, an additional sampling tube, projecting 60 cm. above the air diffuser was attached at the bottom of the column. Five liters of simulated wastewater were then foamed. The air flow rate was 3000 ml/min and the foam height was 30 cm.

After 10 minutes of foaming, 2 samples, one through the tube projecting 60 and one through the tube projecting 3 cm. above the air diffuser, were simultaneously withdrawn. Before taking the samples, the tubes were flushed with a few mls. of the partially treated liquid waste. Following this same procedure, three more sample pairs were taken after 20, 30 and 40 minutes of foaming.

3. 3 Continuous Dispersed Air Flotation Studies

In the continuous experiments, a feed wastewater is continuously introduced into the column and foam and drain liquid streams are continuously removed. The volume of the wastewater is held constant during the operation by adjusting the drain rate equal to the feed rate minus the foam rate. To test the applicability of the dispersed air flotation treatment process to prescreened wastewater from freshwater fish processing plants, a series of continuous experiments were carried out in the same column as that in which the batch studies were made.

The continuous studies however, were extended to real wastewater as well. This was deemed advisable since the studies with simulated wastewater provided information only on the foaming characteristics of that wastewater. They would not necessarily yield information on the effectiveness and applicability of the treatment process to design a dispersed air flotation plant for treatment of wastewater from the Freshwater Fish Corporation Plant.

3. 3. 1 Effect of Liquid Retention Time

For feed rates of 33, 40, 67 and 133 ml/min, experiments were conducted with simulated and real wastewater. The liquid column volume was maintained at 2000 ml. with foam heights of 10 and 20 cm. A single air rate of 3000 ml/min was employed. The concentration of organics and suspended solids, measured as C. O. D. and turbidity of the effluent stream, were then carefully determined. All the experiments were conducted at room temperature and with the feed introduction into the liquid column 28 cm. above the air diffuser.

CHAPTER 4

DISCUSSION OF RESULTS

4.1 Batch Dispersed Air Flotation Studies

Investigated were the effects of air flow rate, initial volume of wastewater or liquid height, original concentration, foam height, temperature, air diffuser porosity, column diameter and sampling height.

The purpose of these studies was twofold; to establish the independent variables that influence dispersed air flotation, and to determine quantitatively the effect of each independent variable of significance for design purposes. Foaming times varied from 35 to 60 minutes.

4.1.1 Effect of Air Flow Rate and Initial Volume of Wastewater or Liquid Height

C. O. D. and turbidity removal curves at 2000 and 3000 ml/min air flow rate, 2000 ml. of simulated wastewater and 20 ± 1 cm. foam height are shown in Figure 2. The figure shows an increase in rates of C. O. D. and turbidity removal with an increase in air flow rate and a smaller difference in final removal. This higher removal was to be expected since for this aeration system, the number of bubbles given off per unit time is larger. The larger number of bubbles resulted in greater surface area and a greater mechanically entrained liquid volume carried out of the foam column with the bubbles.

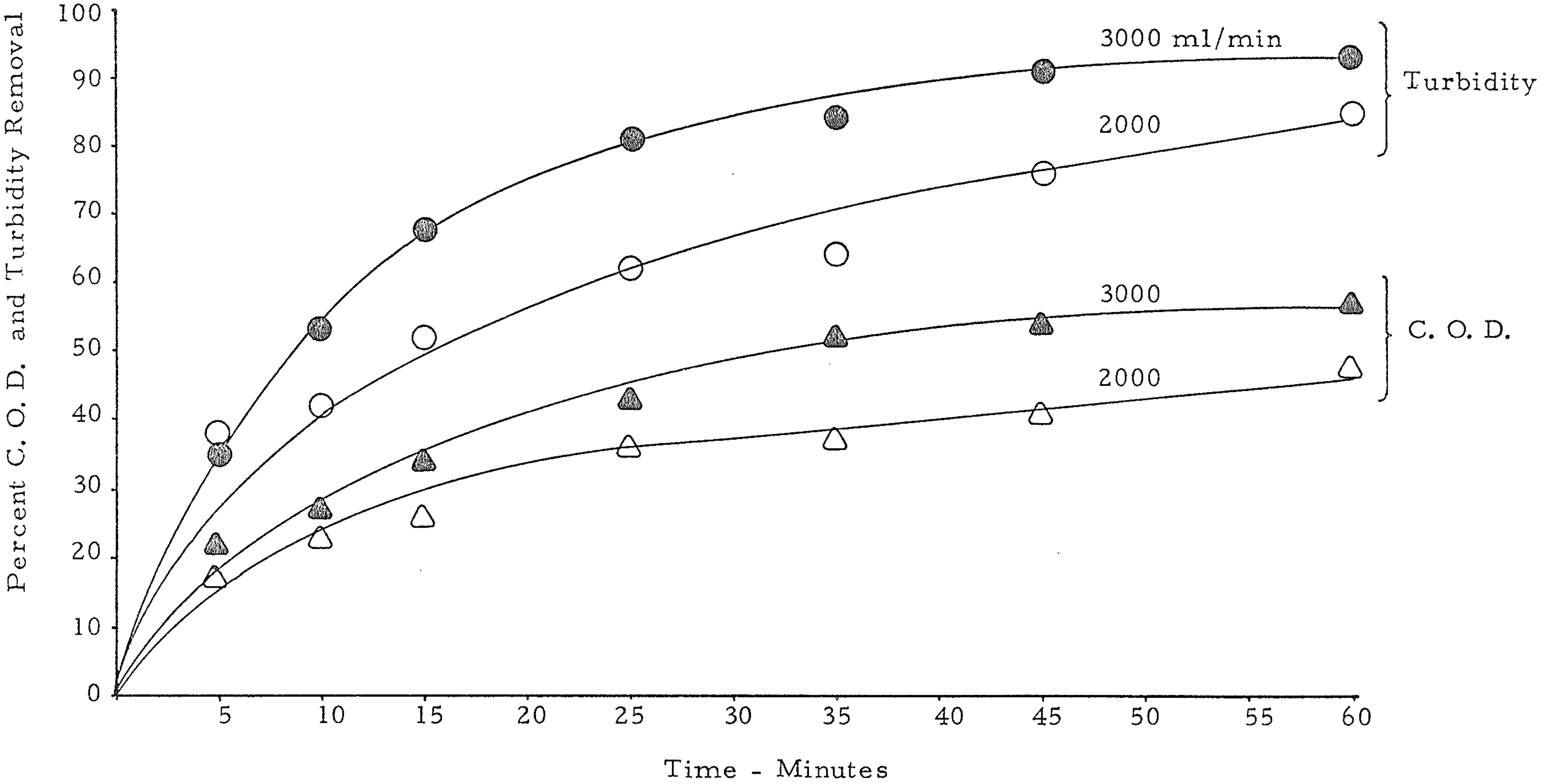

Fig. 2 Effect of Air Flow Rate on C. O. D. and Turbidity removal

V = 2000 ml. , H_F = 20 cm.

Similar results are shown in Figure 3. Here, the volume of wastewater is 3000 ml. and the removal rates are slightly less than that observed with 2000 ml. of wastewater. The plot also shows the effect of air flow rate on the liquid carried into the foam. The latter increases with increasing air flow rate.

Figure 4 indicates the effect of initial volume of wastewater on the removals and liquid reflux at 3000 ml/min air flow rate. The plot discloses that removals and percent of liquid carried into the foam decrease very little with increasing initial volume or liquid height of wastewater foamed.

The shape of the curves indicates that the following empirical formula may be applicable:

$$\% \text{ removal} = A(1 - e^{-kt})$$

$$\therefore \log_{10} = (A - \% \text{ removal}) = \log A - kt$$

where A = final removal (percent)

t = time (minutes)

k = removal rate constant (min^{-1})

Figure 5 is a plot of C. O. D. removal curves of Figures 2 and 3. The plot discloses that the curves are first order and yield straight lines. The removal rate constants produced by the slopes of the lines, increase as the air rate increases and decrease as the initial volume of wastewater decreases. The removal rate constant is a good indication of the speed of removal. Hence, the speed of removal

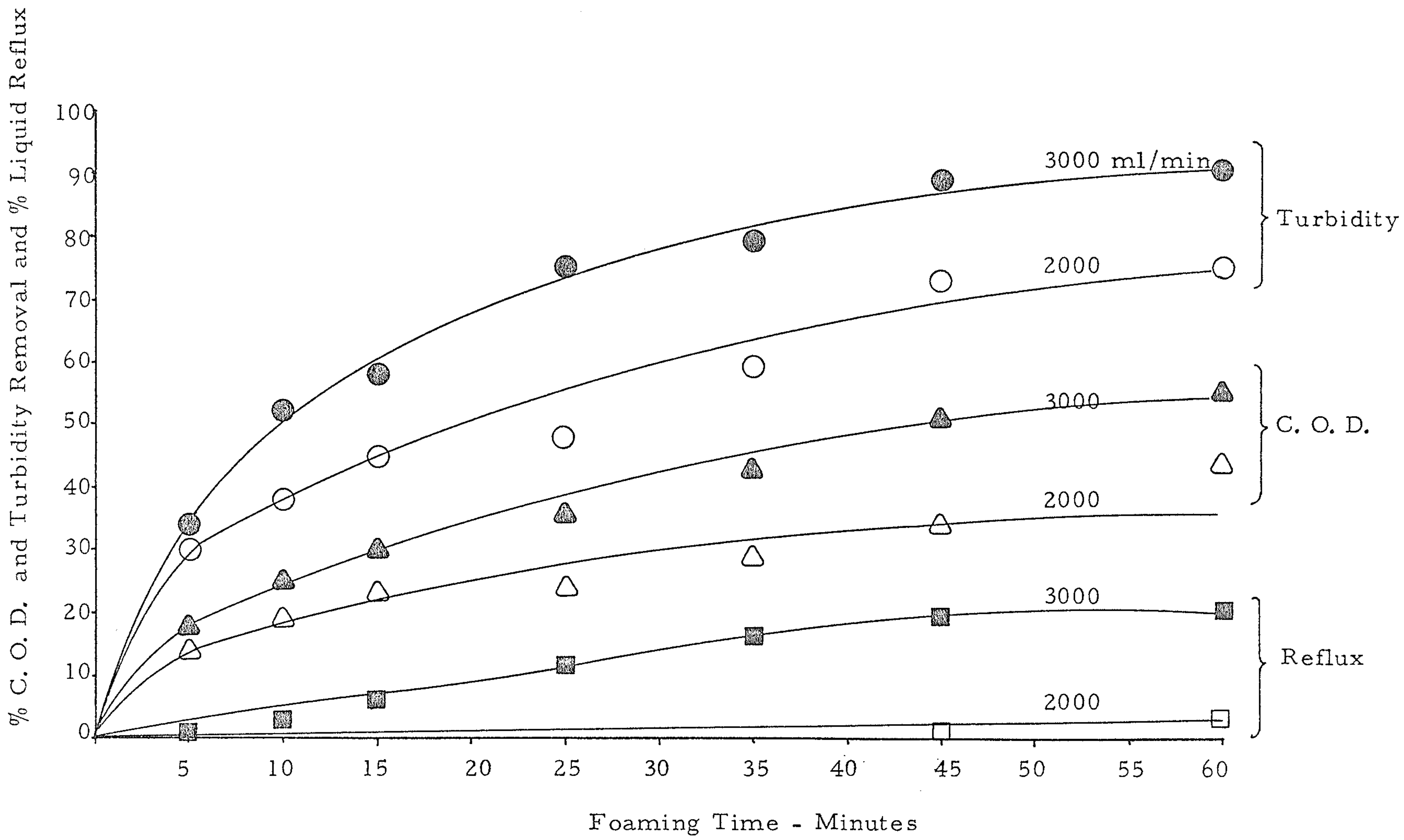

Fig. 3 Effect of Air Flow Rate on Percent C. O. D. and Turbidity removal and on Percent Liquid Reflux; V = 3000 ml., H_F = 20 cm.

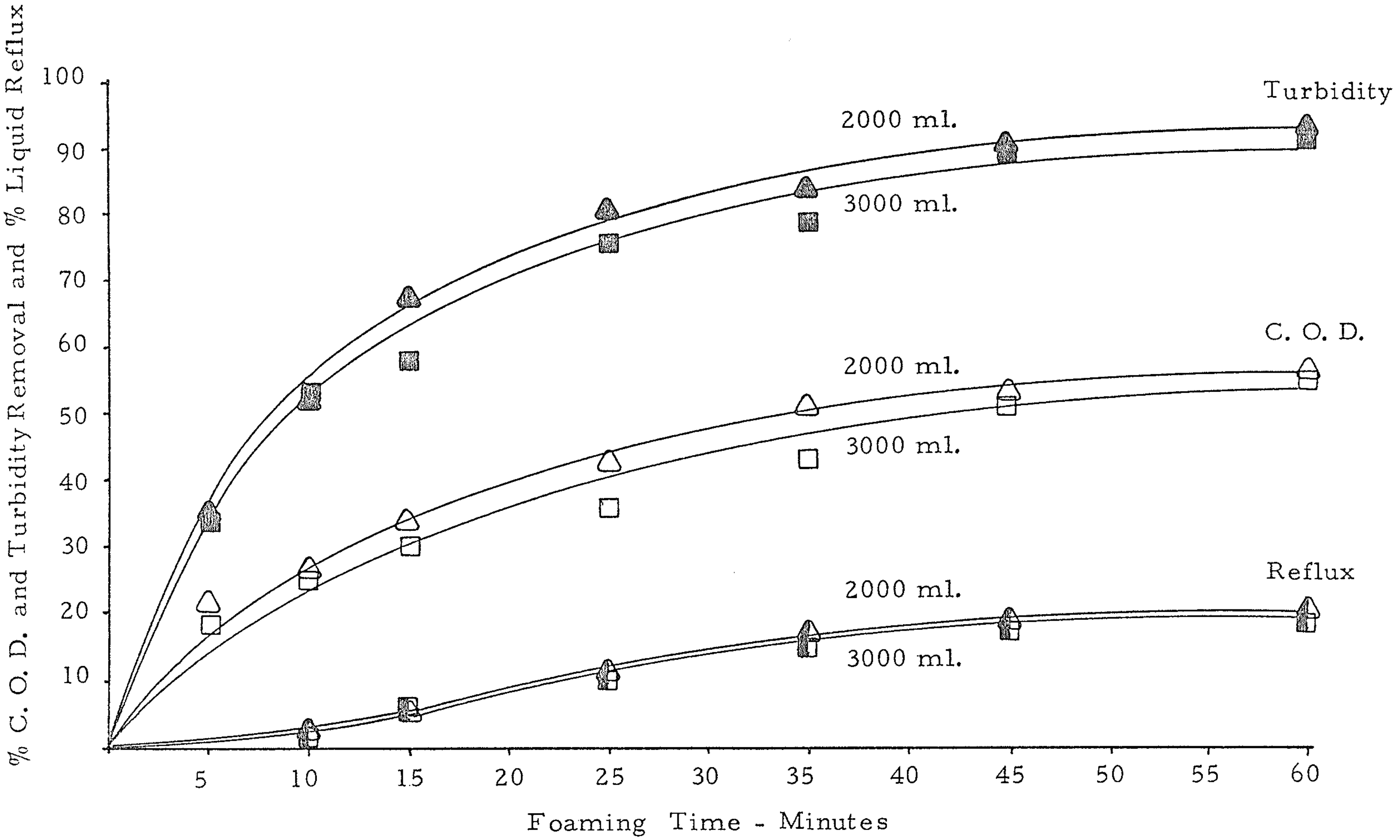

Fig. 4 Effect of Initial Volume on percent C. O. D. and Turbidity removal and on Liquid Reflux for G = 3000 ml/min and H_F = 20 cm.

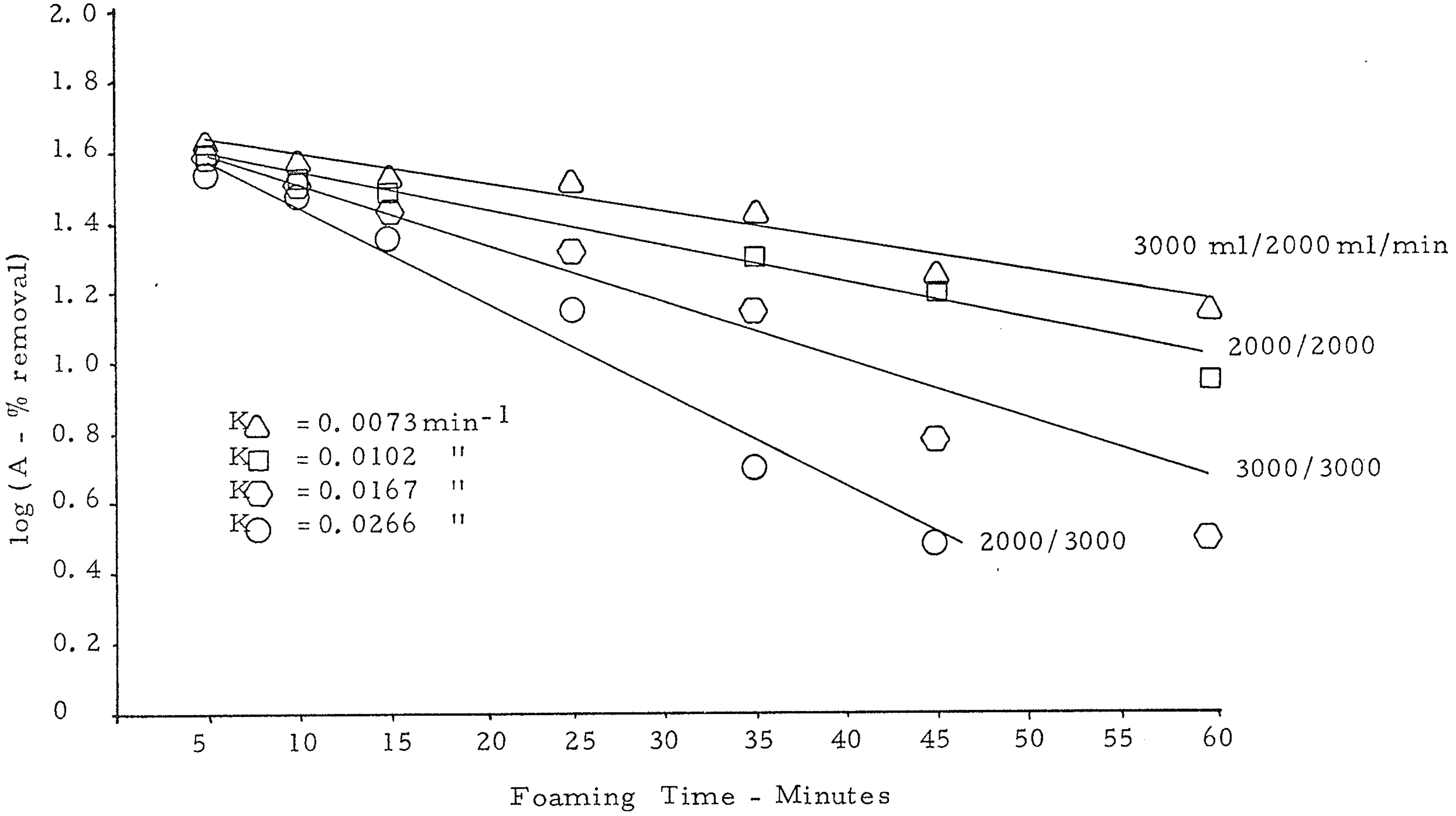

Fig. 5 C. O. D. removal rate constants for 3000 ml/2000 ml/min, 2000/2000, 3000/3000 and 2000/3000 Initial Volume to Air Rate Ratios.

increases as the air flow rate increases, and decreases as the initial volume of wastewater increases. The increase however, is greater than the decrease only at the lower values of air flow rate and initial volume of wastewater. At the higher values, the two opposite effects are almost equal. Seemingly, this is due to the higher percentage of liquid carried out of the column into the foam.

Figure 6 shows that removals and liquid carried into the foam are different at the same initial volume of wastewater to air flow rate ratio. For the higher values of initial volume (V), and air flow rate (G), the removals are higher than for the lower values, but the percentages of liquid carried into the foam are much higher. After 25 minutes of foaming, the percentage of liquid carried into the foam is less than one percent for V/G = 2000 ml/2000 ml/min, 10 - 11 percent for V/G = 3000 ml/3000 ml/min, and almost 30 percent for V/G = 4000 ml/4000 ml/min. Hence, the higher removal rates must be due at least in part, to the early and continuous reduction of the wastewater volume being foamed.

It is important to note that the experimentally observed effects of air flow rates and initial volume of wastewater are not simple. There were sub-effects such as gross circulation and bubble diameter changes that could not be controlled. The breaking patterns of air bubbles are different for different air flow rates, and when

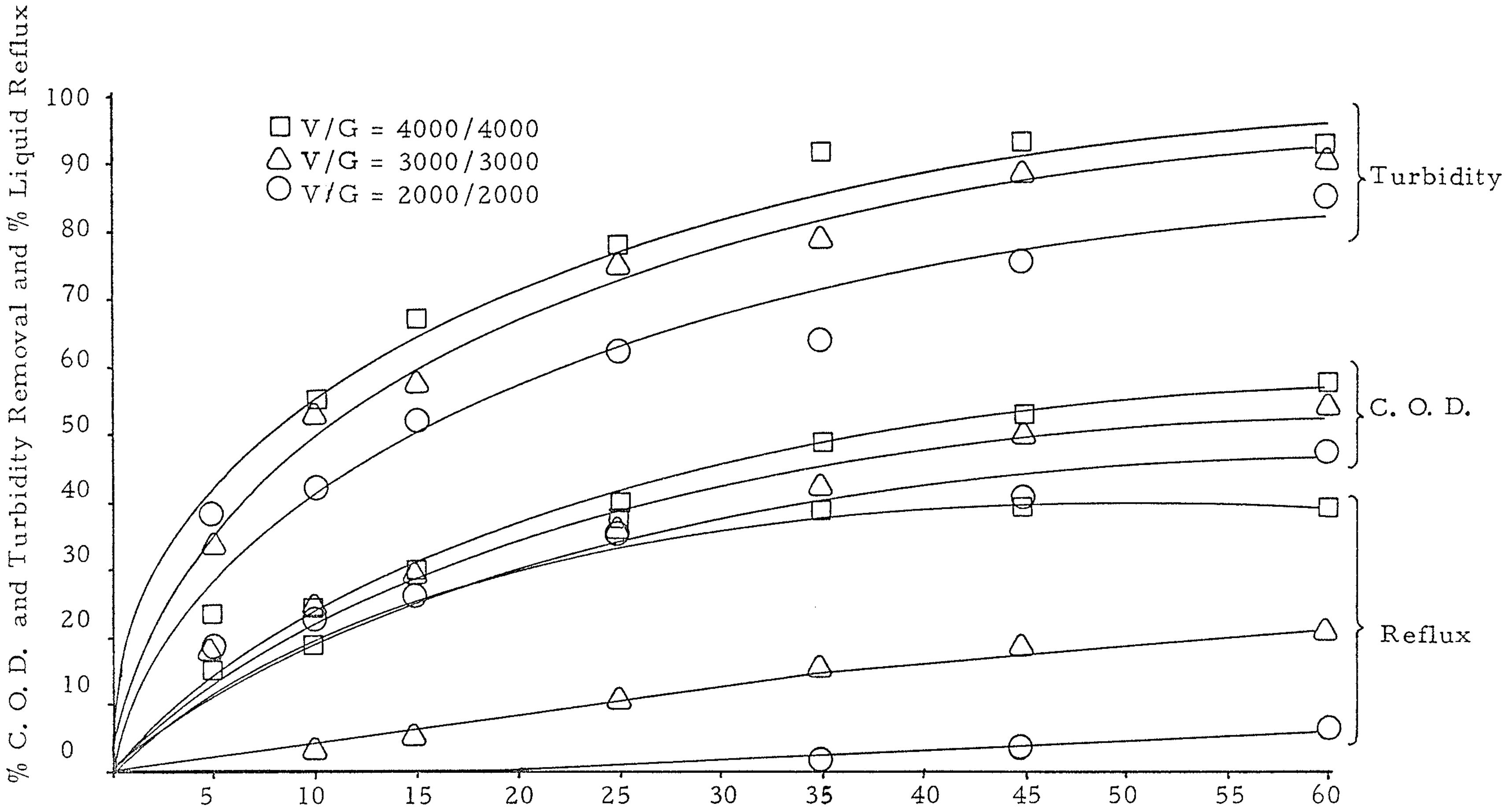

Fig. 6 Effect of V/G on percent C. O. D. and Turbidity removal and on percent Liquid Reflux for H_F = 20 cm.

bubbles break, a part of the liquid falls back into the semi-purified wastewater. At the present time, there is no way of determining a priori the extent to which these sub-effects interfered. For any one condition however, the removals depend primarily upon the air flow rate and are less dependent upon the initial volume of wastewater or liquid height.

4. 1. 2 Effect of Original Concentration

The results of aerating two wastewaters of different original concentration for 1 hour under the same set of operating conditions, are presented in Figures 7 and 8. From Figure 7, which shows C. O. D. remaining vs. foaming time, it can be seen that after 10, 15, 25, 35, 45, and 60 minutes of foaming the C. O. D. remaining is higher for the more concentrated wastewater. The distance between the curves, however, decreases as foaming proceeds. This indicates that the rate of removal is higher for the more concentrated wastewater, and it seems that the same final C. O. D. can be reached by foaming the more concentrated wastewater for a longer period of time.

Figure 8, a plot of turbidity remaining against foaming time, shows that practically the same final suspended solids concentration is reached in 60 minutes. This clearly indicates that the suspended solids removal rate is higher for more concentrated

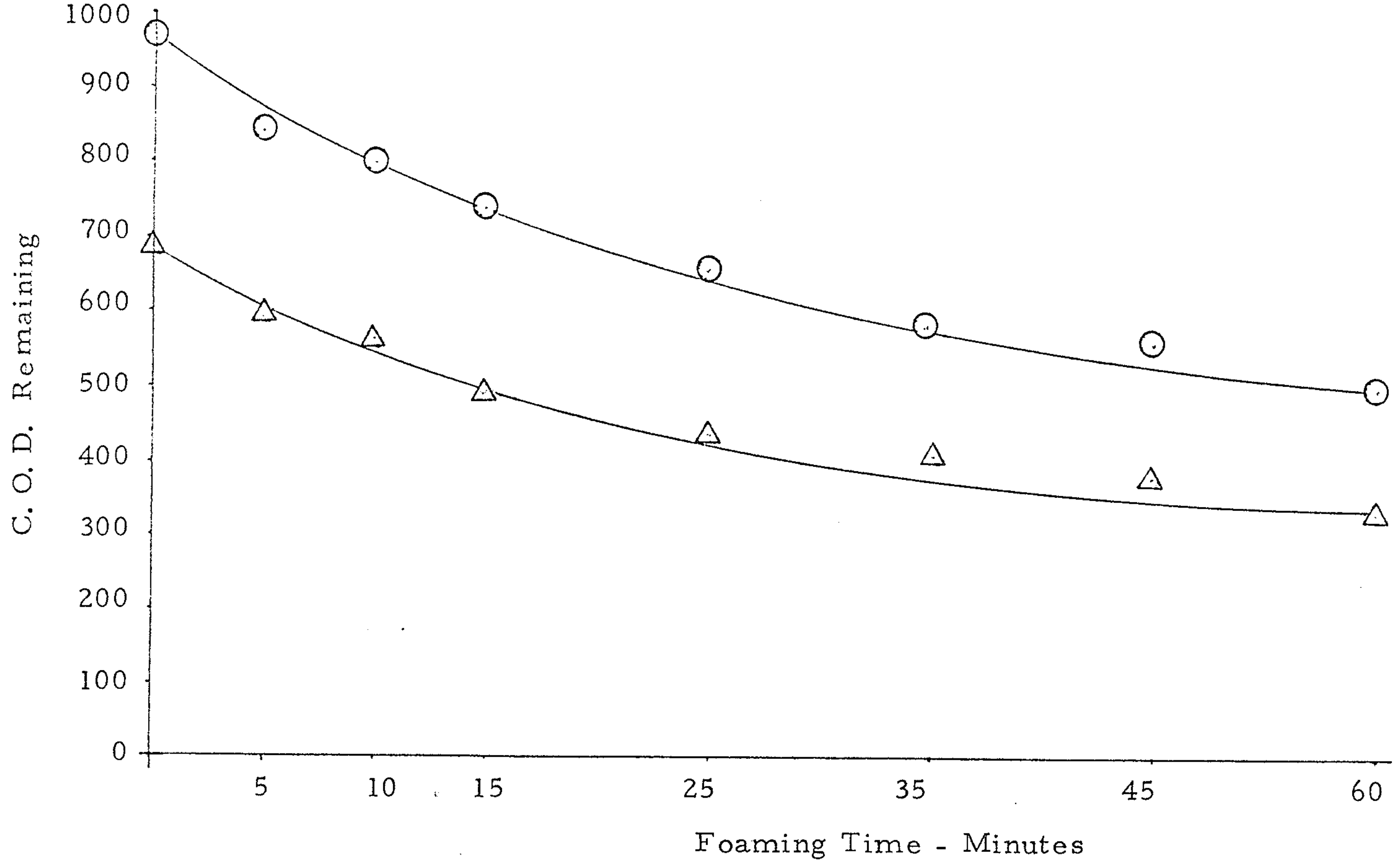

Fig. 7 Plot of C. O. D. Remaining against Foaming Time; V = 3000 ml, G = 3000 ml/min, H_F = 20 cm

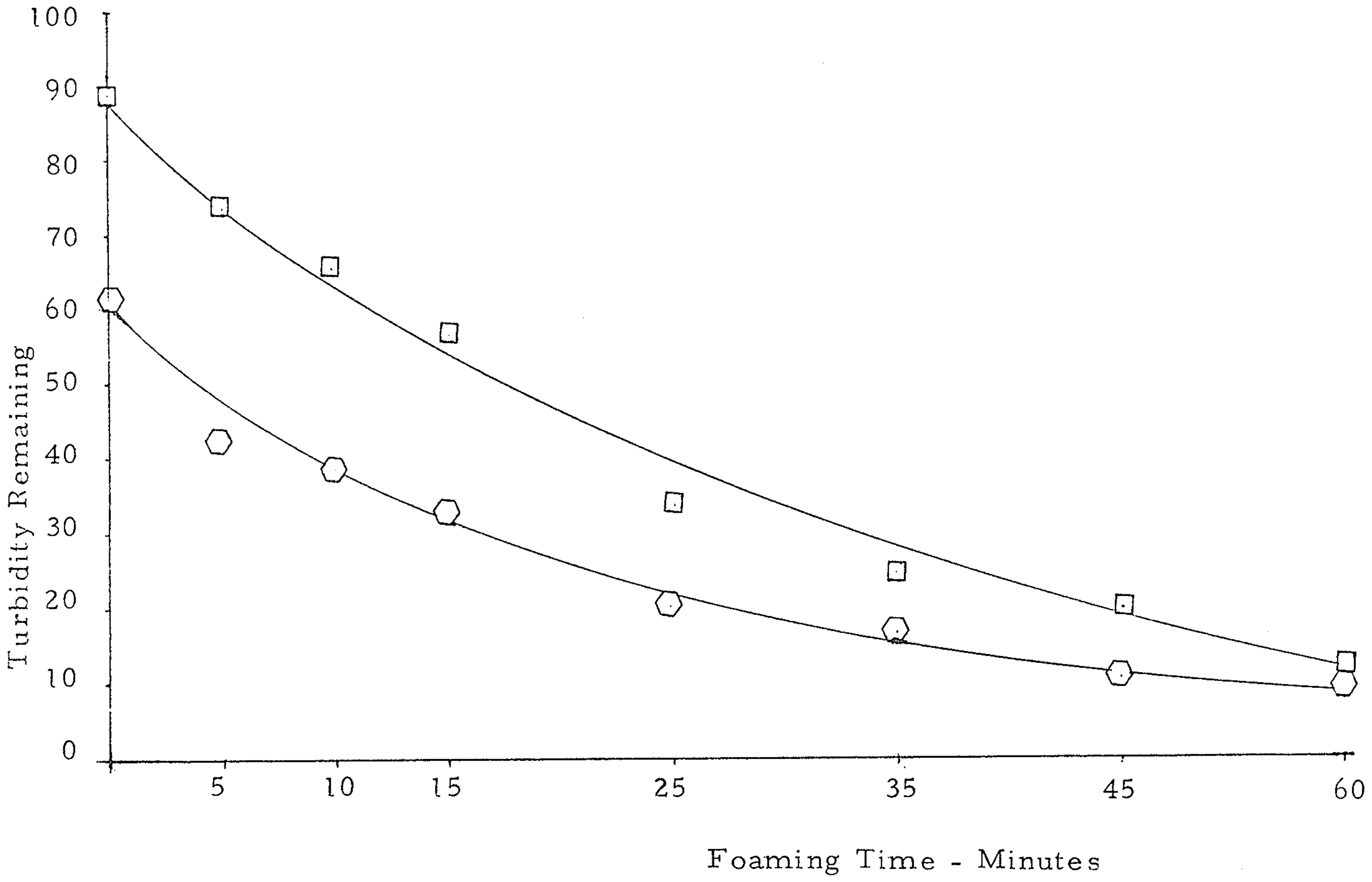

Fig. 8 Plot of Turbidity Remaining against Foaming Time; V = 3000 ml, G = 3000 ml/min, H_F = 20 cm

wastewaters.

The practical implications of these results are two. The first, is that for short foaming time dispersed air flotation is more efficient for suspended solids removal than it is for C. O. D. removal. The second, is that for long foaming times, the process is not dependent upon the initial concentration of the wastewater.

4. 1. 3 Effect of Temperature

In order to illustrate the effect of temperature on C. O. D. and turbidity removals on liquid reflux, two extreme temperatures were studied. Figure 9 shows that the C. O. D. and turbidity removals, as well as the liquid carried into the foam, increased with temperature for fixed values of air flow rate, initial volume of wastewater, foam height and concentration. It was observed while performing the experiments, that by warming up the wastewater, particles were formed. These were very much like floc, and provided they were not too large, the air bubbles were more effective in carrying them up stream. This appears to be the main cause for the higher removals.

The reason for the larger quantity of liquid carried into the foam at the higher temperature is not clear. Viscosity decreases

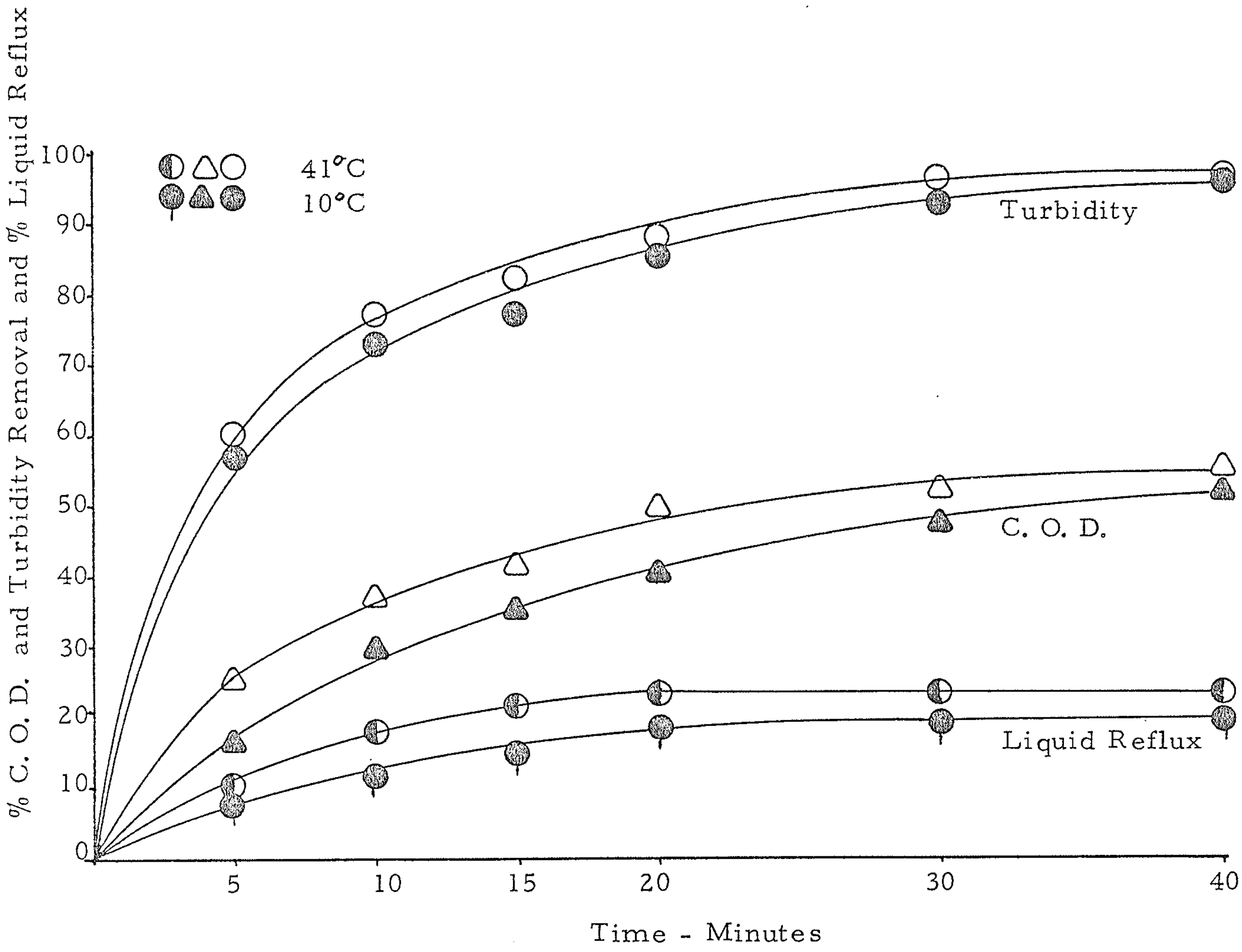

Fig. 9 Effect of Temperature on C. O. D. and Turbidity removal and Liquid Reflux

Simulated Wastewater = 3000 ml, Air Flow Rate = 4000 ml/min, H_F = 25 cm.

Original C. O. D. = 425 mg/l Original Turbidity = 30 Turbidity Units with temperature and foam drainage increases with viscosity. Hence, liquid carried into the foam which decreases as foam drainage increases should have been lower at the higher temperature. The fact that it was higher, indicates that foam drainage depends on factors besides viscosity. From Figure 9, it may also be noted that the difference in final removals, and the difference in liquid carried into the foam decreased as foaming continued. This can be attributed to the fact that the temperature was not held constant during the foaming period. The warmer wastewater cooled off to 30°C, and the cooler wastewater warmed up to 15°C.

4.14 Effect of Air Diffuser Porosity

Because bubble diameter varied with time and position and is difficult to measure experimentally (Grieves et al, 1970), air diffuser porosity was investigated as the independent variable. Typical results of the investigation are shown in Figure 10. Removals appear to be generally higher when using finer porosity. The highest percentage of removals as well as liquid reflux (collapsed foam), were obtained with fine porosity air diffuser. The difference however, is not that evident in Figure 10. The percent C. O. D. removal for fine and medium porosities is practically the same, and so is the turbidity and liquid reflux for medium and coarse porosity air diffuser. The coarse porosity air diffuser

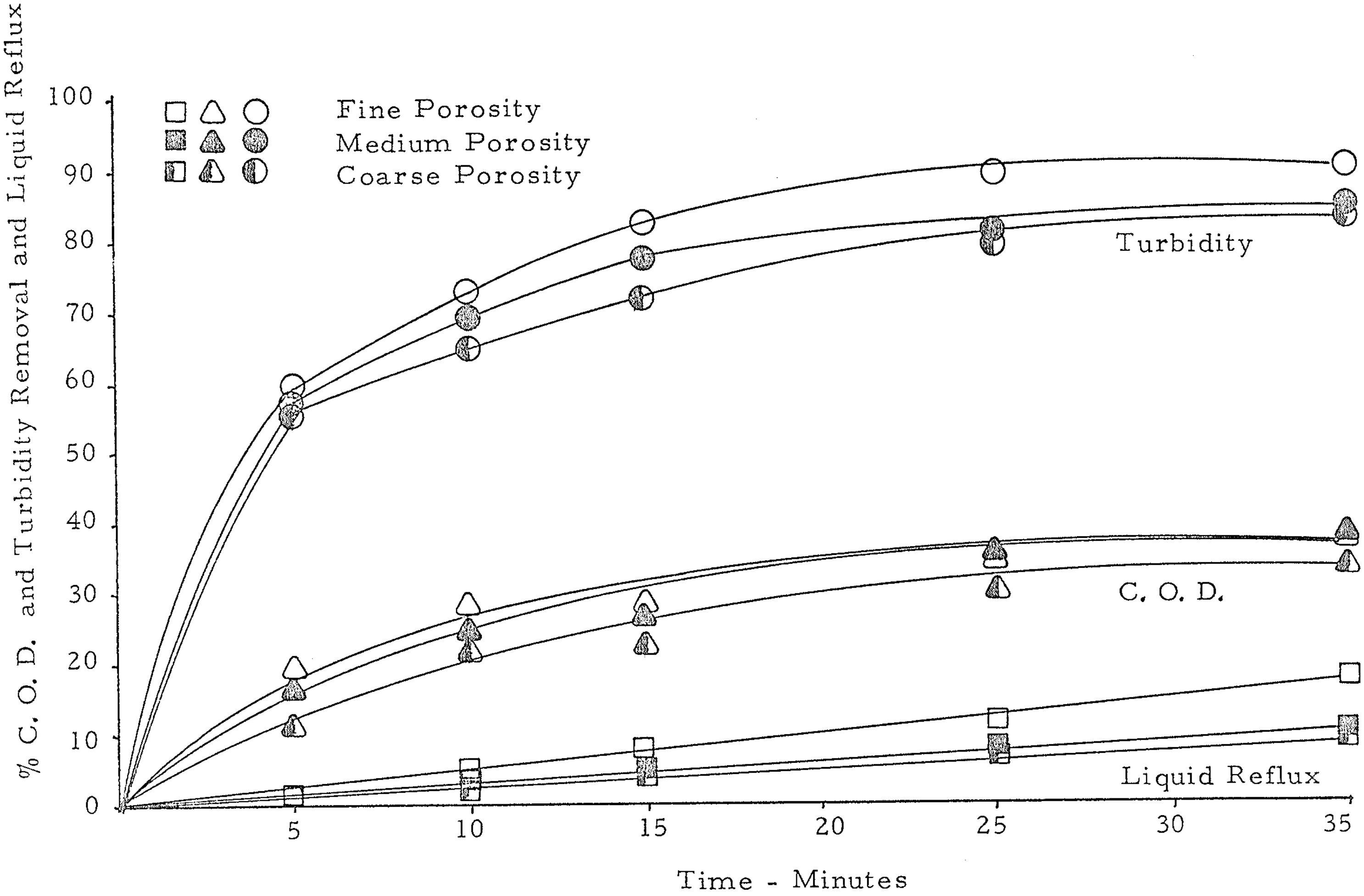

Fig. 10 Effect of Air Diffuser Porosity on C. O. D. and Turbidity removal and on Liquid Reflux; Simulated Wastewater Volume = 3000 ml, G = 3 l/min., H_F = 20 cm.

gave bubbles which were considerably less uniform. The structure of the foams produced with the the three air diffusers was the same. Since it is desirable to reduce the C. O. D. and turbidity in the effluent to a minimum and at the same time, provided concentrated foam stream of low flow rate, the medium porosity air diffuser was chosen for further experiments.

4. 1. 5 Effect of Foam Height

The results of the experiments carried out to establish the operable foam height for the treatment of simulated wastewater indicated that foam height affects the removals achieved. The effect is most pronounced at lower air flow rates. The variations in removals with foam height, were brought about by changes in the amounts of liquid carried into the foam stream. Excellent examples of this behavior are provided by experiments carried out at air rates of 2000 and 4000 ml/min, and initial liquid volume of 4000 and 2000 ml. The results are shown in Figures 11 and 12. It is important to note in both Figures the pronounced difference in percentage of liquid carried into the foam stream as the foam height was changed from 20 to 40 cm. This is not surprising because as the bubbles from the diffuser rise through the wastewater, they tend to carry some of the liquid with them. As they pass through the surface layer, and

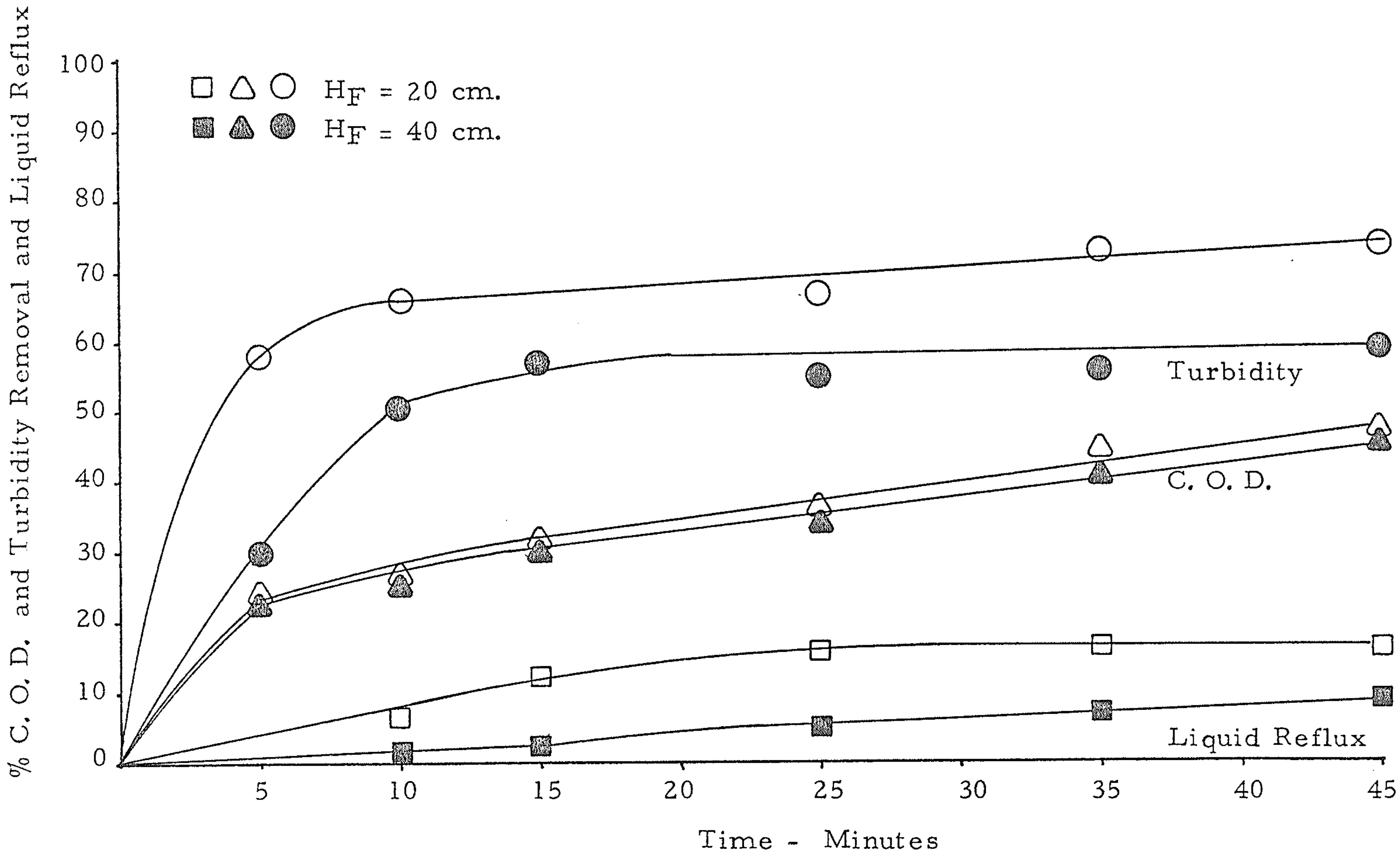

Fig. 11 Effect of Foam Height on C. O. D. and Turbidity removal and on Liquid Reflux Simulated Wastewater Volume = 4000 ml., G = 2000 ml/min.

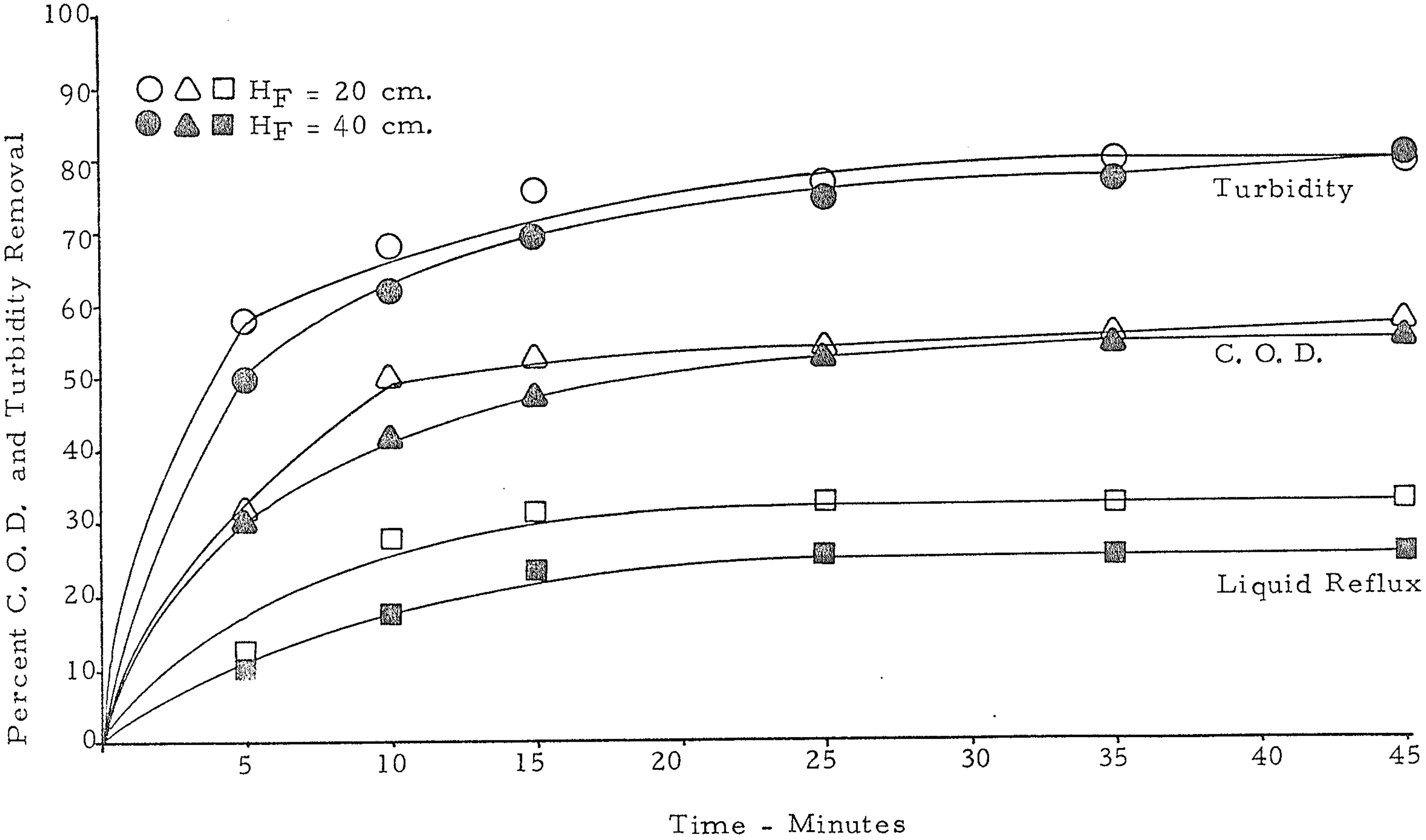

Fig. 12 Effect of Foam Height on C. O. D. and Turbidity removal Simulated Wastewater Volume = 2000 ml, G = 4000 ml/min.

while they remain in contact with the surface of the liquid, the pollutant in the surface layer has an opportunity to migrate to the air-liquid interfaces associated with the bubbles. The bubbles then become part of the foam phase with thin liquid layer separating them. A large amount of the liquid is carried into the foam phase and it is essential that this be given ample opportunity to drain back into the liquid column. With short foam height, this opportunity is insufficient; hence more liquid carried into the foam, and higher removals are obtained.

The differences in removals and liquid volume carried into the foam at the two different air-to-liquid volume ratios shown in Figures 11 and 12 should also be noted. Comparing results for both ratios, the effect of foam height is greater for the lower ratio. At V/G = 0.5, the effect on removal is minimal; however some of the response may have been shielded by the higher volume of liquid that was carried into the foam at the beginning of the run, and by the higher air flow rate that was used.

4.1.6 Effect of Column Diameter

The effect of column diameter is shown in Figures 13 and 14. The results, especially C.O.D. removals, show that the removals are affected by the column diameter.

For each set of values of initial volume of wastewater, air flow rate, and foam height, a change in column I. D. from 8. 3 cm. to 14. 6 cm. results in a decrease in percent turbidity and C. O. D. removals.

From Figure 13, it can be seen that the fraction of liquid carried into the foam after 60 minutes of foaming, is approximately 20 percent for the narrow column, while it is less than 0. 5 percent for the wide column. The differences in C. O. D. and turbidity removals are approximately 23 and 12 percent respectively.

For constant aeration period, the influence of a variation in internal column diameter is practically the same for each initial volume, but the effect of column diameter becomes more evident as aeration continues. This is also to be expected, since for this aeration system, the foam rate is much higher for the narrow foam column. The higher foam rate leads to a decrease in wastewater volume being foamed, and since for both columns the removals were affected by the initial volume, it is clear why the effect of I. D. column becomes more evident as aeration continues. The effect of column diameter is due mainly to the column's walls. With narrow column, the air bubbles have less opportunity to circulate. This lower circulation

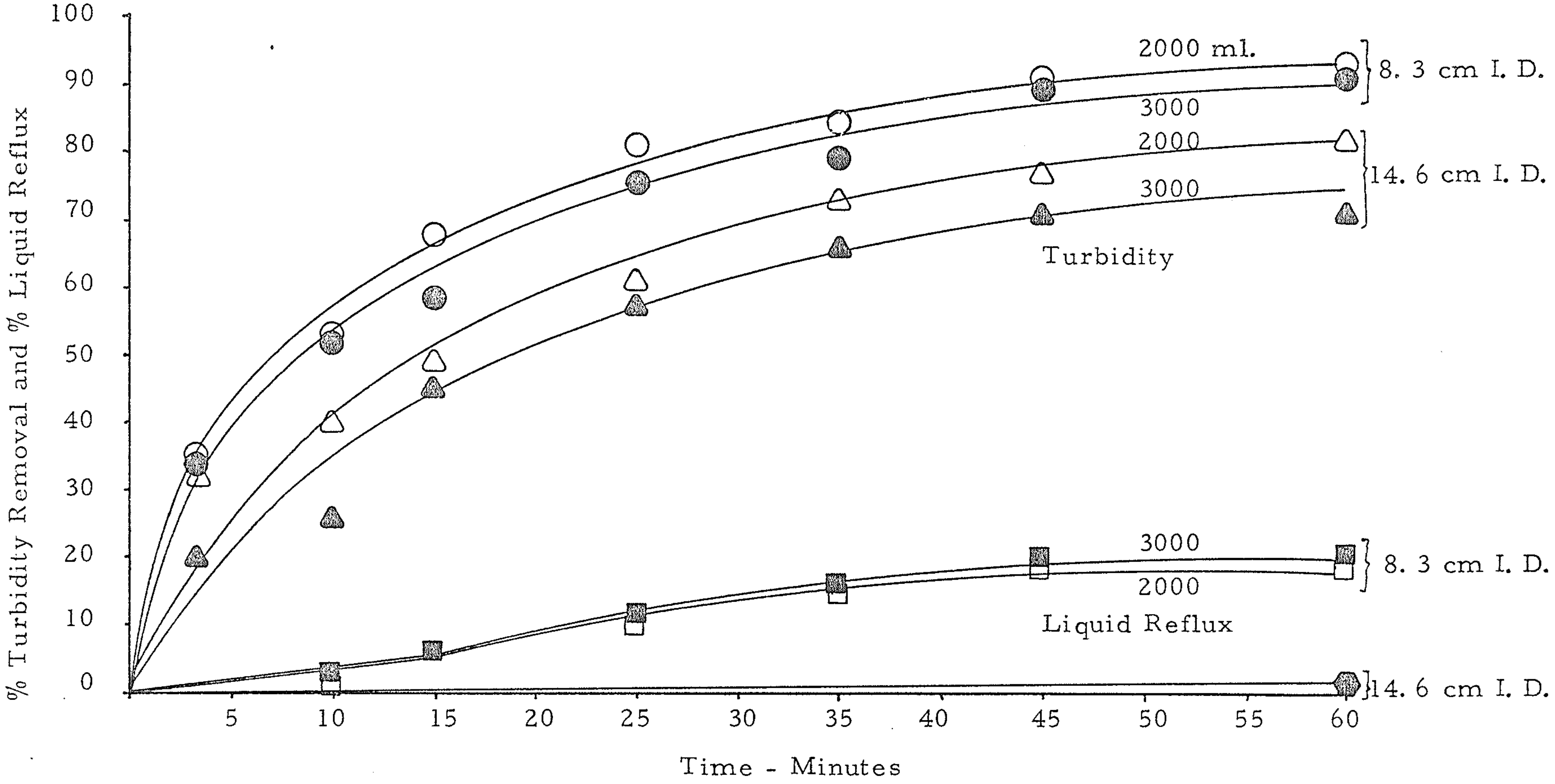

Fig. 13 Effect of Column Diameter on Turbidity removal and Liquid Reflux
Air Flow Rate = 3000 ml/min. H_F = 20 cm.

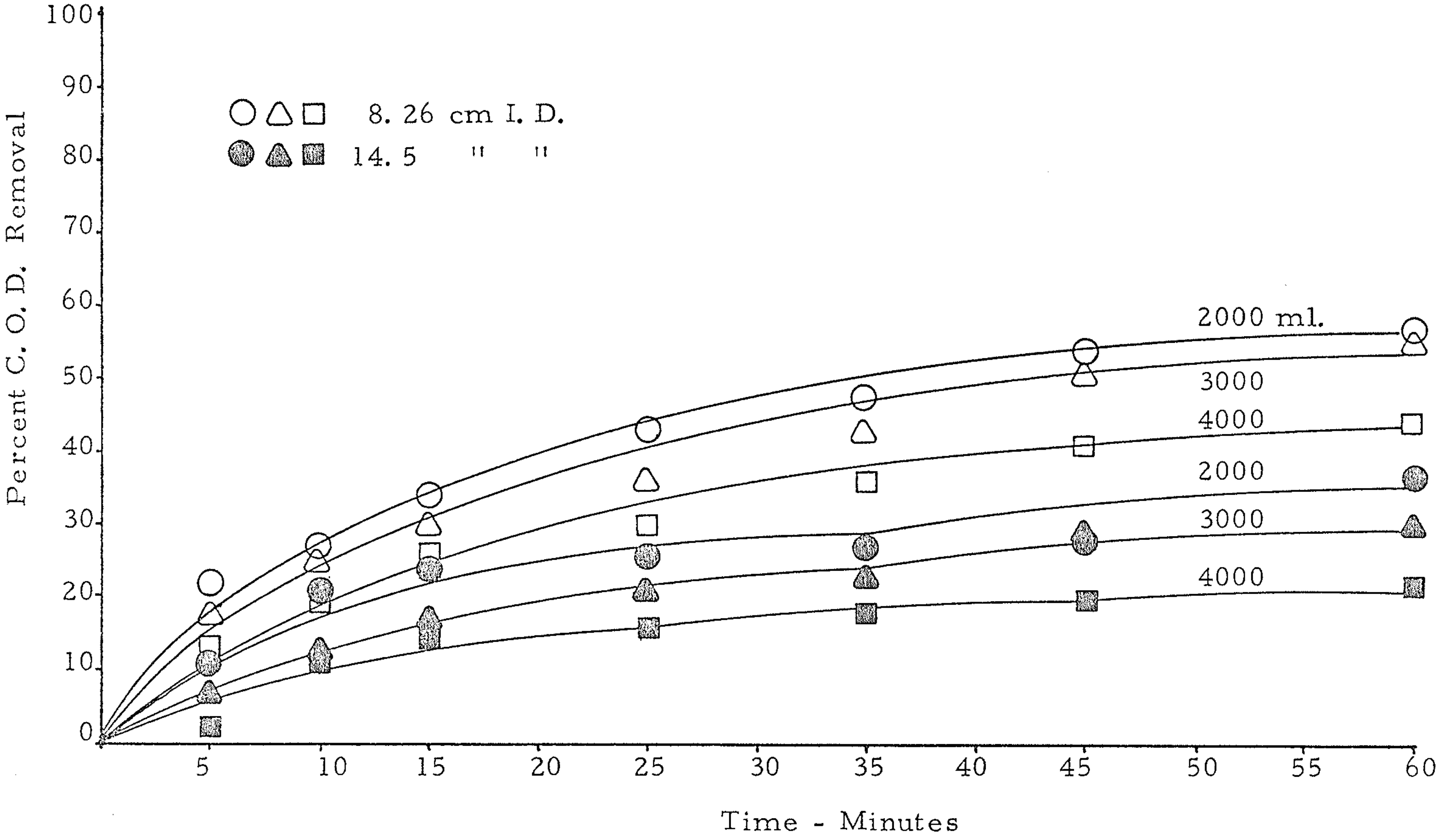

Fig. 14 Effect of Column Diameter on C. O. D. removal
Air Flow Rate = 3000 ml/min., H_F = 20 cm.

leads to an increase in the upward transport of pollutants by the rising bubbles, and hence to higher removals.

While experimenting with the wide column, two observations which may help to better explain the effect of the column diameter were made. The first was that for sometime after the start of aeration, the bursting air bubbles prevented the formation of a foam layer above the liquid surface. The absence of a foam layer caused the "fall back", or redispersion of the organic particles. For the narrow column, there was the same effect, although the time lag for the wider column was much longer. The second observation made during these experiments was the increased stability of foam in the narrow column. Breakdown of the foam structure in the wide column appeared to result from the bursting action of air bubbles, and the lack of support from the wall of the column.

4.1.7 Effect of Sampling Height

Figure 15 illustrates the effect of changing the sampling site. The upward transport of particles and a vertical gradient in turbidity were qualitatively observed visually. Contrary to expectation, the quantitative effect is slight. The results for the two sampling sites reveal a consistent removal pattern. At any one time, the percent C. O. D. and turbidity removals were higher

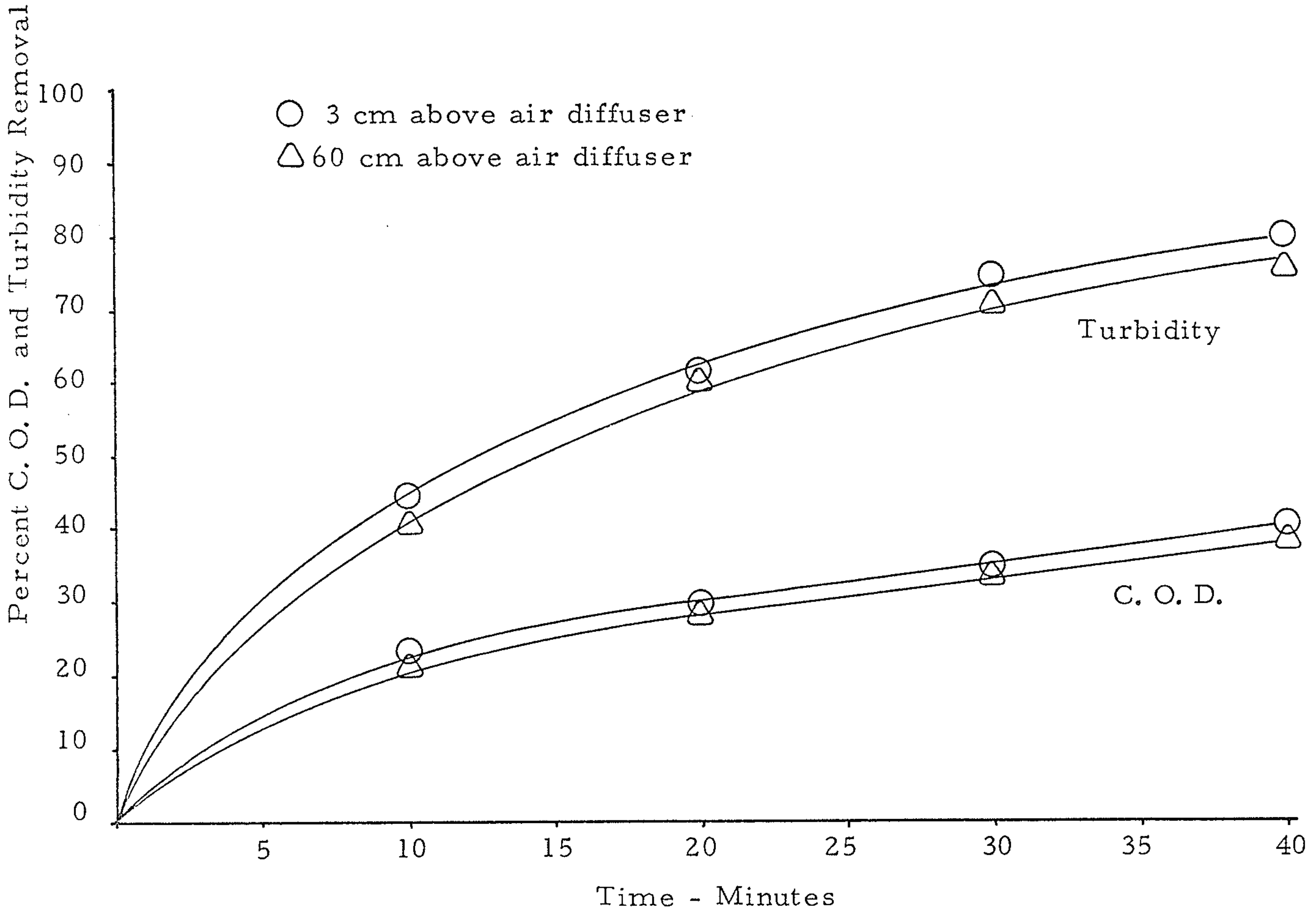

Fig. 15 Effect of Sampling Height on C. O. D. and Turbidity removal; Simulated Wastewater Volume = 5000 ml., G = 3000 ml/min., H_F = 30 cm., Column I. D. = 8. 3 cm., Medium Porosity Diffuser

(slightly) at 3 cm. above the air diffuser than they were at 60 cm. above it. There are apparently two reasons for the the concentration gradient. The first, being the fall back of the solids from the foam due to the breaking of the foam near the liquid-foam interface, and the second is that the rising air bubble surfaces are saturated with pollutants as they pass through the liquid. Just above the air diffuser, the bubbles seem to have more area exposed to pollutants. Hence, adsorption of pollutants of their surface is greater.

The practical implications of the vertical gradient in turbidity are also two. Firstly, it indicates that for batch dispersed air flotation, mixing is not a problem. Secondly, it indicates that in a continuous process, the effluent must be withdrawn just above the air diffuser.

4.2 Continuous Dispersed Air Flotation Studies

Since any practical dispersed air flotation process would be conducted on a continuous basis, an investigation of continuous operation was carried out.

Investigated, was the effect of feed stream flow rate or retention time on C. O. D. and turbidity removal of simulated and real wastewater from Freshwater Fish Marketing Corporation Plant (Winnipeg, Man.). Retention time as used here, refers to the volume of wastewater being foamed divided by the flow rate to the column.

Effluent C.O.D. and turbidity, as well as the collapsed foam stream or liquid reflux, were measured over time with three feed flow rates and 3000 ml/min air flow rate. As in previous studies, the purpose was two-fold: to establish the practicality of the process, and to determine quantitively the effect of retention time. Up to 35 liters of wastewater was foamed for a single run.

4.2.1 Effect of Retention Time or Feed Flow Rate

The length of aeration period necessary to remove turbidity and C.O.D., is important both from the standpoint of efficiency and the economic practicality of the process. Results for the turbidity and C.O.D. removals of simulated wastewater are presented in Figure 16, for a retention time of 50 minutes or a feed flow rate of 40 ml/min. Turbidity removals are much higher than C.O.D. removals. Steady state conditions in liquid turbidity and C.O.D. concentration are reached within 20 to 25 minutes. From then on, removals are fairly constant.

Figure 17 presents results for identical experiments, except that retention times of 60, 30 and 15 minutes were used. The original C.O.D. and turbidity of the wastewater used for

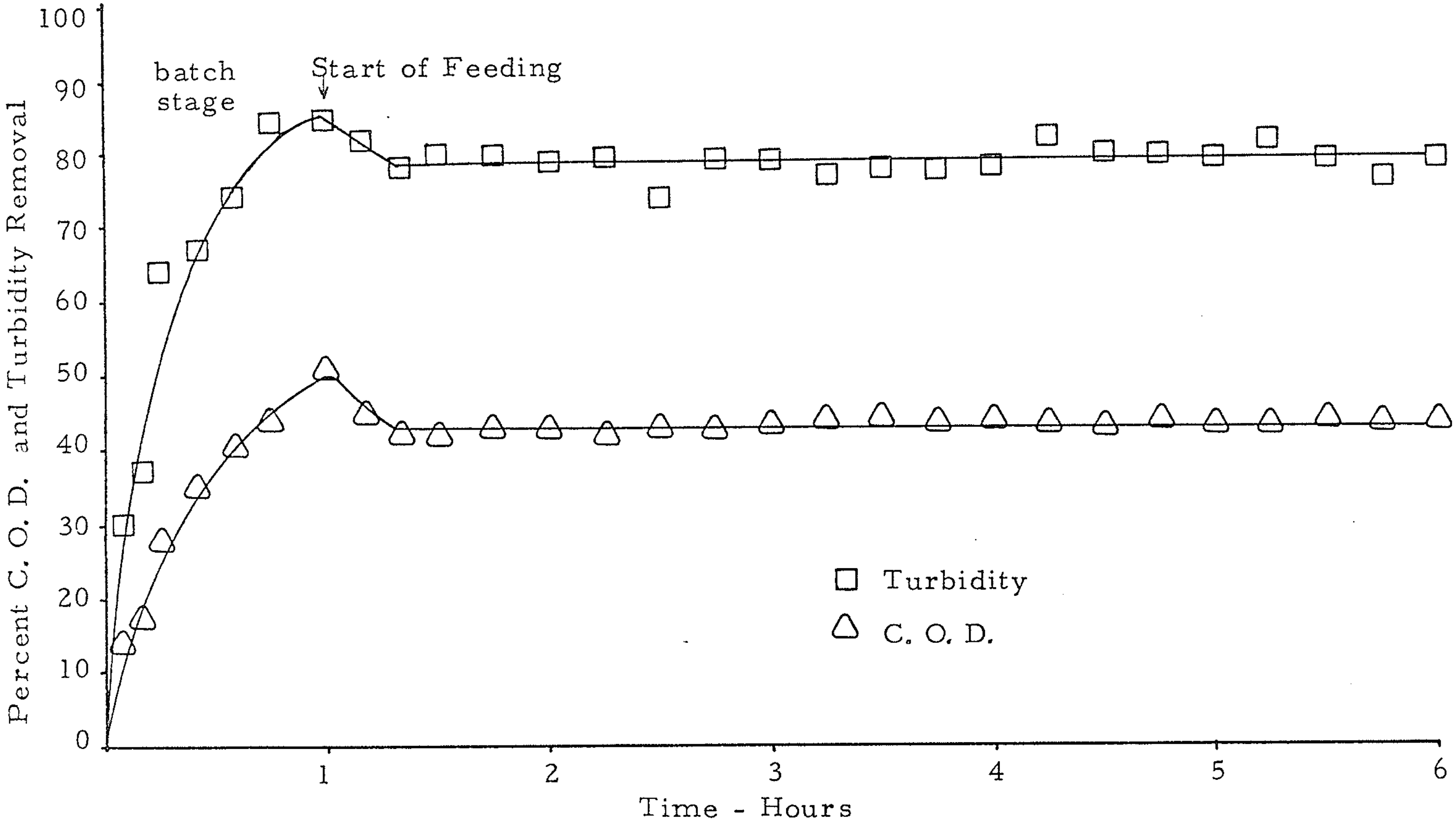

Fig. 16 Plot of C. O. D. and Turbidity removal against Feeding Time for Continuous Dispersed - Air Flotation of Simulated Wastewater; Feed Flow Rate = 40 cc/min, Air Flow Rate = 3000 ml/min, Liquid Level = 2000 ml, H_F = 10 cm.

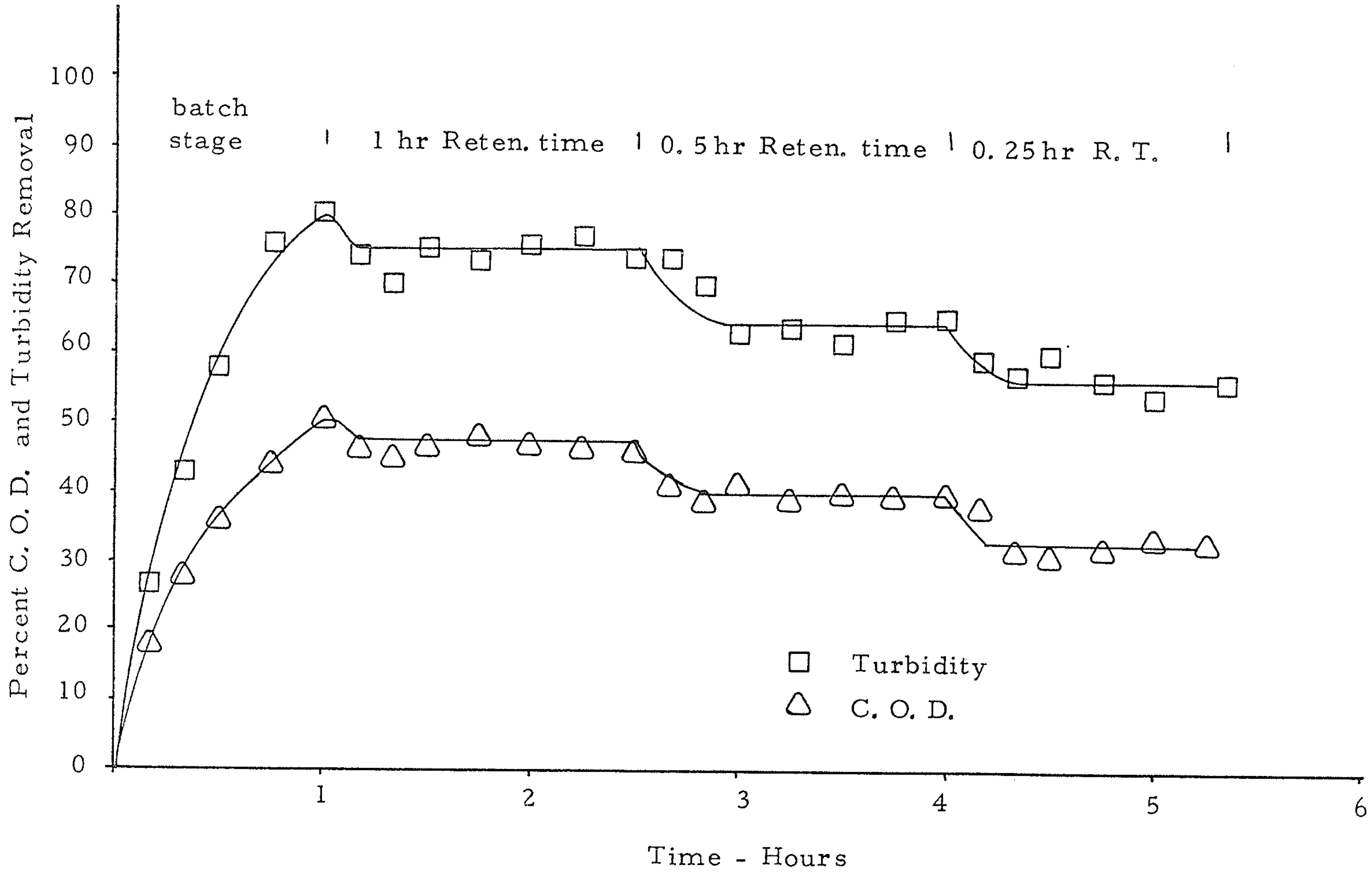

Fig. 17 Effect of Retention Time; Plot of Percentage C. O. D. and Turbidity removal against Feeding Time for Continuous Dispersed - Air Flotation Studies of Simulated Wastewater

these experiments were 669 mg/l and 66 turbidity units respectively. For each retention time, foaming was carried on for 1 1/2 hours. The effect is clear: increase in feed rate or decrease in retention time results in lower removals or increase in effluent concentration. Figure 18 shows the steady state effluent concentration as a function of retention time for the same series of experiments.

The last series of experiments were conducted using real wastewater. Typical results for 60, 30 and 15 minutes retention time are shown in Figures 19 and 20. The highest removals were obtained at high retention time. C. O. D. removals at 60 minutes retention time are 3 percent higher than at 30 minutes, and at 30 minutes approximately 5 percent higher than at 15 minutes. These are very small differences compared to the larger total volumes of air passed through the liquid. Turbidity removals are much higher. For any one retention time or feed rate, the aeration and feeding were carried for a period of 2 hours. In all cases, the line corresponding to the low feed rate, lies above that for the high rate, indicating that a given air flow (3000 ml/min) low rate yields a greater removal.

Figure 19 also discloses that the fractional loss (liquid reflux) of the feed into the collapsed foam stream increases

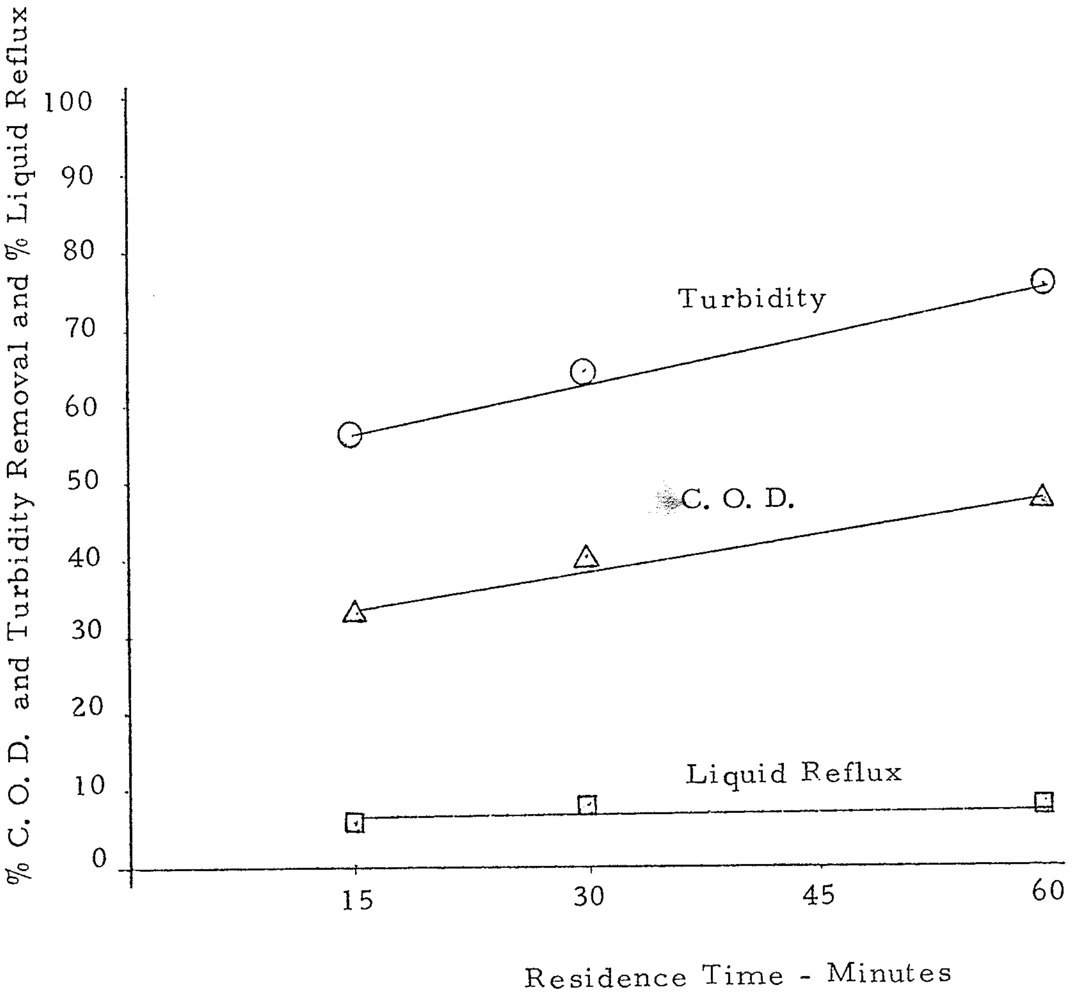

Fig 18 Percent C. O. D. and Turbidity removal and Liquid Reflux against Residence Time for Continuous Dispersed - Air Flotation Studies of Simulated Wastewater; H_F −10 cm

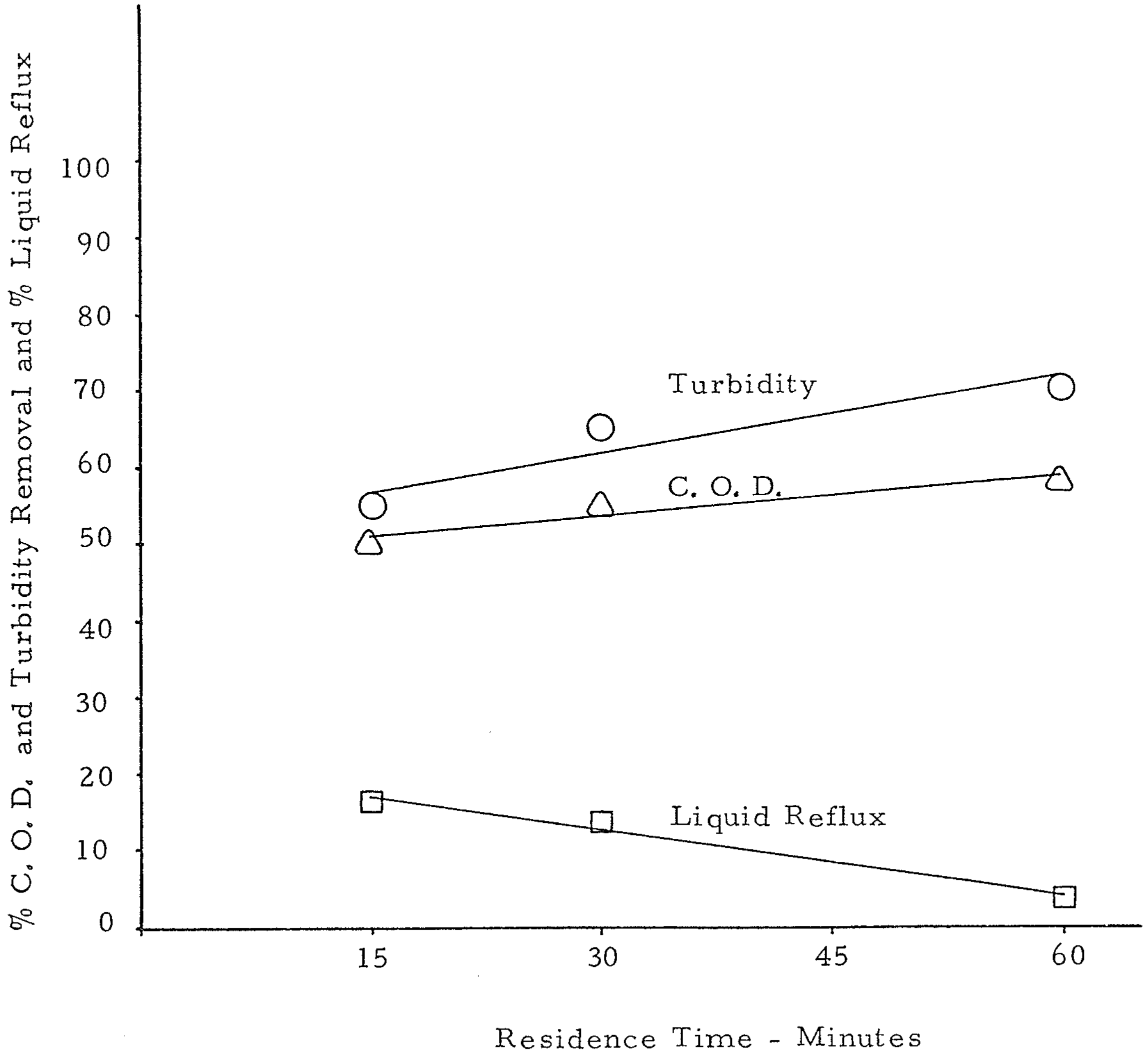

Fig. 19 Percent C. O. D. and Turbidity removal and Percent Liquid Reflux against Residence Time for Continuous Dispersed Air Flotation Studies of Real Wastewater H_F = 10 cm.

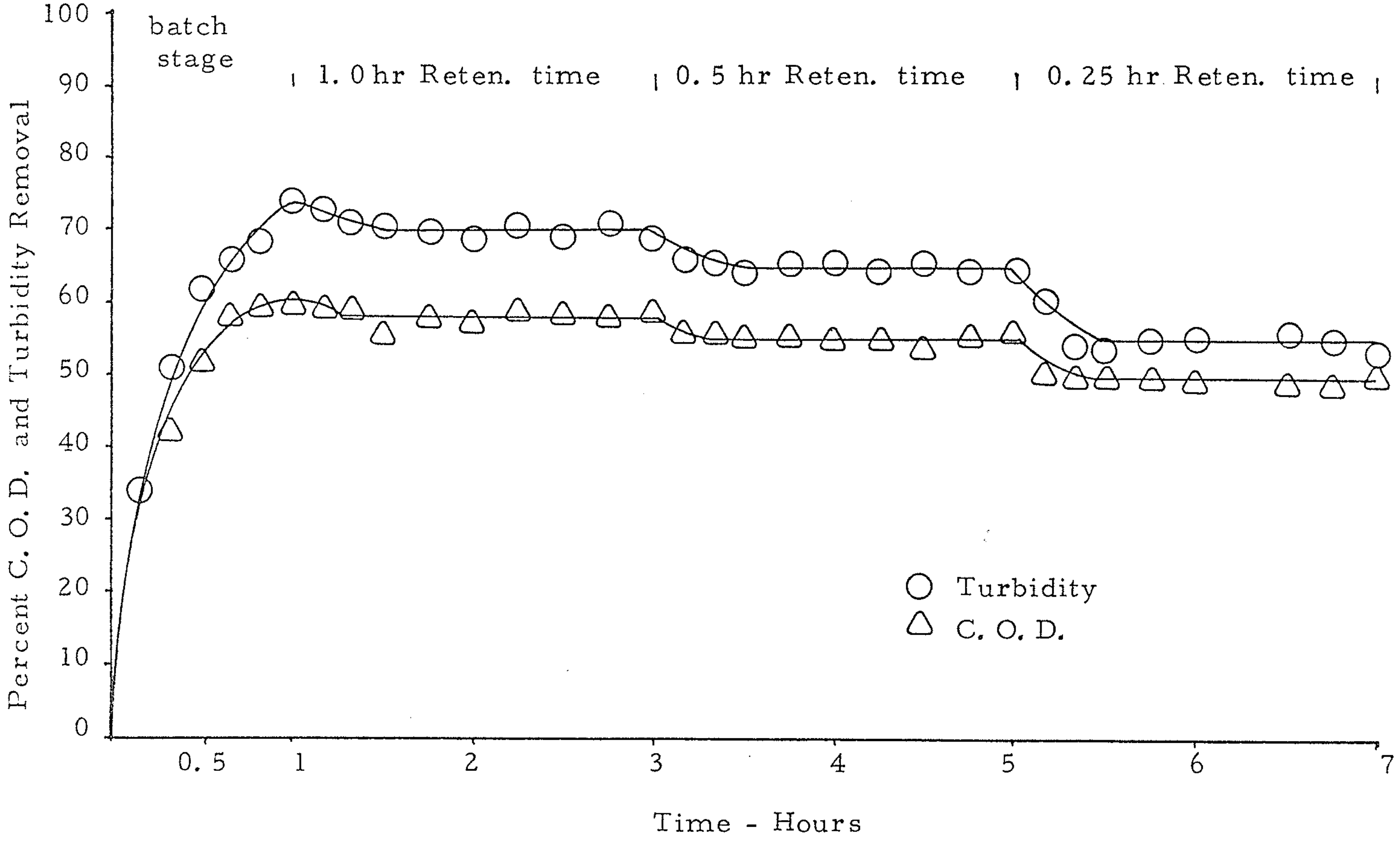

Fig. 20 Effect of Retention Time on C. O. D. and Turbidity removal for Continuous Dispersed - Air Flotation Studies of Real Wastewater H_F = 10 cm., Original C. O. D. = 703 mg/1, Original Turbidity = 73 Neph. U.

with the feed rate, or decreases with retention time. For dispersed air flotation to be of significant value as a wastewater treatment process, the flow rate of the effluent stream must of course, be disposed of,or dried for feeding animals.

For 60 minutes retention time, the maximum fractional loss was 3 percent, producing a foam stream highly concentrated.

4. 3 General Difficulties and Sources of Error

At the outset of the project, it was decided that because of the variability of the wastewater at the Freshwater Fish Marketing Corporation, and because of the expenses inherent in going back and forth from the fish processing plant, to the University, simulated wastewater was going to be used. Attempts were made to keep the concentration of the wastewater from run to run unchanged. This however, turned out to be very difficult. The ground fish scraps used for the preparation were not uniform in size and composition, hence the C. O. D., turbidity and foamability of the wastewater were not quite the same for different batches of simulated wastewater. To have a continuity of waste characteristics, enough wastewater for all the runs necessary to determine the effect of every parameter had to be prepared. Minor difficulties were encountered in keeping the foam height constant. At first, the foam collector was set at a height above the liquid level, and was not moved throughout the run. Then however, it was realized that as foaming proceeded and part of the liquid was carried into the foam, the foam height was changing. To overcome this, it was decided to adjust the foam height to the desired level every five minutes by lowering the foam collector. This of course, solved the problem only partially. Preventing the wastewater from getting from the column, through the air diffuser into the air line between the time the wastewater was poured in the column and the beginning of aeration, was also a problem. To have moist air for a run and dry air for another run or moist air at the start and dry air at the end of the foaming period, would have changed the condition under which the experiments were performed. The problem was solved by having a very low air flow prior to the pouring of wastewater into the column.

The repeatability of the results was ascertained by performing four runs under the same set of conditions. Twenty-four (4 x 6) samples were taken over a 30 minute period of foaming, and analyzed for C. O. D. and turbidity. The maximum error in the determined C. O. D. values was found to be ± 6 %, which is well within the limits of experimental error associated with the method of analysis. Similarily, the maximum error in the turbidity values was found to be ± 17 %, also within the error associated with the method of analysis.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Freshwater fish processing wastewater can be partially purified by continuous dispersed-air flotation. The partial purification occurs because of two phenomena: the quantity of pollutants removed due to adsorption at the gas-liquid interfaces of the bubble, and the quantity per unit time of pollutants removed in the mechanically entrained liquid carried out of the foam column with the bubbles. C. O. D. and turbidity removals are slightly effected by retention time. At 60 minutes retention time, C. O. D. removal is only 3 percent higher than at 30 minutes, and at 30 minutes it is 5 percent higher than at 15 minutes.

For the batch operation, the organic concentration of the stripped effluent is dependent on air flow rate and on the initial volume of wastewater. The height of foam above the foam liquid solution interface, at low gas rate, has an important influence on the removal of the suspended solids. For a given air flow rate to initial volume wastewater ratio, C. O. D. and suspended solids removals, and percentage of liquid carried into the foam increase with increasing air flow rate, but decrease with increasing foam height. Organics and turbidity removals are slightly effected by temperature. The percentage of liquid carried into the foam increases with temperature.

At high gas rates, strong stripping takes place because of the large interfacial area presented by the larger number of bubbles. However, much liquid is entrained in the rapidly rising foam, thus lowering the solute concentration in the liquid foam mixture and yielding a poor enrichment. At lower gas rates, on the other hand, the foam produced rises slowly, drains well and yields a high enrichment.

For given air rate, foam height and wastewater volume, the amount of organics and suspended solids remaining in the effluent is influenced by the original concentration of the wastewater. Foamability is influenced by the original concentration, the volume, gas flow rate, column diameter, and sparger's porosity as well. The sparger's porosity effects removal very slightly, if at all. The process involves simplicity in equipment and a minimum amount of control.

This study represents the first testing of batch and continuous dispersed air flotation study on wastewaters from freshwater fish processing plants. With refinement of the process equipment, and under optimum operating conditions, this process should be quite useful in treating any food processing wastewaters.

5. 2 Economic Considerations

It is generally agreed that economics is a fundamental part of scientific research and isin fact so closely associated, that from a practical point of view, research without economic considerations is meaningless. All too frequently however, even a brief economic analysis is omitted. To overcome this criticism, a rough economic evaluation of the continuous dispersed air flotation process is being attempted.

The cost of the process is dependent mainly upon the retention time, the physical plant design, the air costs, and the labour requirements. At this stage, it is difficult to predict the best shape of the physical plant. It is assumed however, that it will consist of rectangular vessels constructed of 12 inch concrete walls with inside dimensions of 5' x 30' x 10'. The prescreened fish processing plant effluent is gravity fed at an end of the vessel. It flows through and exits at the opposite end, where a level-controlled pump transports the effluent of the vessel to a further treatment process or to the sewer system. Air diffusers will be placed along the tank bottom. The generated foam will spill over on the longer sides of the tank into a trough-type conveyor. This will carry it to further process where the water, oil and solids will be separated, and since there is no chemical addition, the latter may be either combined with similar material obtained from the screening step, or processed separately as supplements for domestic animals.

If a retention time of 15 minutes (75,000 gal/500 G. P. M.) and air flow rate of 1500 c.f.m. were used, one such vessel would be required for a 30,000 gal/hr fish processing plant. Since the vessel is relatively simple, its cost is estimated at about $3500.

Compressor(s), pumps, spargers and control are estimated at about $15,000 and installation of $1000, given a total cost of approximately $19,500 for a 30,000 gal/hr plant. To be conservative, it is assumed at $20,000. Operating costs for retention times of 15 minutes are itemized in Table 5. 1 and are approximately 5.0¢/1000 gallons of treated water.

Table 5. 1

Continuous Dispersed-Air Flotation Operating Costs Without Labour
(Capacity = 30,000 gal/hr, Liquid residence time = 15 minutes, Foamate disposal not included)

Power @ 1¢/kwh	$15.00/16 hrs.-day
Operating labour	-
Maintenance labour (6% of capital)	3.30
Operating and mainten. supply (0.5% of cap.)	0.27
Payroll extra (15% of labour cost)	.45
Overhead (100% of total labour costs)	-
Amortization @ 4% for 25 yrs. (6.4% of cap.)	3.55
Taxes & Insurance (1% of cap.)	0.55
Interest on working cap. (0.72% of foregoing)	0.17
	$23.27
	or 4.85¢/1000 gal.

If the retention time was extended to 30 minutes or 1.0 hr., two or four mirror-image vessels would be required for the same fish processing plant, and the above capital and operating costs would be approximately two or four times larger This of course, would result in higher removals (Fig. 20-21). The above 5¢/1000 gallons of treated water operating cost was calculated on the assumptions that the treatment process does not require an operator, and that the cost for utilization of the foamate is equal to the price of the saleable product. If a worker is assigned to look after the treatment, the cost will be approximately 27¢/1000 gallons (Table 5.2).

Table 5.2

Continuous Dispersed Air Flotation Operating Costs With Labour

(Capacity = 30,000 gal/hr., Liquid residence time = 15 minutes)

Power @ 1¢/kwh	$ 15.00/16 hrs.-day
Operating labour @3.00/hr	48.00
Maintenance labour (6% of capital)	3.30
Operating and mainten. supply (0.5% of cap.)	0.27
Payroll extra (15% of labour cost)	7.70
Overhead (100% of total labour cost)	51.30
Amortization @ 4% for 25 yrs. (6.4% of cap.)	3.55
Taxes & insurance (1% of cap.)	0.55
Interest on working capital (0.72% of foregoing)	0.82
	$130.49 or 27¢/1000 gal.

This is much higher mainly because the plant capacity is small, nevertheless, the dispersed - air flotation process appears competitive with conventional treatment schemes, and if the foamate utilization is profitable, the process may become not merely economically feasible, but economically attractive. The nutrients in the wastewater are presently being wasted. In our highly industrialized society, we may be able to afford to waste these nutrients at the present time. However, this may change in the future, and even now in the less fortunate areas of the world, they may not be able to afford the luxury of wasting these valuable nutrients, this valuable food!

5.3 Recommendations

The amount of information developed to date and the relative success achieved, indicates that this work should be continued. Future work might include:

1. Investigation of additives, such as edible polyelectrolytes for higher removals.
2. A pilot study on a fairly large scale.
3. Determination and evaluation of methods (centrifugation, drying, microorganism culture, etc.) to utilize the foamate.

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APPENDIX 1

SIMULATED WASTEWATER FROM FISH PROCESSING: PREPARATION

For the formulation of a recipe for the preparation of simulated wastewater from fish processing, the wastewater from Freshwater Fish Marketing Corporation Plant was first characterized. A summary of the results is given below in Table I.

Table 1

Characterization of the Wastewater From Freshwater Fish Marketing Corporation Plant

Parameter	Unit	Value
C. O. D.	mg/l	321 - 491
Total Solids	mg/l	340 - 522
Dissolved Solids	mg/l	235 - 352
Suspended Solids	mg/l	115 - 171
Grease	mg/l	39 - 95
Chlorides	mg/l	5 - 10
pH	-	6.9 - 7.2

The type of fish processed, the processing step and a number of other factors not investigated, effected C. O. D., solids, grease and chlorides content of the plant's effluent.

Once the above was known, it was clear that to make up a simulate wastewater some fish product had to be used. Freshwater fish meal, fish oil, cleaning powder and water were first tried. The recipe was made up as follows:

Ingredients	Amount	
Freshwater fish meal	1.0	gm.
Freshwater fish oil	0.05	gm.
Cleaning powder	0.001	gm.
Distilled water	1000.00	ml.

Method

1. weigh out the various ingredients.
2. pour them in a 1000 ml. volumetric flask.
3. add water and mix well.
4. fill to the mark the volumetric flask with more distilled water, mix well and use.

The fish meal however, was found to have very low solubility; hence, discarded.

Ground freshwater fish offals or scraps and water was then tried. The scraps, containing fish heads, bones, fins, guts, scales, skin and some rubbish, were taken from the above said fish processing plant. They were ground by means of a Hobart meat grinder and mixed with water in the following proportions and manner:

Ingredients	Amount	
Ground freshwater fish scraps	5	gm.
Water	1,000	ml.

Method

1. weigh out 5. 0 gm. and place in 1. 0 liter volumetric flask.
2. add 500 ml. of water, mix well.
3. filter through a 40 mesh wire screen.
4. wash the screen by passing more water through it.
5. fill to the mark the 1. 0 liter volumetric flask, mix, and use.

The resulting wastewater was physically very much like the wastewater taken from the Freshwater Fish Marketing Corporation Plant, and was practical and easy to prepare. Its composition is shown in Table 2.

Table 2

Characteristics of Simulated Wastewater

Parameter	Unit	Value
C. O. D.	mg/l	330
Total Solids	mg/l	253
Dissolved Solids	mg/l	99
Suspended Solids	mg/l	154
Grease	mg/l	104
Chlorides	mg/l	2
pH	-	7. 2

APPENDIX 2

BATCH STUDIES - RAW DATA

Run #1: V = 2000 ml, G = 2000 ml/min, H_F = 20 ± 1 cm, Medium porosity air diffuser
Column I. D. = 8. 3 cm, H_S = 3 cm, T = 25 ± 2°c

Foaming Time min.	C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml.	pH
0	660	0	71	0	0	7. 4
5	545	17. 4	44	38	0	7. 5
10	509	23	41. 5	42	0	7. 5
15	490	26	34	52	0	7. 5
25	419	36	27	62	1	7. 5
35	415	37	25	64	32	7. 5
45	389	41	17	76	66	7. 6
60	344	48	11	85	120	7. 6

Run #2 $V = 3000$ ml, $G = 2000$ ml/min, $H_F = 20 \pm 1$ cm, Medium porosity air diffuser
Column I. D. = 8. 3 cm, $H_S = 3$ cm, $T = 25 \pm 2^\circ C$

Foaming Time min.	C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml	pH
0	660	0	71	0	0	7. 4
5	565	14	50	30	0	7. 4
10	534	19	44	38	0	7. 4
15	510	23	39	45	0	7. 5
25	502	24	37	48	0. 5	7. 5
35	466	29	29	59	4	7. 6
45	439	34	19	73	34	7. 6
60	376	43	17	75	130	7. 6

Run #3: $V = 4000$ ml, $G = 2000$ ml/min, $H_F = 20 \pm 1$cm, Medium porosity air diffuser
Column I. D. = 8. 3 cm, $H_S = 3$ cm, $T = 25 \pm 2$°C

Foaming Time min.	C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml	pH
0	660	0	71	0	0	7. 4
5	594	10	48	32	0	7. 4
10	541	18	43	39	0	7. 4
15	521	21	40	44	0	7. 4
25	517	22	39	45	0. 5	7. 5
35	478	28	31	56	120	7. 6
45	435	34	20	72	212	7. 7
60	403	39	19	73	310	7. 7

Run #4: $V = 2000$ ml, $G = 3000$ ml/min, $H_F = 20 \pm 1$ cm, Medium porosity air diffuser
Column I. D. = 8. 3 cm, $H_S = 3$ cm, $T = 25 \pm 2^\circ C$

Foaming Time min.	C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml	pH
0	698	0	80	0	0	7. 4
5	543	22	52	35	1	7. 5
10	508	27	38	53	32	7. 6
15	461	34	26	68	115	7. 7
25	398	43	15	81	210	7. 7
35	339	52	13	84	300	7. 7
45	319	54	7	91	360	7. 7
60	299	57	6	93	355	7. 7

Run #5: V = 3000 ml, G = 3000 ml/min, H_F = 20 ± 1 cm, Medium porosity diffuser,
Column I. D. = 8. 3 cm, T = 25 ± 2°C

Foaming Time min.	C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml	pH
0	698	0	80	0	0	7. 4
5	575	18	53	34	10	7. 5
10	524	25	38	53	94	7. 6
15	492	30	34	58	190	7. 7
25	449	36	20	75	354	7.7
35	401	43	17	79	495	7. 7
45	343	51	8.5	89	580	7. 7
60	311	55	7	91	635	7. 7

Run #6: V = 4000 ml, G = 3000 ml/min, H_F = 20 ± 1 cm, Medium porosity air diffuser, Column I. D. = 8. 3 cm, H_S = 3 cm, T = 25 ± 2°C

Foaming Time min.	C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml	pH
0	616	0	43	0	0	7. 4
5	539	13	20	53	345	7. 5
10	496	20	10	77	655	7. 6
15	484	21	9	79	860	7. 7
25	433	30	8	81	1, 155	7. 7
35	398	36	8	81	1, 370	7. 7
45	362	41	4	91	1, 460	7. 7
60	343	44	4	91	1, 480	7. 7

Run #7: V = 2000 ml, G = 4000 ml/min, H_F = 20 ± 1 cm, Medium porosity air diffuser, Column I. D. = 8. 3 cm, H_S = 3m, T = 25 ± 2°F

Foaming Time min.	C. O. D. mg/1	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml	pH
0	616	0	43	0	0	7. 4
5	504	18	19	56	325	7. 5
10	441	28	10	77	575	7. 6
15	398	36	7	84	740	7. 7
25	350	43	6	86	800	7. 7
35	323	48	5	88	800	7. 7
45	303	51	4	91	800	7. 7
60	283	54	4	91	800	7. 7

Run #8: V = 3000 ml, G = 4000 ml/min, $H_F = 20 \pm 1$ cm, Medium porosity air diffuser, Column I. D. = 8. 3 cm, $H_S = 3$ cm, T = 25 ± 2°C

Foaming Time min.	C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml	pH
0	616	0	43	0	0	7. 4
5	504	18	20	53	500	7. 5
10	469	24	12	72	890	7. 5
15	429	30	11	74	1, 175	7. 6
25	394	36	10	77	1, 430	7. 7
35	346	44	8	81	1, 430	7. 7
45	331	46	8	81	1, 430	7. 7
60	319	48	7. 5	83	1, 430	7. 7

Run #9: V = 4000 ml, G = 4000 ml/min, H_F = 20 ± 1 cm, Medium porosity air diffuser, Column I. D. = 8. 3 cm, H_S = 3 cm, T = 25 ± 2°C

Foaming Time min.	C. O. D. mg/1	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml	pH
0	698	0	80	0	0	7. 4
5	593	15	62	23	550	7. 5
10	520	26	36	55	756	7. 6
15	488	30	27	67	1, 175	7. 6
25	417	40	18	78	1, 475	7. 7
35	354	49	7	92	1, 550	7. 7
45	327	53	6	93	1, 560	7. 7
60	291	58	6	93	1, 565	7. 7

Run #10: V = 2000 ml, G = 2000 ml/min, $H_F = 20 \pm 5$ cm, Fine porosity air diffuser, Column Int. diameter = 8. 3 cm, $H_S = 5$ cm, $T = 25 \pm 2°C$

Foaming Time min.	C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml
0	528	0	44	0	0
5	469	11	28	36	0
10	442	16	22	50	0
15	407	23	18	57	1
25	400	24	15	66	40
35	369	30	12	73	69
45	353	33	10	77	83

Run 11: V = 2000 ml, G = 3000 ml/min, H_F = 20 ± 5 cm, Fine porosity air diffuser, Column I. D. = 8. 3 cm, T = 25 ± 2°C

Foaming Time min.	C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml
0	543	0	42	0	0
5	458	16	29. 5	30	2
10	400	26	25. 5	39	52
15	380	30	21	50	143
25	353	35	12	71	250
35	322	41	8	81	265
45	310	43	7	83	268

Run #12: V = 2000 ml, G = 4000 ml/min, H_F = 20 ± 5 cm, Fine porosity air diffuser, Column I. D. = 8. 3 cm, T = 25 ± 2°C

Foaming Time min.	C. O. D. mg/1	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml.
0	461	0	41	0	0
5	419	8. 9	23	44	90
10	384	16. 5	19. 5	52. 5	260
15	339	26	14	66	430
25	-	-	10. 5	74	476
35	324	30	9	78	476
45	312	32	8	80. 5	476

Run #13: V = 3000 ml, G = 2000 ml/min, H_F = 20 ± 5 cm, Fine porosity air diffuser,
Column I. D. = 8.3 cm, T = 25 ± 2°C

Foaming Time min.	C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml.
0	513	0	42.5	0	0
5	489	4.5	32	25	0
10	457	11	22	48	0
15	427	17	17	60	0.5
25	407	21	16	62	29
35	369	28	14	67	89
45	369	28	7.5	82	122

Run # 14: V = 3000 ml, G = 3000 ml/min, H_F = 20 ± 5 cm, Fine porosity air diffuser,
Column I. D. = 8. 3 cm, T = 25 ± 2°C

Foaming Time Min.	C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph Units	Turbidity % Removal	Liquid Reflux ml
0	972	0	110	0	0
5	913	6	95	13. 6	0
10	869	10. 6	85	23	0
15	802	17. 5	68. 5	38	0. 5
25	700	28	43	61	86
35	648	33. 3	22	80	255
45	585	40	19	83	460

Run #15: $V = 3000$ ml, $G = 4000$ ml/min, $H_F = 20 \pm 5$ cm, Fine porosity air diffuser,
Column I. D. = 8.3 cm, $T = 25 \pm 2$°C

Foaming Time min.	C. O. D. mg/1	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml
0	972	0	110	0	0
5	834	14	89	19.2	5
10	747	23	63	42.7	100
15	688	29	51	53.6	205
25	597	39	29.5	73	470
35	519	47	26.5	76	800
45	482	50	7.5	93	1,100

Run #16: V = 4000 ml, G = 2000 ml/min, H_F = 20 ± 5 cm, Fine porosity air diffuser, Column I. D. = 8. 3 cm, T = 25 ± 2°C

Foaming Time min.	C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml.
0	531	0	42	0	0
5	458	14	32. 5	23	0
10	458	14	25. 5	39. 3	0
15	450	15	24. 5	42	0
25	396	18	15. 5	63	22
35	380	28. 5	13. 5	68	80
45	376	29. 2	10	76	150

Run #17: V = 4000 ml, G = 3000 ml/min, H_F = 20 ± cm, Fine porosity air diffuser, Column I. D. = 8. 3, T = 25 ± 2°C

Foaming Time min.	C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml.
0	972	0	110	0	0
5	874	10	100	9. 1	0
10	866	11	94	14. 6	0
15	-	-	84	23. 6	1
25	719	26	57	48	120
35	636	35	30	73	340
45	605	38	25	77	554

Run #18: V = 4000 ml, G = 4000 ml/min, H_F = 20 ± 5 cm, Fine porosity air diffuser,
Column I. D. = 8. 3 cm, T = 25 ± 2°C

Foaming Time min.	C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml.
0	917	0	108	0. 0	0
5	826	10	-	-	55
10	715	22	-	-	164
16	670	27	-	-	400
25	573	38	-	-	740
35	518	44	-	-	880
45	407	56	-	-	1, 150

Run #19: V = 3000 ml, G = 3000 ml/min, H_F = 20 ±1cm, Column I. D. = 8. 3 cm, T = 25 ± 2°C

Run #19a: Fine porosity air diffuser

Foaming Time: min	C. O. D. mg/l	C. O. D. % Rem.	Turbidity Neph. U.	Turbidity % Rem.	Liquid Reflux ml
0	635	0	52	0	0
5	508	20	21	60	45
10	454	29	14	73	150
15	450	29	9	83	250
25	412	35	6	90	375
35	396	38	5	90	550

Run # 19b: Medium porosity air diffuser

0	650	0	50	0	0
5	550	17	21	58	0. 5
10	485	25	15	70	50
15	475	27	11	78	110
25	416	36	10	80	210
35	400	39	8	85	275

Run #19c: Coarse porosity air diffuser

0	602	0	48	0	0
5	533	11. 5	21	56	0. 5
10	472	22	17	65	70
15	466	23	14	72	130
25	418	31	9	81	240
35	399	34	8	83	320

Run #20: V = 4000 ml, G = 4000 ml/min, H_F = 20 ± 1 cm,
Fine porosity air diffuser, Column I. D. = 8. 3 cm,
T = 25 ± 2°C

Foaming Time min.	C. O. D. mg/l	C. O. D. % Removal	Liquid Reflux ml.
0	850	0	0
10	685	19. 5	510
20	606	29	980
30	512	40	1, 240
40	433	49	1, 490
50	393	54	1, 600

Run #21: V = 4000 ml, G = 4000 ml/min, H_F = 30 ± 1 cm,
Fine porosity air diffuser, Column I. D. = 8. 3 cm,
T = 25 ± 2°C

0	835	0	0
10	630	24. 5	400
20	598	28	870
30	527	37	1, 240
40	449	46	1, 475
50	389	53	1, 600

Run #22: V = 4000 ml, G = 4000 ml/min, H_F =40 ± 1 cm,
Fine porosity air diffuser, Column I. D. = 8. 3 cm,
T = 25 ± 2°C

0	819	0	0
10	654	20	450
20	571	30	850
30	507	38	1, 150
40	453	45	1, 400
50	385	52	1, 530

Run #23: V = 4000 ml, G = 2000 ml/min, H_F = 20 ± 1cm, Fine porosity air diffuser, Column I. D. = 8. 3 cm, T = 25 ±2°C

Foaming Time min.	C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml.
0	539	0	59. 5	0	0
5	419	23. 3	29. 5	50. 4	90
10	396	27	-	-	240
15	365	32. 4	20	66	335
25	341	37	19. 5	67	485
35	299	45	16	73	595
45	283	47. 5	15	74	687

Run #24: V = 4000 ml, G = 2000 ml/min, H_F = 40 ± 1cm, Fine porosity air diffuser, Column I. D. = 8. 3 cm, T = 25 ± 2°C

Foaming Time min.	C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml.
0	555	0	55. 5	0	0
5	422	24	39	30	5
10	410	26	27	51. 4	52
15	387	30	26	53	100
25	367	34	25	55	200
35	328	41	24. 5	56	282
45	310	46	22. 5	59	346

Run #25: V = 2000 ml, G = 4000 ml/min, H_F = 20 ± 1 cm, Fine porosity air diffuser, Column I. D. = 8. 3 cm, T = 25 ± 2°C

Foaming Time min.	C. O. D. mg/1	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml.
0	590	0	60	0	0
5	402	32	35	58	250
10	297	50	23	62	500
15	277	53	14. 5	76	635
25	273	54	14	77	650
35	258	56	12	80	650
45	246	58	12	80	650

Run #26: V = 2000 ml, G = 4000 ml/min, H_F = 40 ± 1 cm, Fine porosity air diffuser, Column I. D. = 8. 3 cm, T = 25 ± 2°C

Foaming Time min.	C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml.
0	543	0	60	0	0
5	375	31	30	50	200
10	316	42	19	68	350
15	285	47. 5	18	69	460
25	254	53	15	75	510
55	242	55	14	77	510
45	242	55	11. 5	81	510

Run #27: V = 5000 ml, G = 3000 ml/min, H_F = 30 ± 1 cm, Medium porosity air diffuser, Column I. D. = 8.3 cm, H_{S_1} = 3 cm, H_{S_2} = 25 cm, H_{S_3} = 60 cm

Foaming Time min.		C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml.
0		695	0	73	0	0
10	$\rightarrow H_{S_1}$	529	23	40.5	44.5	125
	$\rightarrow H_{S_2}$	558	20	38	48	125
	$\rightarrow H_{S_3}$	550	21	43.4	40.5	125
20	$\rightarrow H_{S_1}$	486	30	28	62	385
	$\rightarrow H_{S_2}$	498	28	26.5	64	385
	$\rightarrow H_{S_3}$	498	28	28.5	61	385
30	$\rightarrow H_{S_1}$	451	35	18.5	75	575
	$\rightarrow H_{S_2}$	433	38	21.5	70	575
	$\rightarrow H_{S_3}$	458	34	21	71	575
40	$\rightarrow H_{S_1}$	414	40.5	15	80	700
	$\rightarrow H_{S_2}$	-	-	-	-	700
	$\rightarrow H_{S_3}$	430	38	18	76	700

Run #28: V = 4000 ml, G = 2000 ml/min, $H_F = 20 \pm 1$ cm, Medium porosity air diffuser, Column I. D. = 8. 3 cm, $H_{S_1} = 22$ cm, $H_{S_2} = 57$ cm.

Foaming Time min.		C. O. D. mg/1	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml.
0		667	0	50	0	0
5	H_{S_1}	598	10. 3	29	42	65
	H_{S_2}	610	8. 6	30	40	65
10	H_{S_1}	586	11. 5	25	50	165
	H_{S_2}	590	12. 5	28	44	165
15	H_{S_1}	563	15. 6	20	60	265
	H_{S_2}	570	14. 5	23	54	265
25	H_{S_1}	507	23. 9	19	62	445
	H_{S_2}	507	23. 9	21	58	445
35	H_{S_1}	484	27	14	72	545
	H_{S_2}	496	25	15	70	545

Run #29: V = 2000 ml, G = 3000 ml/min, $H_F = 20 \pm 1$ cm, Medium porosity air diffuser, Column I. D. = 14. 5 cm, $H_S = 3$ cm, $T = 25 \pm 2°C$

Foaming Time min.	C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml.	pH
0	798	0	62	0	0	7. 2
5	711	11	42	32	0	7. 2
10	634	21	38	40	0	7. 3
15	646	19	32	49	0	7. 3
25	593	26	24	61	0	7. 3
35	580	27	17	73	0	7. 4
45	577	28	14	77	0	7. 4
60	502	37	11. 5	82	15	7. 4

Run #30: V = 3000 ml, G = 3000 ml/min, H_F = 20 ± 1 cm, Medium porosity air diffuser, Column I. D. = 14.5 cm, H_S = 3 cm, T = 25 ± 2°C

Foaming Time min.	C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml.	pH
0	798	0	62	0	0	7.2
5	744	7	50	30	0	7.3
10	695	13	45	26	0	7.3
15	667	17	38	45	0	7.3
25	630	21	27	57	0	7.3
35	617	23	21	66	0	7.3
45	564	29	18	71	0	7.3
60	560	30	18	71	0.5	7.4

Run #31: $V = 4000$ ml, $G = 3000$ ml/min, $H_F = 20 \pm 1$ cm, Medium porosity air diffuser, Column I. D. = 14.5 cm, $H_S = 3$ cm, $T = 25 \pm 2°C$

Foaming Time min.	C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal	Liquid Reflux ml.	pH
0	798	0	62	0	0	7.2
5	786	2	48	23	0	7.25
10	708	11	47	24	0	7.25
15	683	14	43	32	0	7.25
25	675	16	35	44	0	7.3
35	654	18	31	50	0	7.3
45	642	20	29	53	0	7.3
60	621	22	27	57	0	7.3

Run #32: V = 3000 ml, G = 4000 ml/min, H_F = 25 ± 5 cm,
Medium porosity air diffuser, Column I. D. = 8. 3 cm,
T = 41 ± 2°C

Foaming Time: min	C. O. D. mg/l	C. O. D. % Rem.	Turbidity Neph. U.	Turbidity % Rem.	Liquid Reflux ml.
0	430	0	29	0	0
5	320	26	12	60	300
10	270	37	7	78	550
15	250	42	5	83	650
20	215	50	4	88	700
30	203	53	1	97	705
40	191	56	1	97	710

Run #33: V = 3000 ml, G = 4000 ml/min, H_F = 25 ± 5 cm,
Medium porosity air diffuser, Column I. D. = 8. 3 cm,
T = 10 ± 2°C

Foaming Time: min	C. O. D. mg/l	C. O. D. % Rem.	Turbidity Neph. U.	Turbidity % Rem.	Liquid Reflux ml
0	422	0	31. 5	0	0
5	352	17	14	57	240
10	297	30	8. 5	73	350
15	273	35	7	78	450
20	250	41	5	86	550
30	219	48	2	94	580
40	199	53	1	97	600

Run #34: V = 3000 ml, G = 1650 ml/min, Simulated wastewater,
H_F = 15 ± 5 cm, Medium porosity air diffuser,
Column I. D. = 8. 3 cm, H_S = 5 cm

Run# 34a:

Foaming Time min.	C. O. D. mg/l	C. O. D. % Removal	Turbidity Neph. Units	Turbidity % Removal
0	406	0	31. 5	0
5	322	21	15. 5	51
10	273	33	12	62
15	284	30	7. 5	76
20	281	31	6	81
30	250	38	5	84
Run #34b:				
0	402	0	31. 5	0
5	318	21	15. 5	51
10	283	30	9. 5	70
15	272	32	6	81
20	264	34	5. 5	83
30	242	40	5	84
Run #34c:				
0	351	0	31. 5	0
5	297	15	15	51
10	266	24	10	68
15	246	30	8	75
20	238	32	5. 5	83
30	213	39	5	84
Run #34d:				
0	395	0	32.5	0
5	322	18	17. 5	48
10	283	28	11	68
15	-	-	-	-
20	277	30	8	78
30	253	36	4. 9	88

APPENDIX 3

CONTINUOUS STUDIES - RAW DATA

Run #1: Batch & Continuous Stages with Simulated Wastewater.

Batch Stage: V = 3000 ml, G = 3000 ml/min, H_F = 20 ± 1 cm, Medium porosity air diffuser, Column I. D. = 8. 3 cm, H_S = 3 cm

Foaming Time: min	C. O. D. mg/l	C. O. D. % Rem.	Turbidity Neph Un.	Turbidity % Rem.	Liquid Reflux ml	pH
0	972	0	87. 5	0	0	7. 2
5	840	14	73	16. 6	0	7. 4
10	800	18	65	26	0	7. 4
15	741	24	56	36	0	7. 4
25	657	32	33	62	0	7. 5
35	582	40	24. 5	72	5	7. 5
45	566	42	19. 5	78	50	7. 6
60	498	49	12	86	290	7. 6

Continuous Stage: Feed Rate = 40 ml/min, G = 3000 ml/min, H_F = 20 ± 1 cm, Medium porosity air diffuser, Column I. D. = 8. 3 cm, liquid level = 2000 ml, H_S = 3 cm, T = 25 ± 2 C

Feeding Time: hr	C. O. D. mg/l	C. O. D. % Rem.	Turbidity Neph. Un.	Turbidity % Rem.	Liquid Reflux ml	pH
0. 167	482	50. 5	12. 5	86	0	7. 5
0. 33	-	-	14	84	0	7. 45
0. 5	474	51	16. 5	81	0	7. 5
0. 66	-	-	16	81. 7	0	7. 4
0. 83	474	51	17	81. 7	0	7. 4
1. 0	-	-	16. 5	81	0	7. 4
1. 167	526	46	18	79. 4	0	7. 4
1. 33	-	-	16. 5	81	0	7. 3
1. 5	502	48	16. 5	81	0	7. 3
1. 66	-	-	14. 5	83. 4	0	7. 3
1. 83	538	45	18	79	0	7. 4
2. 0	-	-	18. 5	79	0	7. 4
2. 167	526	46	19	78	0	7. 4
2. 33	-	-	18	79	0	7. 4
2. 5	533	45	16. 5	81	0	7. 3
2. 66	-	-	16. 5	81	0	7. 3
2. 83	490	50	20. 5	77	0	7. 2
3. 0	-	-	16	82	0	7. 2
3. 25	530	46	17. 5	80	0	7. 2
3. 5	-	-	18	79. 4	0	7. 2
3. 75	550	43	20	77. 0	0	7. 2
4. 0	-	-	21	76	0	7. 1
4. 25	518	47	18	79	0	7. 1
4. 5	-	-	17. 5	80	0	7. 1
4. 75	522	46	21	76	0	7. 1
5. 0	-	-	21	76	0	7. 1
5. 25	530	46	21	76	0	7. 1
5. 417	-	-	20	77	0	7. 1

Run #2: Batch & Continuous Stages With Simulated Wastewater.

Batch Stage : V = 3000 ml, G = 3000 ml/min, H_F = 20 ± 1 cm, H_S = 3 cm, Medium air diffuser, Column I. D. = 8. 3 cm

Foaming Time: min	C. O. D. mg/l	C. O. D. % Rem.	Turbidity Neph. Un.	Turbidity % Rem.	Liquid Reflux ml	pH
0	684	0	60. 7	0	0	7. 1
5	591	14	42. 5	30	0	7. 2
10	568	17	38	37	10	7. 25
15	494	28	32	47. 5	95	7. 25
25	444	35	20	67	280	7. 3
35	412	40	16	74	470	7. 3
45	381	44	10	84	590	7. 3
60	339	51	9	85	630	7. 3

Continuous Stage: Feed Rate = 40 ml/min, G = 3000 ml/min, H_F = 10 cm, Medium porosity air diffuser, Column I. D. = 8. 3 cm Liquid level = 2000 ml, H_S = 3 cm, T = 25 ± 2 C,

Feeding Time: hr	C. O. D. mg/l	C. O. D. % Rem.	Turbidity Neph. Un.	Turbidity % Rem.	Liquid Reflux ml	pH
0. 167	377	45	11	82	0	7. 25
0. 33	401	42	13. 5	78	15	7. 25
0. 50	397	42	12	80	60	7. 3
0. 75	393	43	12	80	140	7. 3
1. 0	389	43	13	79	220	7. 3
1. 25	401	42	12. 5	79. 4	300	7. 3
1. 5	389	43	16	74	390	7. 25
1. 75	393	43	13	79	480	7. 3
2. 0	393	43	13	79	559	7. 3
2. 25	381	44	14	77	681	7. 3
2. 5	385	44	13. 5	78	710	7. 3
2. 75	389	43	13. 5	78	782	7. 3
3. 0	385	44	13. 5	78	920	7. 3
3. 25	393	43	11	82	1, 050	7. 3
3. 5	393	43	12	80	1, 150	7. 3
3. 75	385	44	12	80	1, 260	7. 3
4. 0	393	43	12. 5	79. 4	1, 364	7. 3
4. 25	393	43	11	82	1, 476	7. 3
4. 5	385	44	12. 5	79. 4	1, 560	7. 3
4. 75	393	43	14	77	1, 666	7. 3
5. 0	389	43. 2	13	79	1, 765	7. 3

Run #3: Batch & Continuous Stages with Simulated Wastewater.

Batch Stage: V = 3000 ml, G = 3000 ml/min, H_F = 20 ± 1 cm, H_S = 3 cm, Coarse porosity air diffuser, Column I. D. = 8.3 cm

Foaming Time: min	C. O. D. mg/l	C. O. D. % Rem.	Turbidity Neph. Un.	Turbidity % Rem.	Liquid Reflux ml	pH
0	669	0	65.5	0	0	7.15
10	551	18	48	26.7	5	7.25
20	480	28	37.5	43	80	7.25
30	429	36	25.7	58	260	7.3
45	378	44	15.5	76	475	7.3
60	331	51	13	80	580	7.3

Continuous Stage I : Retention Time = 1 hr.

Feeding Time hr	C. O. D. mg/l	C. O. D. % Rem.	Turbidity Neph. Un.	Turbidity % Rem.	Liquid Reflux ml	pH
0.167	358	46.5	17	74	0	7.3
0.33	370	45	20	70	5	7.3
0.50	358	46.5	16.5	75	40	7.3
0.75	347	48	18	73	86	7.3
1.0	354	47	16	76	142	7.3
1.25	358	46.5	15	77	198	7.3
1.50	361	46	17	74	250	7.3

Continuous Stage II : Retention Time = 1/2 hr.

0.167	394	41.2	17	74	18	7.3
0.33	406	39	20	70	70	7.3
0.50	394	41.2	24	63	125	7.3
0.75	409	39	23	64	220	7.3
1.0	402	40	25	62	310	7.3
1.25	409	39	23	65	415	7.3
1.50	402	40	23	65	550	7.3

Continuous Stage III : Retention Time = 1/4 hr.

0.167	417	38	27	59	25	7.3
0.33	457	32	28	57	100	7.3
0.50	463	31	26	60	150	7.3
0.75	453	32	29	56	240	7.3
1.0	445	33.5	30	54	380	7.3
1.25	448	33	29	56	584	7.3

Run #4: Batch & Continuous Stages with Real Wastewater.

Batch Stage: V = 3000 ml, G = 3000 ml/min, $H_F = 20 \pm 1$ cm, $H_S = 3$ cm, Coarse porosity air diffuser, Column I. D. = 8. 3 cm.

Foaming Time: min	C. O. D. mg/l	C. O. D. % Rem.	Turbidity Neph. Un.	Turbidity % Rem.	Liquid Reflux ml
0	341	0	47	0	0
10	214	37	26	45	0
20	186	45	22	53	0
30	162	52	20	58	2
40	143	58	19	60	25
50	127	63	18	62	34
60	123	64	15	68	34

Continuous Stage I: Retention Time = 1. 0 hr.

Feeding Time: hr	C. O. D. mg/l	C. O. D. % Rem.	Turbidity Neph. Un.	Turbidity % Rem.	Liquid Reflux ml.
0. 167	127	63	18	62	0
0. 33	135	61	16	66	0
0. 50	131	62	14	70	0
0. 75	143	58	16	66	0
1. 0	134	61	17	64	0
1. 25	131	62	15	68	0
1. 50	137	59	-	-	0
1. 75	135	61	18	62	0
2. 0	139	59	19	60	0

Continuous Stage II: Retention Time = 1/2 hr.

0. 167	146	57	16	66	0
0. 33	158	54	20	58	0
0. 50	158	54	23	51	0
0. 75	170	50	24	49	0
1. 0	154	55	21	56	5
1. 25	155	55	20	58	10
1. 5	155	55	20	58	12
1. 75	146	57	21	56	16
2. 0	139	59	18	62	25

Continuous Stage III: Retention Time = 1/4 hr.

0. 167	174	49	25	47	0
0. 417	166	51	27	43	10
0. 75	178	48	26	45	25
1. 0	209	38	23	51	35
1. 25	174	49	24	49	50
1. 50	186	45	23	52	62
2. 0	186	45	20	58	70

Run #5: Batch & Continuous Stages with Real Wastewater.

Batch Stage: V = 3000 ml, G = 3000 ml/min, H_F = 20 ± 1 cm, H_S = 3 cm, Coarse porosity air diffuser, Column I. D. = 8. 3 cm

Foaming Time: min	C. O. D. mg/l	C. O. D. % Rem.	Turbidity Neph Un.	Turbidity % Rem.	Liquid Reflux ml	pH
0	703	0	73	0	0	7. 2
10	453	36	49	34	0	7. 2
20	402	43	36	51	140	7. 3
30	340	52	28	61	340	7. 4
40	299	58	25	66	425	7. 45
50	285	59	23	69	425	7. 45
60	281	60	19	74	425	7. 5

Continuous Stage I : Retention Time = 1 hr., H_F = 10 cm, liq. lev. = 2 lt.

Feeding Time: hr	C. O. D. mg/l	C. O. D. % Rem.	Turbidity Neph Un.	Turbidity % Rem.	Liquid Reflux ml	pH
0. 167	285	59	20	73	0	7. 45
0. 33	289	59	21	71	5	7. 5
0. 50	312	56	21	71	10	7. 5
0. 75	293	58	22	70	26	7. 5
1. 0	305	57	23	69	38	7. 5
1. 25	289	59	21	71	62	7. 5
1. 50	291	59	23	69	85	7. 5
1. 75	294	58	21	71	115	7. 5
2. 0	289	59	23	69	137	7. 5
Continuous Stage II : Retention Time=1/2 hr.						
0. 167	307	56	24. 5	66	10	7. 5
0. 33	309	56	25	66	60	7. 5
0. 50	316	55	26	64	140	7. 5
0. 75	312	56	26	66	230	7. 5
1. 0	316	55	25	64	350	7. 5
1. 25	316	55	26	64	500	7. 5
1. 5	320	54	25	66	690	7. 5
1. 75	372	56	26	64	875	7. 5
2. 0	309	56	26	64	1, 080	7. 5
Continuous Stage III : Retention Time = 1/4 hr.						
0. 167	348	51	29	60	90	7. 5
0. 33	351	50	34	54	300	7. 5
0. 50	351	50	34	54	600	7. 5
0. 75	351	50	33	55	900	7. 5
1. 0	359	49	33	55	1, 300	7. 5
1. 25	-	-	-	-	1, 750	7. 5
1. 50	355	49	32	56	2, 070	7. 5
1. 75	363	48	33	55	1, 350	7. 5
2. 0	351	50	34	53	2, 670	7. 5

APPENDIX 4

PRELIMINARY EXPERIMENTS ON FLOCCULATION

A series of experiments designed to determine whether alum ($Al_2(SO_4)_3 - 14H_2O$), alum and H_2SO_4, lime ($Ca(OH)_2$), ferric chloride ($FeCl_3$) and "Burtonite #78" would clarify the wastewater from fish processing plants, were carried out.

The procedure followed for all coagulants, other than "Burtonite #78", was the same; 200 ml. of simulated wastewater were poured into a 400 ml. beaker and mixed by running the stirrer at maximum speed. The reagents (coagulant plus chemical for control of pH) were added rapidly to the wastewater, stirred at maximum r. p. m. for 1 minute, then the stirring rate was reduced to the minimum speed and stirred for 10 minutes. The mixture was then transferred rapidly to two graduate cylinders (100 ml.) and settling rate with change in pH as well, were followed. For "Burtonite # 78", 0. 5% plain water solution of the #78 was combined with an equal volume of fish processing wastewater, mixed for 10 minutes, transferred rapidly to two graduate cylinders (100 ml.) and settling rate and pH change followed.

The results obtained indicated that alum, alum & H_2SO_4 and ferric chloride, can be used to reduce the C. O. D. of waste - water. Lime was found to be ineffective; settling was extremely slow, even when large doses were used. As for cost, if it would work, 6 ml. of 1M $Ca(OH)_2$/100 ml. of wastewater is equivalent to 35¢/1000 gallons of wastewater.

With "Burtonite #78", settling was very slow. After 6 hours the water was not very clear. Using 0.5 gm. of dry "Burtonite #78"/1000 ml. of wastewater, there was no precipitation-flocculation whatsoever. As stated above, alum will flocculate solids from fish processing wastewater. Treatment cost of approximately 77¢/1000 gallons is relatively high, and the high dissolved sulphate content of the treated water is even higher than when using alum alone. The best results were obtained with Ferric Chloride. Settling was rapid and the treated water clear. The treatment cost however, is too high ($5.38/1000 gal. of wastewater).

APPENDIX 5

VACUUM FLOTATION TESTS

Vacuum flotation, which has been used successfully to remove grease and suspended solids from sewage and industrial wastewater (Nemerow, 1971), was investigated preliminarily for the treatment of wastewater from freshwater fish processing plants.

The apparatus used was a 59 cm. high and 4. 5 cm. I. D. column, with a removable No. 10 rubber stopper top, and a No. 1 rubber stopper in the centre of the bottom plate. On the top removable stopper were mounted an air outlet (vacuum inlet), a scum outlet, and a pressure gauge. A tube placed through the No. 1 bottom rubber stopper served for the withdrawing of samples.

Simulated freshwater fish processing wastewater (450 ml.) was placed in the column and shaken to allow the air to go into the solution. To remove large bubbles, a brief deaeration period was then provided at atmospheric pressure, the top No. 10 rubber stopper charged and a vacuum of about 9 inches of mercury applied. After 15 minutes, a sample was withdrawn from the bottom of the cell and analyzed for turbidity. Without chemicals, and with the addition of 10 ml. of 1. 0 molar $Ca(OH)_2$ and 20 ml. of 0. 2 normal H_2SO_4 to 450 ml. of wastewater, the process was ineffective. But with the addition of $FeCl_3$ and NaOH, or alum and NaOH, the results were spectacular. A cost analysis however, indicated that the treatment cost would be too high; hence, further investigation ceased.

APPENDIX 6

PEAT MOSS TESTS

Peat moss has been used with some success for the removal of organic electrolytes, such as dyestuffs (Dufort et al. 1972) and proteins, as beef extract (Ruel, 1970; Tinh, 1971) from water. Dugal (1963) stated that the approximate composition of perch and smelt was 78 percent water, 17 percent protein, 3 percent fat and 2 percent ash. Thus, removal of the proteineous material from the wastewater would substantially reduce the amount of polluting matter discharged from the fish processing plants. With this in mind, preliminary experiments were undertaken to establish if an intense investigation of the subject would be worth while.

Wastewater from Freshwater Fish Marketing Corporation Plant and peat moss designated as "Commercial Canadian Sphangnum", 9 - 50 mesh, approximately 34% moisture, were used in the experiments. The procedure used was as follows:

- 0. 5 grams of peat moss were weighed and placed in 250 ml. Erlenmeyer flasks
- Wastewater was pre-equilibrated to contact temperature (40°C) and 100 ml. was introduced into each of the flasks.
- All flasks were shaken at 40 C on a rotary platform shaker at 160 r. p. m. for 60 minutes.

- All samples were filtered through 80 mesh screen to remove suspended peat. C. O. D. was determined by the standard method described by Am. Pub. Health Ass. (1971)

Several trials with wastewater containing 0. 5 meq. H_2SO_4 or 0. 5 meq. NaOH were also performed. The results revealed no C. O. D. reduction; on the other hand, peat moss contributed C. O. D. and the contribution was higher when NaOH was present.