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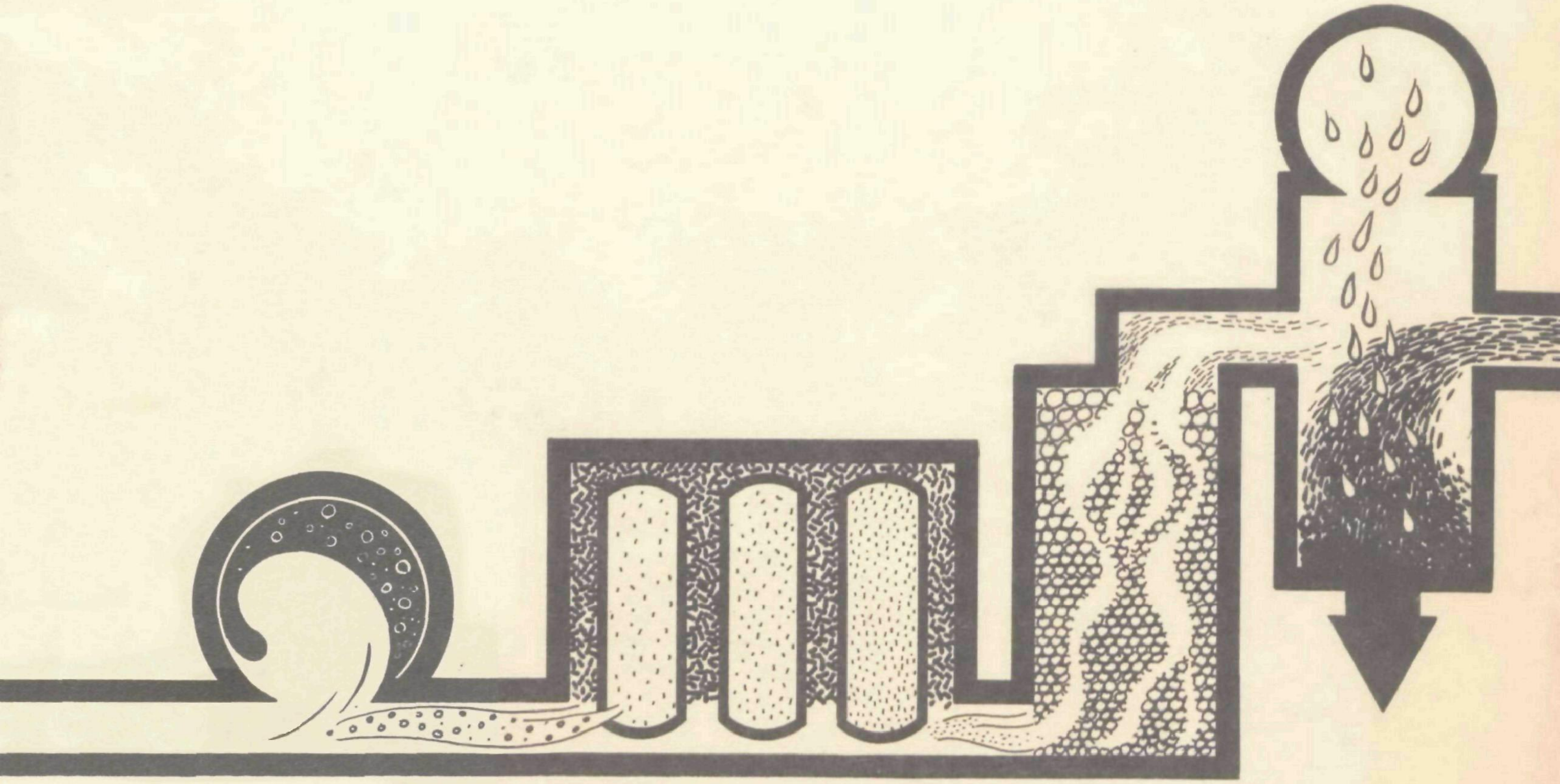
INVESTIGATION OF A HIGH-PRESSURE FOAM WASTEWATER TREATMENT PROCESS



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INVESTIGATION OF A HIGH-PRESSURE FOAM WASTEWATER TREATMENT PROCESS

by

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for the

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DEPARTMENT OF THE INTERIOR

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ABSTRACT

A foam fractionation-flotation process for the separation of organic materials and other contaminants from primary and secondary sewage effluent was studied to determine its technical and economic feasibility. Air and waste water were mixed and held at pressures exceeding 150 psi for periods of 6 to 25 minutes. The mixtures were then bled to a release vessel where pressures were reduced to atmospheric. Dissolved air was released as extremely fine bubbles which formed a thick creamy froth. Soluble organic and particulate matter collected at the bubble-water interfaces and was removed with the froth at the overflow of the release vessel. Air flow rates corresponding to between 40 and 125% of saturation, different pressures, and varying contact times were studied. Several release vessels and a variety of additives were also tested. The most promising results were obtained with 300-400 mg/l of either ferric chloride or alum as coagulants, at pressures greater than 175 psi, and at air-to-water volume ratios of 0.17 to 1. These conditions gave chemical oxygen demand reductions of about 70%, phosphate reductions exceeding 90%, and suspended solids reductions of 40-80%. Estimated treatment costs, exclusive of chemicals, would be less than $0.05/1,000 gal. for a 10 mgd plant.

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INTRODUCTION

An urgent need exists for a low cost method to reduce contaminants in wastewater to levels that will not cause pollution problems in receiving streams nor be objectionable in water reuse. A combination of high pressure foam fractionation and flotation offers a potential solution to this problem. Foam fractionation at lower pressures has been used to remove non-biodegradable detergents; flotation is used in many industrial processes where particulate matter is separated from a liquid. Preliminary laboratory experimentation indicated that by increasing operating pressure in the foam fractionation process and by combining the process with a flotation step large quantities of pollutants could be removed from wastewater. When the air and water are contacted at high pressure, more air is dissolved than would occur at atmospheric pressure. When the pressure is reduced to atmospheric, numerous very small bubbles are released from the solution. The froth and the waste material which it contains is then separated from the purified water and disposed of. Such a method might be used to remove soluble organic material, phosphates, and particulate matter. The dissolving of large quantities of air during the high pressure treatment would be beneficial in reducing Biochemical oxygen demand (BOD). The process might also find industrial application in the treatment of cannery and pulp and paper waste or any other wastes which contain large quantities of suspended solids.

Soluble organic and particulate matter collects at air bubble-water interfaces and can be removed by foam fractionation and flotation. Soluble phosphates can be precipitated with alum or iron salts and removed by flotation. The pressure, air-to-water ratio, and water-air contact time all affect the physical properties of the froth and the effectiveness of the process in purification of wastewater. This investigation was intended to study each of these variables, using equipment which might be used in a sewage treatment facility. Additional studies were made to determine the effect of various chemical coagulants on foam production and removal of organic matter and soluble phosphates. All experiments were run in a small scale pilot plant.

EXPERIMENTAL PROGRAM AND DISCUSSION OF RESULTS

Wastewater used in this project was municipal primary or secondary effluent obtained immediately before its use from the Pomona, California sewage treatment plant. The small pilot plant equipment was fabricated from commercially available parts and is described in detail in the following section.

Experimental Equipment

Figure 1 describes the pilot unit used in this investigation. A 200 gal., agitated feed tank was used to hold the sewage effluent prior to introduction into the processing circuit. Reagents in solution and low pressure air could be introduced to the wastewater stream before it entered the suction of the gear pump. The pump was driven with a variable speed motor which allowed for control of both the flow rate and pressure. The wastewater feed and the air lines had rotameters calibrated for the operational conditions which made it possible to control the air-to-liquid ratio. Two dissolving tanks, fed by the pump, had a capacity of about six gallons each. Air dissolving (retention) time was varied by removing one of the tanks from the circuit and piping directly from the other to the foam separator.

A box-type foam separator (Figures 2 and 3) was originally constructed of lucite but was replaced with a stainless steel unit having lucite windows. The separator was a square box having a pyramidal metal top and a volume of 22 gal. Initial experiments were made with this separator, and a number of problems were encountered. The froth accumulated on the sloping sides of the top and could be seen falling back to the bottom of the vessel. It was apparent that the volume of the vessel was too large for the system and, as a consequence, the foam retention time was long enough to cause sedimentation and deposition of the froth on the walls and top of the vessel.

A channel-type separator (Figures 4 and 5) was then designed to eliminate flat surfaces which the froth could contact. Difficulties in controlling the liquid level were encountered. The foam skimmer would first remove too much foam and then remove none at all. When replacement of the overflow weir with three weirs and attachment of a vacuum apparatus still proved unsatisfactory, a moving paddle was devised to help push the foam toward two adjustable weirs built into the channel. While this last change improved separation to some extent, results with the channel-type separator were not satisfactory.

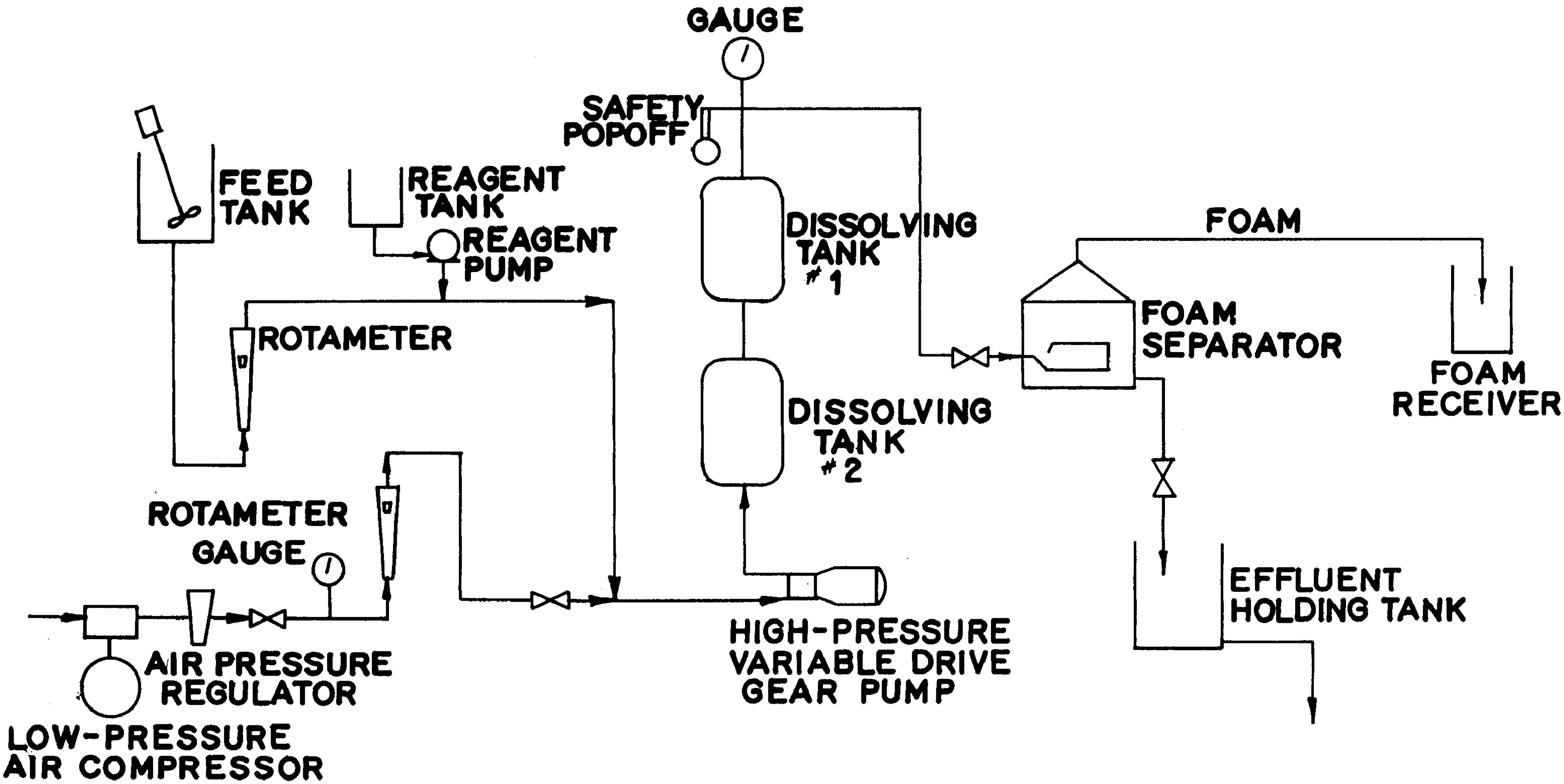


FIGURE 1

EQUIPMENT ARRANGEMENT
FOR FOAM FRACTIONATION-
FLOTATION PROCESS

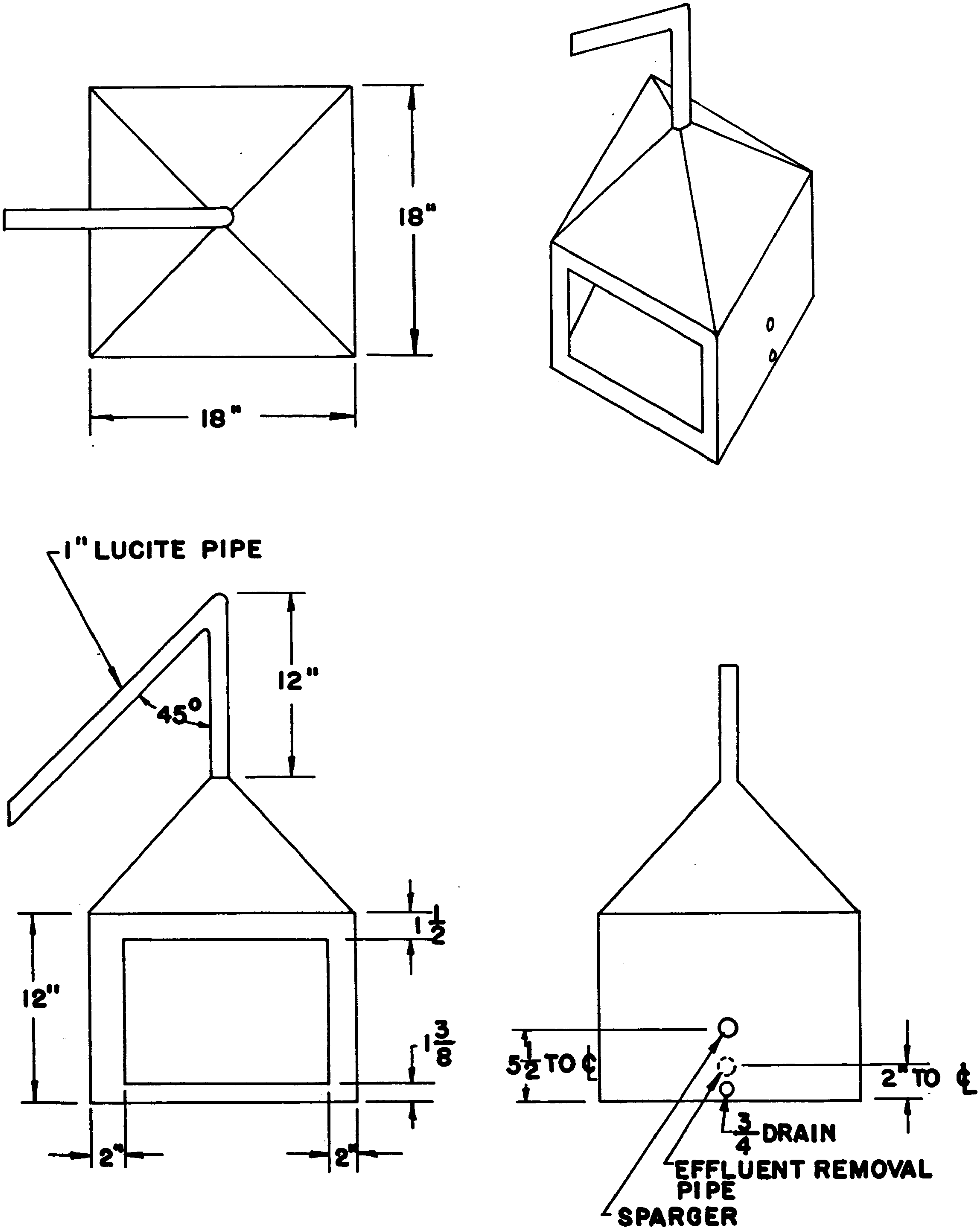
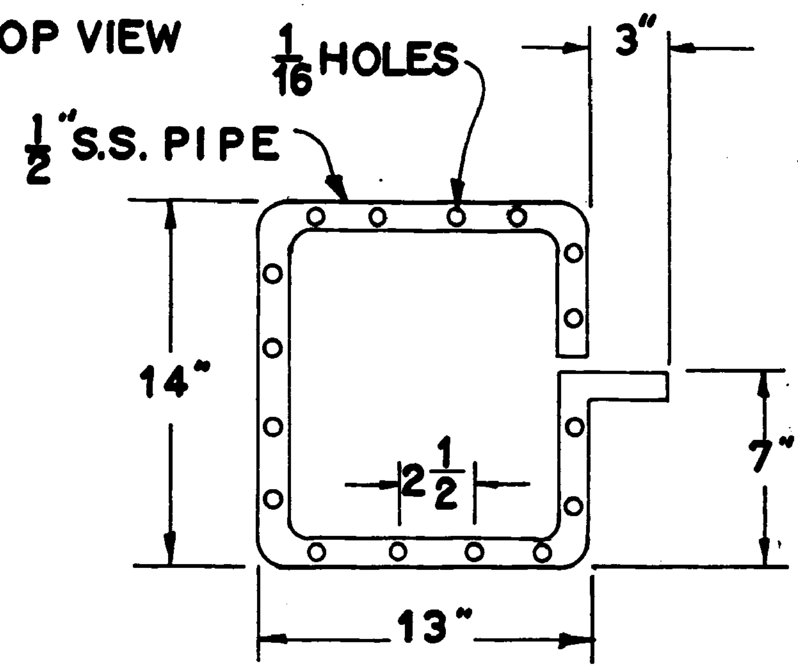


FIGURE 2

BOX-TYPE FOAM SEPARATOR

SPARGER-TOP VIEW



EFFLUENT REMOVAL PIPE - FRONT VIEW

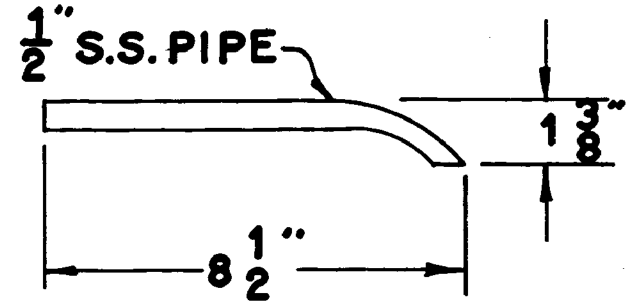


FIGURE 3

INTERNALS OF
BOX-TYPE FOAM SEPARATOR

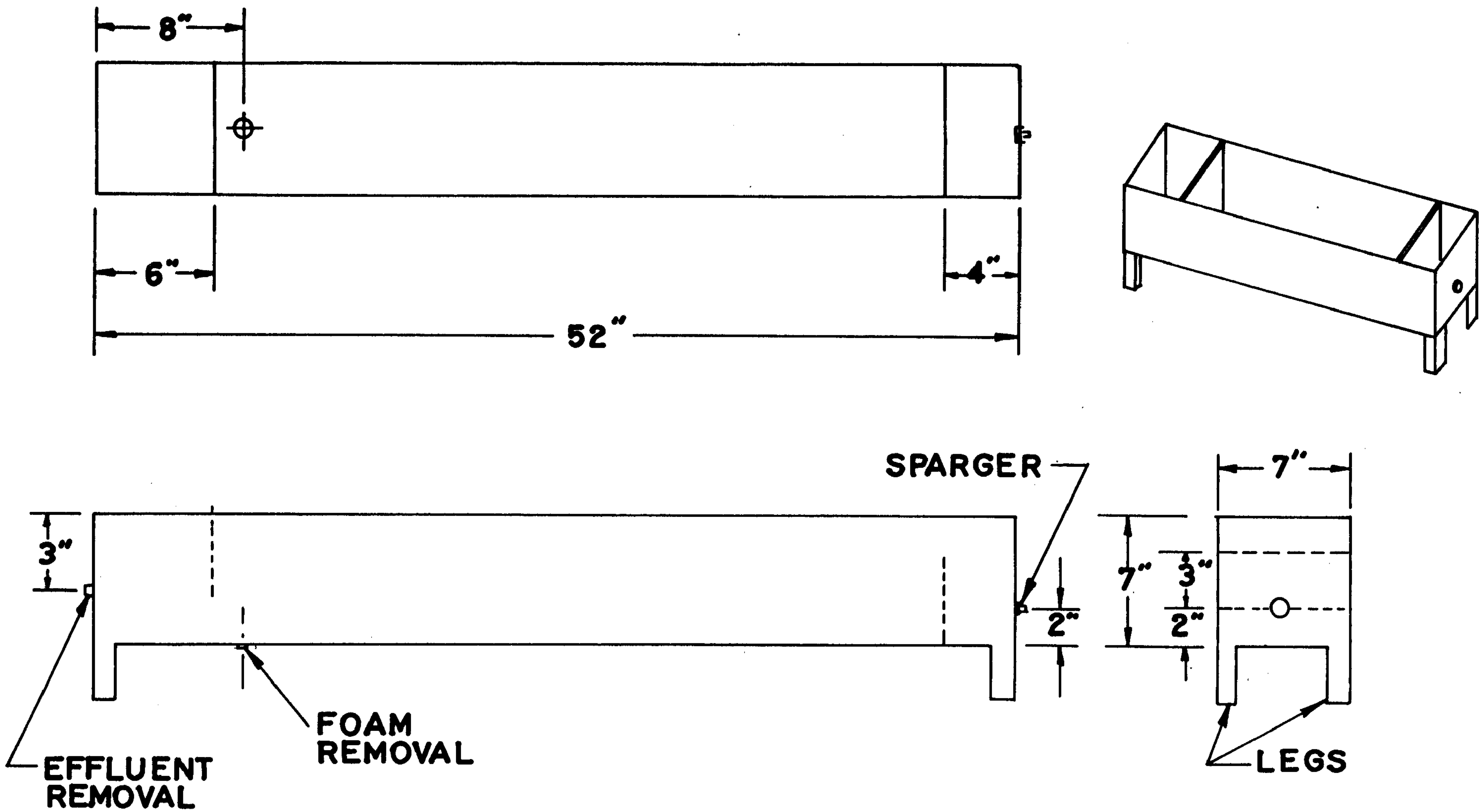
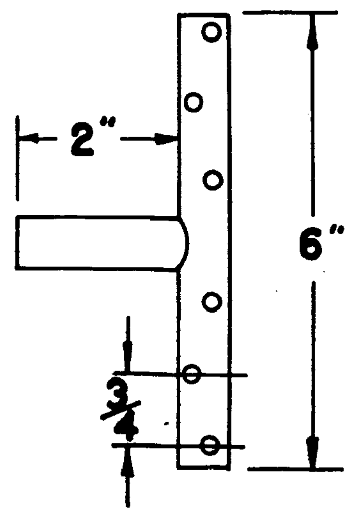


FIGURE 4

TROUGH-TYPE FOAM SEPARATOR

SPARGER - TOP VIEW



FOAM REMOVAL DRAIN - SIDE VIEW

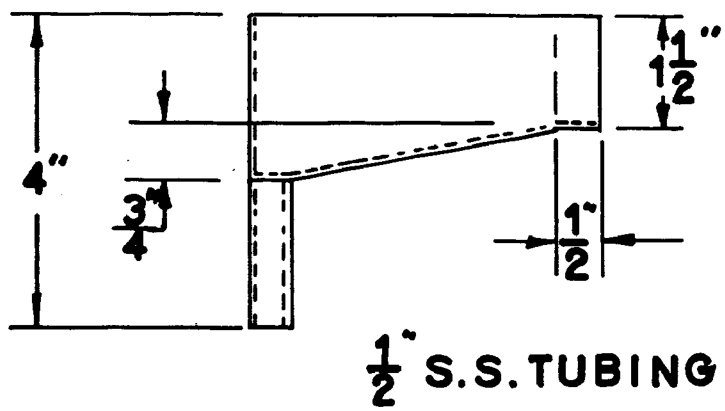


FIGURE 5

DETAILS OF TROUGH-TYPE FOAM SEPARATOR

Alternatively, a proven separator design was used to permit adequate testing of other variables within the project budget. A cylindrical separator with a foam skimmer is shown in Figure 6. A similar separator used previously in experimental work had performed satisfactorily. Modifications were made to adapt this separator to the foam fractionation-flotation process, and most of the experimental runs were made with it.

Preliminary Experiments Without Chemical Additives

Initial experiments were made without any chemical coagulants to determine optimum operating parameters for reduction in chemical oxygen demand (COD). Although chemical additives are needed if good phosphate reductions are to be achieved, experiments with additives were deferred until other variables had been studied. Feed material for nearly all of the experiments was primary sewage effluent which had been allowed to settle for two hours. Secondary sewage effluent was used as feed for a few experiments. Variations in COD were noted depending on the time of day at which a sample was obtained. Morning samples ran 100 mg/l COD or less, which was not considered typical of primary effluent. Work hours were rearranged and samples were obtained in the afternoon when the COD was usually between 150 and 210 mg/l.

In the initial experiments using secondary effluents, an attempt was made to do material balances for the entire system. The results, shown in Table 1, are somewhat erratic. Because of the difficulty encountered in accurately sampling the high COD foam concentrates, material balances were found to be less reproducible than desired.

Primary sewage effluent with rather low COD was used as feed in a series of preliminary experiments to determine the general effects of pressure, contact time, and air-to-liquid ratios. The results are shown in Table 2. Average COD reductions were 28.7% at 235 psi and 20.2% at 175 psi. Average turbidity reductions were 29.8% and 40.2% for the same pressures, respectively.

Two residence times in the dissolver were tested by first operating with two pressure tanks in the circuit and then with only one tank in the circuit. The residence times were 13.3 minutes and 6.7 minutes. COD reductions at 13.3 minutes averaged 25.5% while at 6.7 minutes the average reduction was 22.1%. Reductions in turbidity averaged 36.6% and 31.8% for the two residence times, respectively.

Air flow rates corresponding to 42, 78 and 125% of saturation at the operating pressures were tested to determine if a larger quantity of dissolved air would cause an

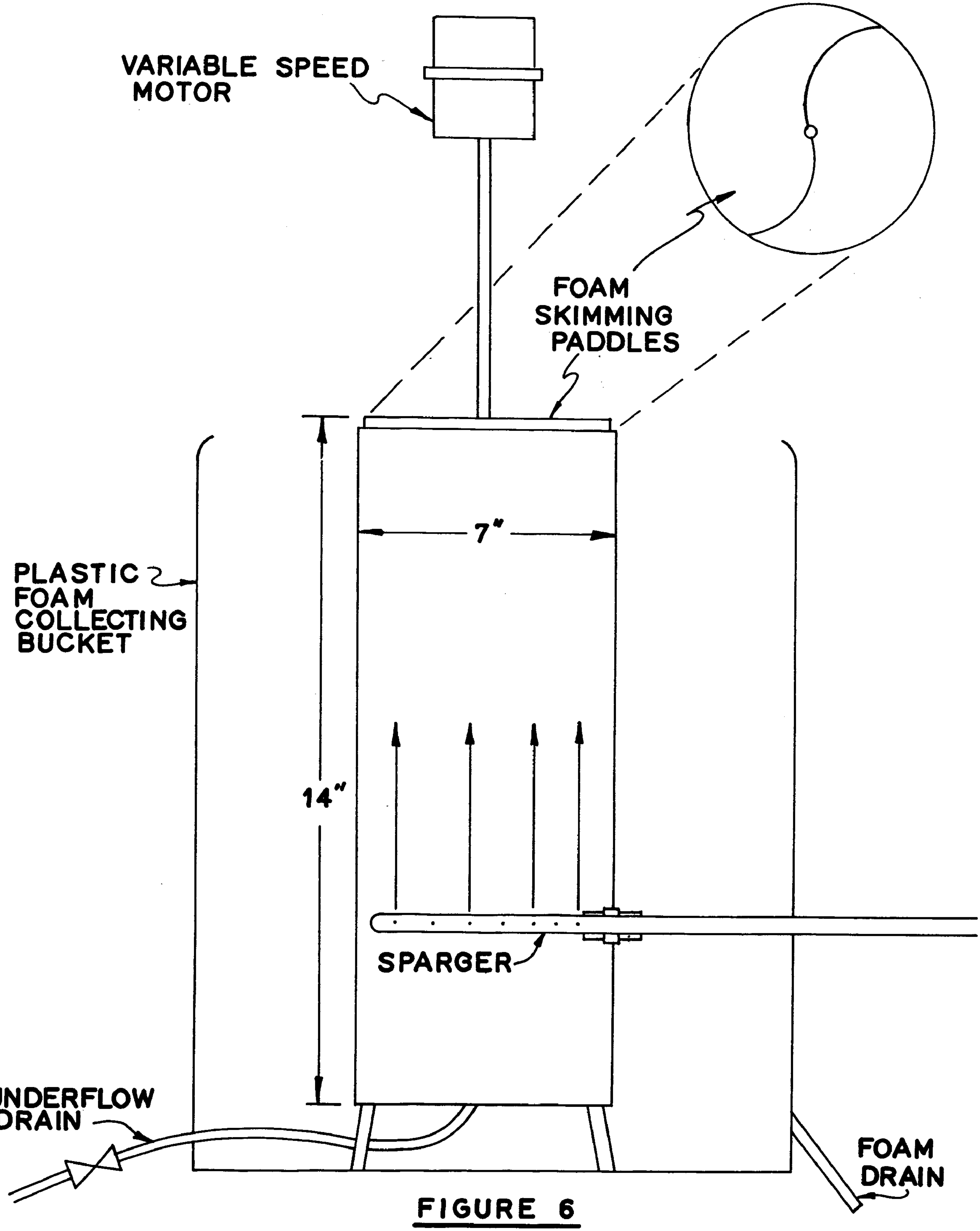


FIGURE 6

CYLINDRICAL
FOAM SEPARATOR
WITH FOAM SKIMMER

TABLE 1

Foam Fractionation Data
Material Balance for System Using Secondary Effluent as Feed

Box-Type Foam Separator
Feed Flow Rate: 0.9 gpm
Pressure: 235 psi
Time in Dissolver: 13.3 minutes
Time in Separator: 22.0 minutes
Air-to-Water Ratio: 0.09 to 1
% of Theoretical Saturation: 42

COD, mg/l				
Feed	Effluent	Foam Concentrate	Volume of Concentrate, % of original feed	Material Balance, % accounted for
85	68	896	1.0	90
65	57	325	21.0	209
60	46	134	1.0	79
60	36	256	9.0	98
60	39	157	12.0	97

TABLE 2

Foam Fractionation Data
Waste Water Treatment Without Chemical Additives

Low COD-Primary Effluent Feed
Box-Type Foam Separator
Feed Flow Rate: 0.9 gpm
Time in Separator: 22 minutes

		Air Flow Rate		COD		Turbidity	
Pressure, psig	Dissolver Time, minutes	% of Feed Volume	% of Saturation	Feed, mg/l	Reduction, %	Feed, mg/l SiO_2	Reduction, %
175	6.7	9.5	42	71	31	40	38
175	6.7	17.0	78	88	8	82	21
175	6.7	25.5	125	74	32	55	50
175	13.3	9.5	42	98	9	108	28
175	13.3	17.0	78	82	4	107	33
175	13.3	25.5	125	69	19	67	33
175	13.3	17.0	78	60	35	85	70
175	13.3	17.0	78	82	3.5	85	33
175	13.3	17.0	78	60	40	85	56
235	6.7	11.5	42	85	19	40	10
235	6.7	20.0	78	88	5	82	21
235	6.7	33.0	125	92	38	45	51
235	13.3	11.5	42	61	44	--	13
235	13.3	20.0	78	72	27	8	42
235	13.3	33.0	125	60	30	42	44
235	13.3	21.0	78	85	20	92	50
235	13.3	11.5	42	61	41	25	14
235	13.3	33.0	125	57	34	64	23

increase in COD reduction. Average COD reductions were 28.8% at 42% of saturation, 17.8% at 78% of saturation, and 30.6% at 125% of saturation. Turbidity reductions, however, increased from 28.6% at 42% of saturation to 40% at both 78 and 125% of saturation.

In these runs and those that follow it was necessary to use a number of different batches of effluent. This variability in feed composition makes interpretation of results more difficult than when a single feed composition can be used. Conclusions about the effect of operating variables must be considered preliminary. An expanded experimental program would be required to make conclusions more firm. The above experiments suggested that only a slight gain in COD removal would be realized by increasing the system pressure above 175 psi or by increasing residence time in the pressure tank to greater than seven minutes. Turbidity measurements suggested that increased air flow, at rates corresponding to somewhat less than 78% of saturation, would provide for better separation of particulate matter than would lower flow rates. A limit, however, was reached at some point below 78% of saturation where no further increase in turbidity reduction was noted. COD results did not confirm this observation. Visual observations indicated that air, in excess of that needed to reach theoretical saturation at the elevated pressures, caused extreme turbulence in the release vessel. The turbulence seemed to destroy much of the froth and it was expected that COD removal would be drastically reduced. Again, the COD analyses did not confirm the visual observations, and there was no evidence to indicate that COD removal had been affected. Further experiments were run to determine if higher COD feed material might be used to better define the effects of operating variables. The results of these experiments are shown in Table 3. Two pressures, two residence times and two air flow rates were tried. The lower pressure of 175 psi gave slightly better COD removals than did 235 psi. Residence time in the pressure vessel had exactly the same effect on the high COD feed that it had on the low COD feed. A very slight increase (from an average of 13 to 16%) in COD removal was noted when residence time was increased from 6.7 minutes to 13.3 minutes. Air flow rates corresponding to 125% of theoretical saturation gave approximately 18% greater COD reductions (average) than did air flow rates corresponding to 42% of saturation.

Turbidity measurements on the underflow from the foam separator varied widely when primary effluents with COD of greater than 150 mg/l were used as feed. An increase in turbidity was observed for the same feed material under the same conditions when the pump speed was increased in the pilot plant circuit. Apparently agglomerates were broken up at high speeds and caused the turbidity readings to increase. Table 4 describes a series of five measurements made during

TABLE 3

Foam Fractionation Data
Waste Water Treatment Without Chemical Additives

Primary Effluent Feed
Box-Type Foam Separator
Feed Flow Rate: 0.9 gpm
Time in Separator: 22 minutes

		Air Flow Rate		COD		Turbidity	
Pressure, psig	Dissolver Time, minutes	% of Feed Volume	% of Saturation	Feed, mg/l	Reduction, %	Feed, mg/l SiO_2	Reduction, %
175	6.7	9.5	42	186	16	78	18
175	6.7	25.5	125	206	14	78	31
175	13.3	9.5	42	152	9	78	16
175	13.3	25.5	125	205	22	108	0
235	6.7	11.5	42	206	9	45	15
235	6.7	33	125	186	13	78	4
235	13.3	11.5	42	205	19	108	0
235	13.3	33	125	152	14	45	-33

Table 3

TABLE 4

Foam Fractionation Data
Effect of Pump Speed on Turbidity

Primary Effluent Feed, (152 mg/l COD)
Box-Type Foam Separator

Feed Flow Rate:	0.9 gpm
Pressure:	235 psi
Time in Dissolver:	13.3 minutes
Time in Separator:	22.0 minutes
Air-to-Water Ratio:	0.09 to 1

Pump Speed*	Turbidity, mg/l SiO_2
0	76
30	87
48	91
60	98
76	102

* A variable speed motor was used on the effluent pump. The Pump Speed figures are readings taken from the control rheostat and are not rpm.

one experiment to demonstrate the effect of pump speed on turbidity. While pump speed was varied, all other variables were held constant and as the table shows, there was a well defined increase in turbidity as pump speed was increased.

As an alternative to the turbidity analysis, a quantitative suspended solids determination was attempted. This analysis proved to be too expensive in relation to the allowed analytical budget however, and no further consideration was given it. Turbidity measurements were continued throughout the experimental program with constant pump speed to assure comparability of turbidity results.

Two experiments with the trough-type separator, using no coagulants, offered no improvement over the box-type separator used in all of the above experiments. Both runs with the trough-type separator were made at 175 psi, with air flow rates corresponding to 125% of saturation. The feed was 181 mg/l COD primary effluent, at a rate of 0.9 gpm. Residence time in the pressure vessel was 13.3 minutes and residence time in the fractionator was 10 minutes. One experiment gave a COD reduction of 13.3% and the other, 45.6%. The separator was difficult to control and after one experiment with alum as an additive (described later) the trough-type separator was replaced by the cylindrical separator.

The cylindrical separator was tested without chemical additives and some promising results were obtained as shown in Table 5. The COD in the feed for these experiments varied from 289 to 128 mg/l. The average COD reduction for two experiments at 235 psi was 26.5%. At 175 psi, the average COD reduction was 34.7%; one run at 210 psi gave a reduction of 39%. Apparently, no correlation exists between air-to-water ratios and COD reductions; e.g., one test at 42% of saturation gave a COD reduction of 50%, while another gave only a 26% reduction. Another test at 109% saturation gave a 48% reduction, while a repeat of the same test gave only a 6% reduction.

The results of tests without chemical coagulants indicated that COD reductions of as much as 50% were possible under the proper conditions. Reductions in turbidity of up to 71% were also observed. However, to remove phosphate and to improve removal of organic matter, it was necessary to study the effect of chemical coagulants (phosphate precipitants) such as alum and some iron salts.

Experiments Using Chemical Additives

Before the box-type and trough-type separators were replaced by the cylindrical separator, a few experiments were run using chemical coagulants. Tests with the box-type

TABLE 5

Foam Fractionation Data
Waste Water Treatment Without Chemical Additives

Primary Effluent Feed
Cylindrical Foam Separator
Feed Flow Rate: 0.9 gpm
Time in Separator: 2.5 minutes

		Air Flow Rate		COD		Turbidity	
Pressure, psig	Dissolver Time, minutes	% of Feed Volume	% of Saturation	Feed	Reduction, %	Feed, mg/l SiO_2	Reduction, %
210	13.3	26.4	108	212	39	163	71
175	13.3	22.4	109	128	6	92	27
175	13.3	8.7	42	221	50	242	36
235	13.3	33.8	125	187	27	116	41
235	13.3	11.3	42	289	26	102	24
175	13.3	22.4	109	220	48	--	--

separator used iron salts, while those with the trough-type used alum. Results of experiments with both separators are shown in Table 6. Although there was enhanced froth production over runs without additives, the resultant increase in froth volume did not cause COD reductions to increase because of the inability of either of these separators to separate adequately the foam from the water. The greatest COD reduction in these six experiments was 22.1% while the average was only 10.8%.

During experiments with the cylindrical foam separator, using no chemical additives, the high rate of upward flow in the 7-inch diameter vessel tended to concentrate the column of bubbles at the center and provide a support for particles of floc which would have otherwise fallen to the bottom of the separator. The flow rate in this vessel was 3.3 gal./sq ft-min for a feed rate of 0.9 gpm as compared with a flow rate of 0.32 gal./sq ft-min for the same feed rate using the box-type separator. The cylindrical separator seemed to satisfy well the residence time and foam removal requirements for good contaminant removal.

<u>COD Reduction</u>. The first experiments with chemical additives in the cylindrical separator were designed to study the effects of low concentrations of alum and ferrous sulfate. Results of these experiments are shown in Table 7. Because alum was more effective, ferrous sulfate was not used in further experiments. Three experiments with 100 mg/l of alum gave an average COD reduction of 27.7%. Two other alum experiments were run with 50 and 200 mg/l and, surprisingly, the 50 mg/l concentration gave the best results (30% reduction in COD), possibly because of the very high feed COD. All of these experiments, however, gave less COD reduction than was considered essential for the process to be very useful.

Additional experiments were then run to determine the relationship between increased chemical additive concentrations and removal of wastewater contamination. Fixed operating conditions were used and only the type and concentration of additive was varied. Feed flow rate was 0.52 gpm with the resultant foam separator flow rate of 1.94 gal./sq ft-min and a separator residence time of five minutes. Operating pressure was 230 psig and an air-to-water volume ratio of 0.173 to 1 (65% of theoretical saturation) was used

Alum and ferric chloride were first tested and the results are shown in Tables 8 and 9. A secondary settling tank (with a retention time of 10 minutes) was added to the pilot plant circuit to determine whether or not a settling step would produce an improved effluent. As indicated by the data in Tables 8 and 9, the secondary settler did not generally prove useful. COD reductions, however, using

TABLE 6

Foam Fractionation Data
Preliminary Experiments Using Chemical Additives

Primary Effluent Feed
Feed Flow Rate: 0.9 gpm
Time in Dissolver: 13.3 minutes
Time in Separator: 22.0 minutes for box-type
10.0 minutes for trough-type

Separator	Additive	Concentration, mg/l	Pressure, psig	Air Flow Rate		COD	
				% of Feed Volume	% of Saturation	Feed, mg/l	Reduction, %
Box	$FeSO_4$	50	235	11.5	48	176	17.6
Box	$FeSO_4$	50	175	25.5	125	176	22.1
Box	$FeSO_4$	100	235	11.5	48	111	2.7
Box	$FeSO_4$	200	235	11.5	48	157	5.0
Box	$FeCl_3 \cdot 6H_2O$	100	235	11.5	48	155	4.5
Trough	Alum	100	175	25.5	125	118	12.7

TABLE 7

Foam Fractionation Data
Waste Water Treatment Using Low Concentrations of Chemical Additives

Primary Effluent Feed
Cylindrical Foam Separator
Feed Flow Rate: 0.9 gpm
Time in Dissolver: 25 minutes
Time in Separator: 5 minutes

Additive	Concentration, mg/l	Pressure, psig	Air Flow Rate: % of Feed Volume	Air Flow Rate: % of Saturation	COD: Feed	COD: Reduction, %
Alum	50	175	22.4	109	551	30
Alum	100	225	22.4	86	375	21
Alum	200	225	11.3	44	94	21
Alum	100	175	22.4	109	120	44
Alum	100	175	22.4	109	146	18
$FeSO_4$	100	175	33.8	164	121	7
$FeSO_4$	100	175	22.4	109	121	21

TABLE 8

Foam Fractionation Data
COD Reduction Using Alum

Primary Effluent Feed
Cylindrical Foam Separator

Feed Flow Rate:	.52 gpm
Pressure:	230 psig
Time in Dissolver:	25 minutes
Time in Separator	5 minutes
Air-to-Water Ratio:	0.173 to 1
Theoretical Saturation:	65%

Alum Concentration, (mg/l)	COD Foam Separator		COD Secondary Settler	
	Feed	Reduction,%	Feed	Reduction,%
157	141	24	109	3.5 increase
173	142	16	120	2.0
222	199	20	159	3.0 increase
234	177	29	126	1.5
250	139	29	98	7.0
270	107	59	43	2.3
300	144	57	62	5.0
305	178	41	106	2.0
340	94	61	--	--
340	136	72	38	21.0
350	171	36	110	11.0 increase
376	115	58	48	10.0 increase
400	144	67	47	0.0
450	175	70	52	9.5
450	170	64	61	27.0
500	190	78	42	4.5
550	148	78	33	9.0

TABLE 9

Foam Fractionation Data
COD Reduction Using Ferric Chloride

Primary Effluent Feed
Cylindrical Foam Separator
Feed Flow Rate: .52 gpm
Pressure: 230 psig
Time in Dissolver: 25 minutes
Time in Separator: 5 minutes
Air-to-Water Ratio: 0.173 to 1
Theoretical Saturation: 65%

$FeCl_3 \cdot 6H_2O$ Concentration, mg/l	COD Foam Separator Feed	COD Foam Separator Reduction, %	COD Secondary Settler Feed	COD Secondary Settler Reduction, %
135	161	28	116	0.0
156	135	29	96	11.0
180	145	24	111	11.0 increase
200	162	24	124	4.0
225	151	39	93	8.5
270	175	44	98	21.0
338	133	62	51	6.0 increase
338	138	65	49	4.0
340	107	79	--	--
376	156	47	83	5.0 increase
450	204	71	59	34.0
500	173	80	34	12.0 increase
520	173	80	34	26.0 increase

300-400 mg/l of either alum or ferric chloride were quite encouraging. Above 375 mg/l, the rate of increase in COD removal decreased with an increase in additive concentration. COD reductions for the alum and ferric chloride experiments are plotted against additive concentrations in Figures 7 and 8. The plots are almost identical for the two additives. The optimum concentration appears to be about 350 mg/l for both additives.

Phosphate Reduction. Phosphate determinations were made in some of the experiments using alum and ferric chloride to study the effects of these additives on phosphate removal. The data are plotted in Figures 9 and 10. Considering the scatter in the data over much of the range of chemical doses, there does not appear to be much difference in the removal capability of the two additives on a weight basis. At very high doses the removal by ferric chloride was slightly better. Two runs resulted in over 95% removal.

Additional experiments were done to test the effectiveness of calcium hydroxide and zinc sulfate in phosphate removal. Neither of these additives gave results comparable to either ferric chloride or alum.

Suspended Solids Removal. Turbidity measurements were made for most of the chemical additive runs. The turbidimeter was calibrated against known suspended solids samples to provide data approximating actual suspended solids removal. Results are presented in Tables 10 and 11. The results are extremely erratic for both chemicals, but the variability is almost certainly caused by poor analytical accuracy. If a rapid, accurate method to quantitatively determine suspended solids had been available, the data would have likely been much more useful. It can be inferred from the data that removal increased with increasing chemical concentrations. This is more obvious with alum than with ferric chloride. Reductions of up to 93% were obtained. It appears, however, that somewhat lower removals are to be expected generally.

One additional bit of experimental data should be mentioned, even though there was no follow-up work done on it due to budget limitations. Sodium silicate was tested as an additive at 100 mg/l and under conditions similar to the alum experiments described in Table 7. At 225 psig and with air flow rates corresponding to 130, 86, and 44% of saturation, the average COD removal was 36%. This average figure is considerably better than the results for alum at that same concentration and it is certainly possible that sodium silicate might be a more effective additive than any of the others tried.

FIGURE 7

Foam Fractionation Data
COD Reduction Using Alum

Primary Effluent Feed	
Cylindrical Foam Separator	
Feed Flow Rate:	0.52 gpm
Pressure:	230 psig
Time in Dissolver:	25 minutes
Time in Separator:	5 minutes
Air-to-Water Ratio:	0.173 to 1
Theoretical Saturation:	65%

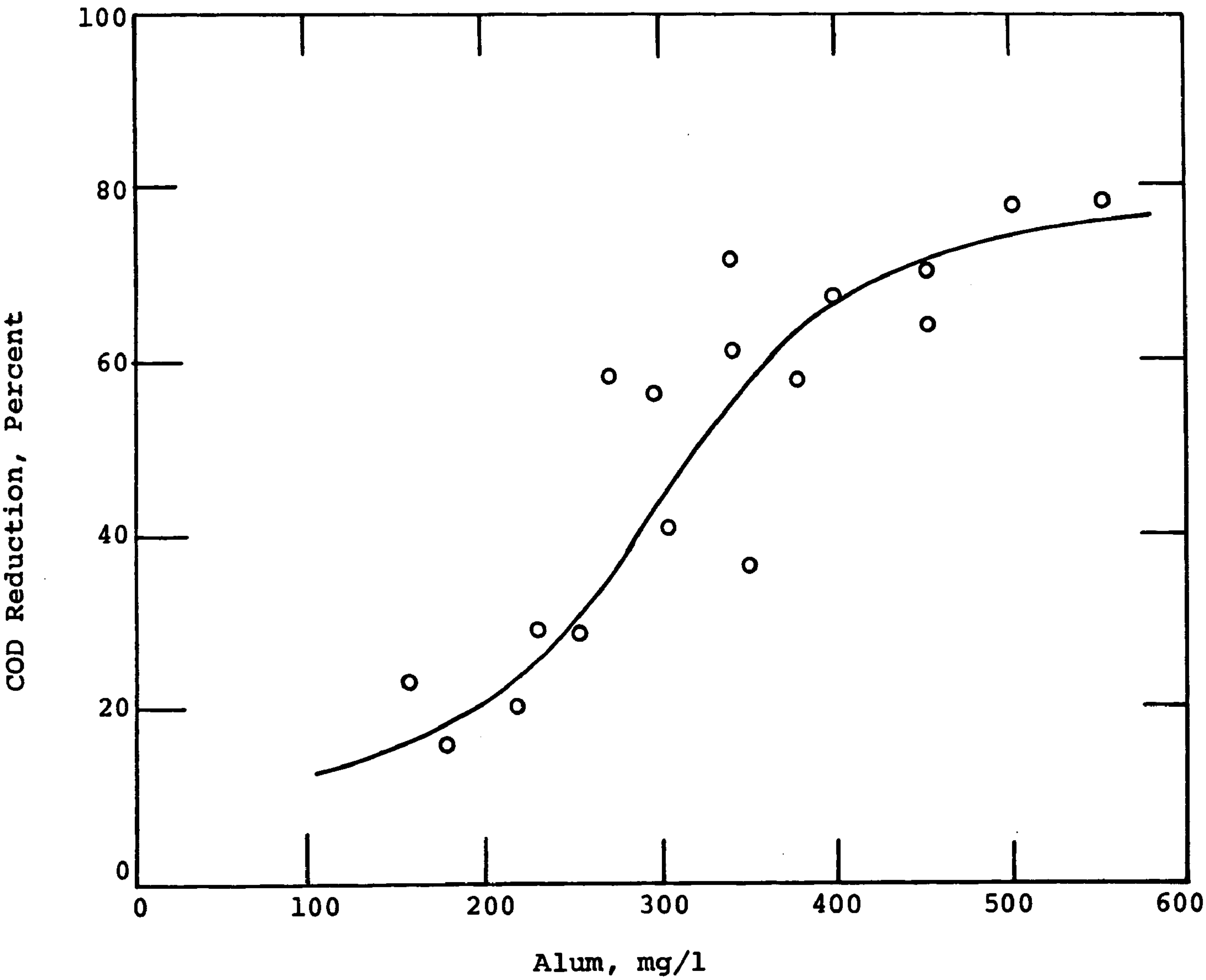


FIGURE 8

Foam Fractionation Data
COD Reduction Using Ferric Chloride

Primary Effluent Feed
Cylindrical Foam Separator

Feed Flow Rate:	0.52 gpm
Pressure:	230 psig
Time in Dissolver:	25 minutes
Time in Separator:	5 minutes
Air-to-Water Ratio:	0.173 to 1
Theoretical Saturation:	65%

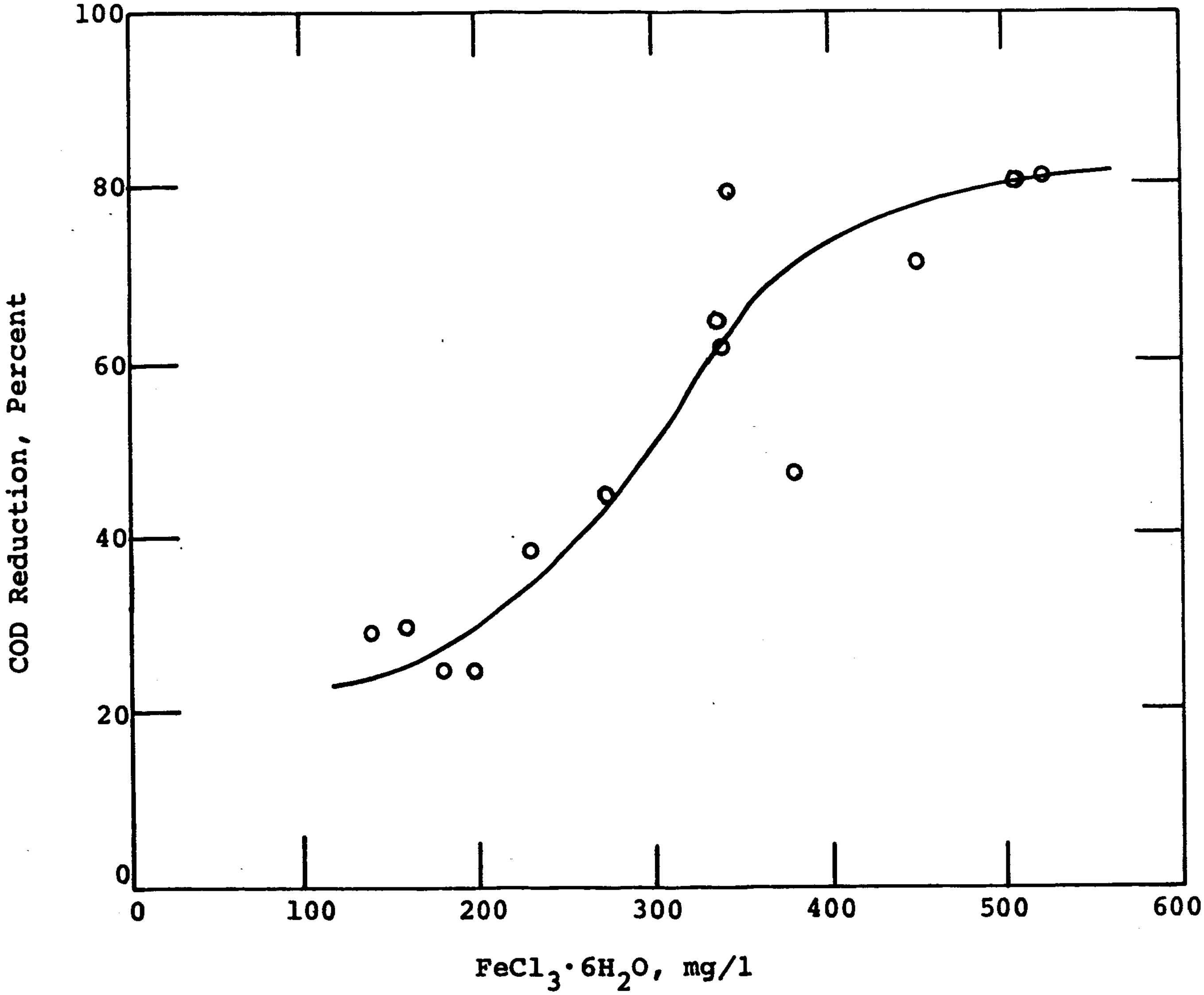


FIGURE 9

Foam Fractionation Data
Phosphate Removal Using Alum

Primary Effluent Feed	
Cylindrical Foam Separator	
Feed Flow Rate:	0.52 gpm
Pressure:	230 psig
Time in Dissolver:	25 minutes
Time in Separator:	5 minutes
Air-to-Water Ratio:	0.173 to 1
Theoretical Saturation:	65%

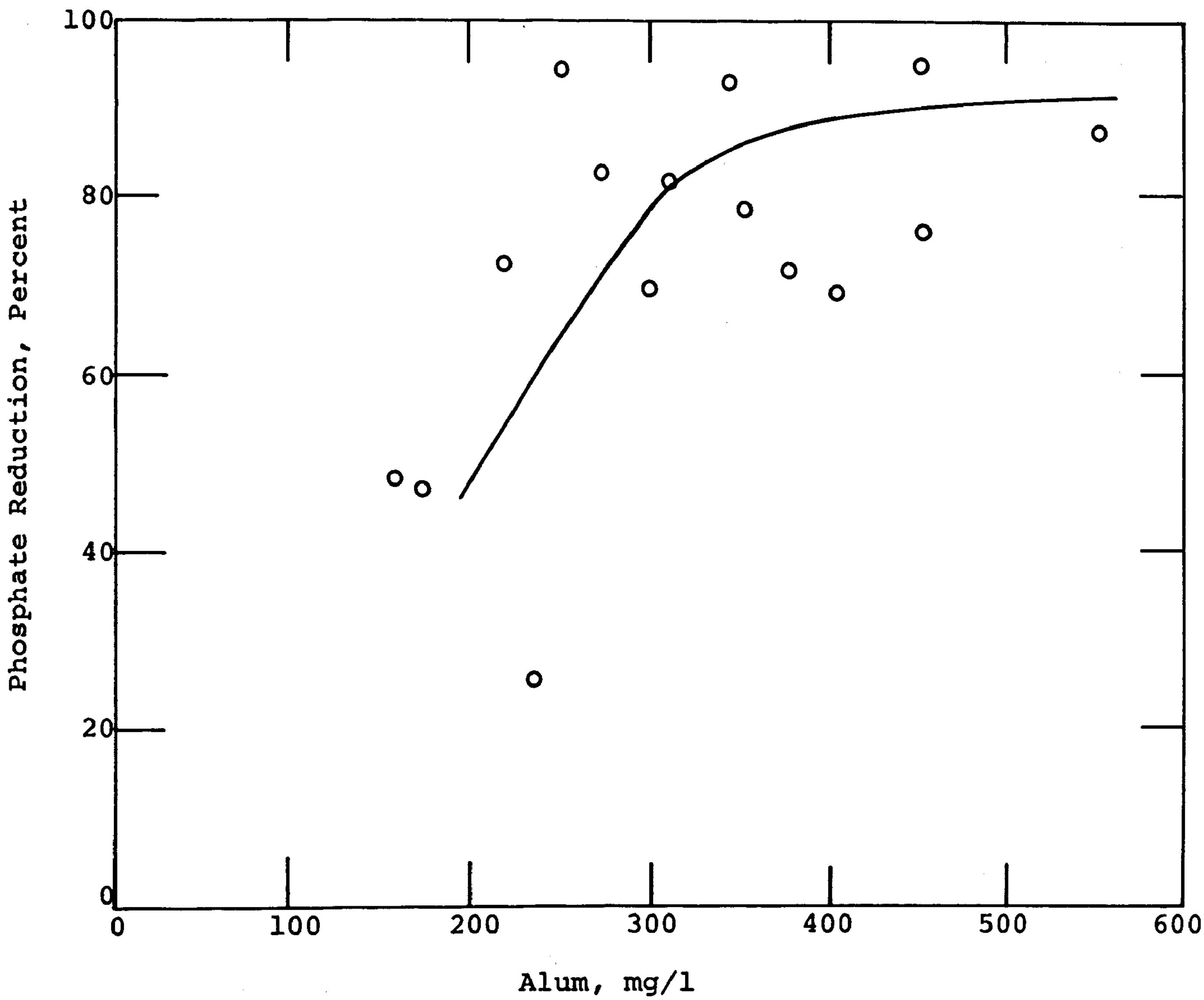


FIGURE 10

Foam Fractionation Data
Phosphate Removal Using Ferric Chloride

Primary Effluent Feed
Cylindrical Foam Separator
Feed Flow Rate: 0.52 gpm
Pressure: 230 psig
Time in Dissolver: 25 minutes
Time in Separator: 5 minutes
Air-to-Water Ratio: 0.173 to 1
Theoretical Saturation: 65%

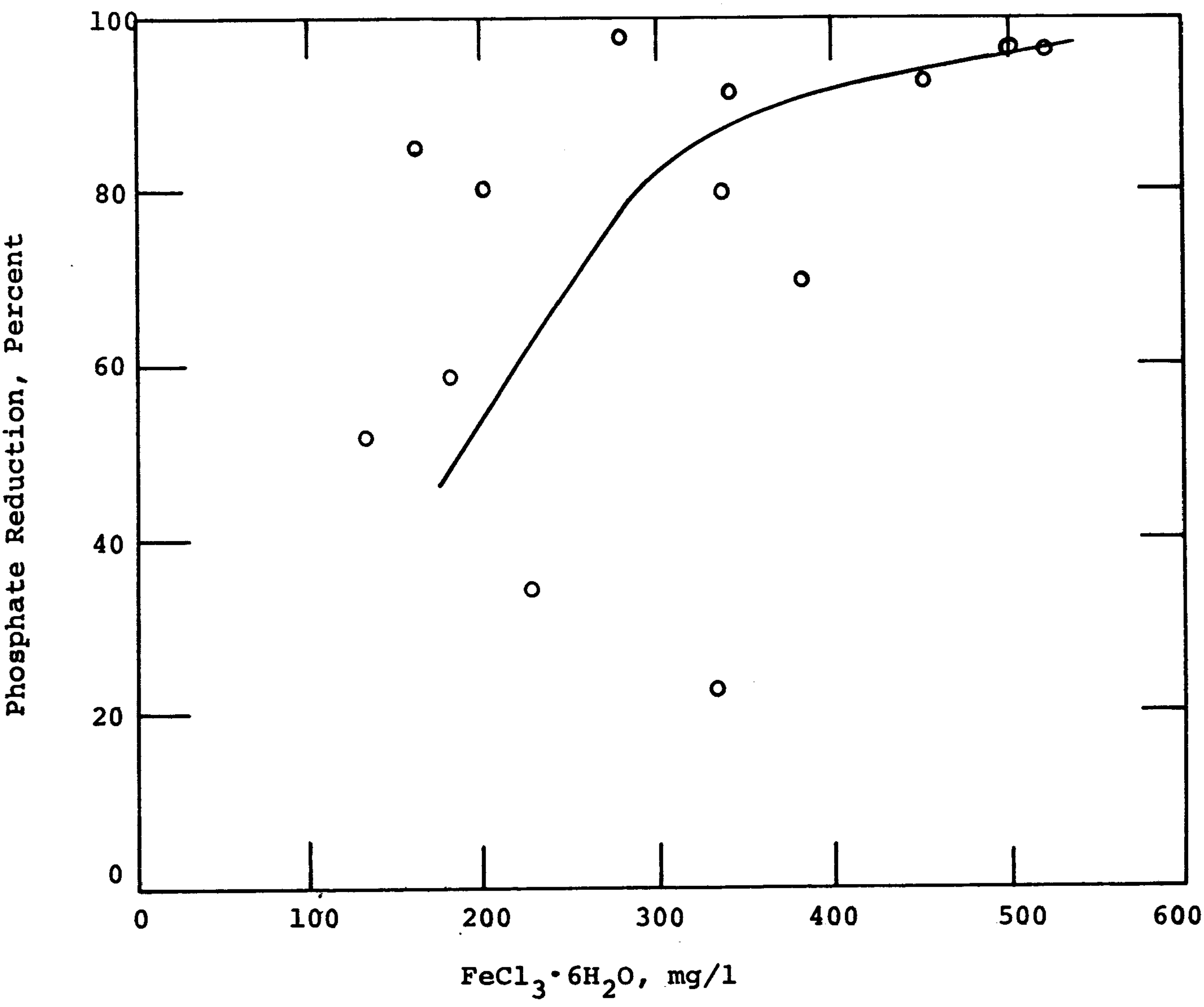


TABLE 10

Foam Fractionation Data
Reduction of Suspended Solids Using Alum

Primary Effluent Feed
Cylindrical Foam Separator

Feed Flow Rate:	0.52 gpm
Pressure:	230 psig
Time in Dissolver:	25 minutes
Time in Separator:	5 minutes
Air-to-Water Ratio:	0.173 to 1
Theoretical Saturation:	65%

Alum, mg/l	Suspended Solids in Feed, mg/l	Decrease in Suspended Solids in Effluent, %
157	176	62
173	142	20
222	170	40
234	64	41
250	64	64
270	32	41
300	142	38
305	85	33
340	51	63
340	68	72
376	77	65
400	140	43
450	130	66
450	177	75
500	150	82
550	150	75
600	130	82

TABLE 11

Foam Fractionation Data
Reduction of Suspended Solids Using Ferric Chloride

Primary Effluent Feed
Cylindrical Foam Separator

Feed Flow Rate:	0.52 gpm
Pressure:	230 psig
Time in Dissolver:	25 minutes
Time in Separator:	5 minutes
Air-to-Water Ratio:	0.173 to 1
Theoretical Saturation:	65%

$FeCl_3 \cdot 6H_2O$, mg/l	Suspended Solids in Feed, mg/l	Decrease in Suspended Solids in Effluent, %
135	128	16
180	128	41
225	175	63
270	130	42
338	128	70
338	92	59
340	32	41
376	114	33
450	130	48
500	205	93
520	200	56

CONCLUSIONS

Experiments using the foam fractionation-flotation unit indicate that COD reductions of up to 50% are possible without the addition of chemical coagulants or precipitants. Turbidity reductions of 70% were also observed. With modifications in the foam separator, these results can almost certainly be improved.

Results of experimentation also indicate that both alum and ferric chloride are effective in COD reduction, phosphate removal and removal of suspended solids from wastewater. Concentrations of 300-400 mg/l are required for both additives to remove 75% of the COD, 90% of the phosphates and 65% of the suspended solids. These reductions are sufficiently high to consider this treatment as an alternative to conventional methods for treatment of effluent from primary treatment plants.

With refinement of the process equipment and under optimum operating conditions, this process should be quite useful in treating wastewater from any industrial process where high concentrations of particulate matter must be removed.

ECONOMICS

If a retention time of 10 minutes in the air-dissolving tank were used, a vessel capacity of about 70,000 gal. would be required for a 10 mgd plant. Assuming an operating pressure of 200 psi, the air-dissolving tank would cost about 75 cents per gal. of capacity, or $52,000. A residence time in the foam separator of five minutes would require a capacity of about 35,000 gal. Since this vessel is relatively simple, its cost is estimated at about 25 cents per gal. of capacity, or $9,000. Pumps, piping and instrumentation are estimated at $80,000 and installation at $150,000, giving a total cost of approximately $290,000 for a 10 mgd plant. The land requirement is small (approximately one-half acre), with the cost estimated at $10,000, giving a total cost for the plant of $300,000. The power requirement would be about 1,200 H.P. Operating costs are itemized in Table 12 and are approximately 5¢/1,000 gal.

The quantities of additives used in this study were probably greater than would be necessary in actual operation, and actual cost should not exceed 6¢/1,000 gal. This, together with the other operating costs, should give a total cost of not more than 11¢/1,000 gal. of treated water.

The foam fractionation-flotation process appears competitive with conventional treatment schemes at the same plant size. The cost of any post-treatment that might be

TABLE 12

Foam Fractionation-Flotation Plant Operating Costs

Capacity, 10 mgd

Power, @ 1¢/kwh	$218/day
Operating labor, 2 men @ $3.00/hr.	48
Maintenance labor (6% of capital)	49
Operating & maintenance supplies (0.5% of capital)	4
Payroll extras (15% of labor cost)	15
Overhead, (100% of total labor cost)	97
Amortization @ 4% for 25 years (6.4% of capital)	53
Taxes & insurance (1% of capital)	8
Interest on working capital (0.72% of foregoing)	4
	$496/day
	or 5¢/1,000 gal.

required would need to be added to the foaming costs, however, to make a realistic comparison. The foaming process does offer the advantage of requiring less land than conventional treatment, which could be a significant factor in land-short areas.

RECOMMENDATIONS

The amount of information developed to date, and the success achieved, indicates that this work should be continued. The possibilities of the process expand as the work progresses and future work might include:

1. Determination of methods (agitation, recirculation, etc.) to get a larger percentage of the theoretically soluble air into solution during a short residence time.

2. Investigation of combinations of additives, such as an inorganic for phosphorus removal and a polyelectrolyte for suspended solids removal.

3. Changing equipment and/or the flow arrangement to improve separation of the foam from the water.

4. Investigation of the removal of nitrogen compounds with additives. With the high percentage of dissolved organics that are removed, it is only logical that some soluble nitrogen compounds are also being removed.

5. Batch-type studies using ten(or more) small compressed gas bottles (two gallons each) which could be filled with the same COD feed material, sealed, and pumped with an air compressor to the desired experimental pressure. The bottles could be agitated by shaking them or left undisturbed for static tests. Ten or more concentrations of one additive could be tested at one time or ten different pressures could be tried, etc. The bottles could be bled off into identical, low cost, lucite foam separators and the analytical work could then be done. A short (two month) effort could probably define all of the parameters necessary to attain optimum results from the pilot scale equipment.

It is recommended that the work be continued in three phases: a) batch-type experimentation, b) additional work on the operational scale of the present contract, and c) a pilot study on a fairly large scale to prove the process on a continuous basis.

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