AN ABSTRACT OF THE THESIS OF

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(Name) (Degree) (Major)

Date thesis is presented August 10, 1964

Title HIGH-SHEAR AND PRESSURE ACTIVATED SLUDGE TREATMENT — SOLID-LIQUID SEPARATION

Abstract approved [redacted]
(Major professor)

Since the development of the activated sludge process in 1913 many attempts have been made to improve it. One approach has been to increase the oxygen available to the bio-mass. This study combined the use of elevated pressure and high-shear mixing to increase the oxygen transfer.

The conventional method of separating activated sludge has been flocculation followed by sedimentation. High-shear mixing breaks up the bio-mass thus hindering flocculation. Flotation, a method of solid-liquid separation used in industrial processes, could utilize the dissolved air released when the elevated pressure is released.

A laboratory-scale, activated sludge treatment unit was operated at various combinations of pressure and mixing. The solid-liquid separation characteristics of the mixed liquor were studied. Separation by settling was investigated when the unit was operated at atmospheric pressure and separation by flotation was investigated when the

unit was operated at an elevated pressure of 30 psig.

It was concluded from these tests that: (1) the effluent provided by sedimentation and flotation following medium and high-shear mixing is not adequate for discharge to most water-courses. (2) Flotation does not yield as clear an effluent as sedimentation. (3) Suspended solids removal by flotation requires a shorter detention time than by sedimentation. (4) Flotation yields a denser sludge than sedimentation. (5) In the flotation process no advantage was found by using a pressure release of more than 20 psi.

HIGH-SHEAR AND PRESSURE ACTIVATED SLUDGE TREATMENT — SOLID-LIQUID SEPARATION

by

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A THESIS

submitted to

OREGON STATE UNIVERSITY

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

August 1964

APPROVED:

[redacted]

Associate Professor of Civil Engineering

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Date thesis is presented August 10, 1964

Typed by Lucinda Nyberg

ACKNOWLEDGEMENTS

The writer wishes to express his appreciation for the assistance given in the preparation of this thesis, especially to Associate Professor Donald C. Phillips, Professor Fred Merryfield and Professor Fred Burgess for their guidance, suggestions and inspiration throughout the year. Thanks are also due the U. S. Department of Health, Education and Welfare for their traineeship through the Public Health Service which enabled the writer to do graduate work at Oregon State University.

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HIGH-SHEAR AND PRESSURE ACTIVATED SLUDGE TREATMENT—SOLID-LIQUID SEPARATION

INTRODUCTION

The activated sludge process for sewage treatment was unchanged for almost 30 years after its development in England in 1913. Since World War II many modifications of the original process have been made to increase the efficiency and capacity. Many of these changes were made by plant operators in an effort to solve operational problems. Laboratory studies have investigated the utilization of tonnage oxygen to increase the oxygen availability. The use of high-shear mixing to increase oxygen transfer has also been investigated. A possible method of increasing the efficiency of the process would be to place the system under pressure and introduce high-shear mixing.

According to Henry's Law the ability of a gas to dissolve in a fluid is a function of the partial pressure of the gas in the two media. The elevated pressure would thus increase the partial pressure of oxygen and thus the ability to be dissolved. The high-shear mixing would serve to keep the oxygen dispersed evenly throughout the system and prevent the biota from flocculating, thus increasing the surface area available for transfer of oxygen and dissolved organic matter.

As bacterial cells can be held in suspension by Brownian

movement, flocculation must take place for sedimentation to occur. The effects of high-shear mixing may thus make conventional sedimentation an ineffective method of removing the bio-mass. The dissolved air in the system may possibly be used to separate suspended solids from the clear liquor. Releasing the elevated pressure will cause the air to come out of solution. As the air comes out of solution, fine bubbles will become attached to the suspended solids and cause the solids to float to the surface.

The purpose of this thesis is to study the separation characteristics of activated sludge under various mixing and pressure conditions. The research was carried on in conjunction with a study of oxygen uptake of the bio-mass under the same conditions.

A laboratory model activated sludge plant was operated under various pressure and shear conditions with the aeration rate, organic loading, temperature and pH held constant. The system was operated at zero, medium and high-shear levels at both atmospheric and 30 psig pressure. The settling characteristics were observed when the system was under atmospheric pressure and the flotation characteristics when under elevated pressure. The types of biological growths as well as the biological oxygen demand and chemical oxygen demand removals were determined at each operating condition.

THEORY

In the activated sludge process the waste water is mixed with an active biological growth and aerated for six to eight hours, to stabilize the dissolved organic matter. This mixture then flows to a sedimentation tank where the biological growth flocculates and settles out, leaving a clear effluent to be discharged. The settled growth, called activated sludge, is recycled as needed for seeding the influent and the remainder is wasted to a digester or other method of disposal.

Activated sludge consists of bacteria, fungi, protozoa, rotifers, and other higher forms of microscopic life. The bacteria is the most important group as they are primarily responsible for the stabilization of the organic matter and floc formation. The ratio of available food to the bio-mass is of importance in floc formation. Flocculation will not take place when this ratio is high. As the ratio decreases, the bacteria lack the energy to separate after colliding and thus flocculate readily.

Until Hazen's (13, p. 45-88) classical paper in 1904, sedimentation basins were designed on the basis of experience. Hazen's analysis, based on discrete particles, showed that the surface area of the basin was the controlling factor for clarifying the liquid overstream rather than detention time. The later works of Camp (6, p. 445-486), Coe and Clevenger (3, p. 1-7) confirmed Hazen's work.

Many mathematical formulas have been proposed to explain sedimentation of discrete solids. These empirical relationships are modifications of Stoke's Law and take the basic form of:

$$\text{settling velocity} = \frac{(\text{constant})(\text{particle size})(\text{density difference})}{\text{viscosity}}$$

Activated sludge is not made of discrete particles and the settling properties do not follow these mathematical relationships. Instead the settleability is influenced greatly by physical and chemical characteristics of the process.

A measure of the settleability of activated sludge was conceived by Theriault (10, p. 214) in 1920 and is called the sludge volume index (SVI). He defined the sludge volume index as the percent sludge by volume that settles in a specific length of time divided by the percent sludge concentration.

Fitch (17, p. 159-169) divided settling into four types; (1) clarification — class-1, (2) clarification — class-2, (3) zone settling and (4) compression. Class-1 clarification occurs with particles in a dilute suspension having little tendency to flocculate during settling. If the particles flocculate during settling it is referred to as class-2 clarification. Zone settling takes place when the mass of particles subside as a unit. Compression takes place when the particles are mechanically supported by lower particles. This thesis will be concerned with only the last two.

When activated sludge is allowed to settle under quiet conditions a distinct interface forms between the clear liquor and suspended solids. Under conditions of zone settling the interface descends at a uniform velocity, which is a function of the initial solids concentration and flocculation characteristics. Simultaneously a compression zone builds up from the bottom. The settling velocity remains constant until the transition zone is reached. Here, the settling velocity decreases due to the increased density and viscosity of the mixture until mechanical support is provided by lower solids in the compression zone. Once again the settling velocity becomes constant but of very low magnitude. Stirring sludge in compression increases the settling velocity by allowing the trapped water to escape. Figure 1 shows the path of a liquid-solid interface as it descends.

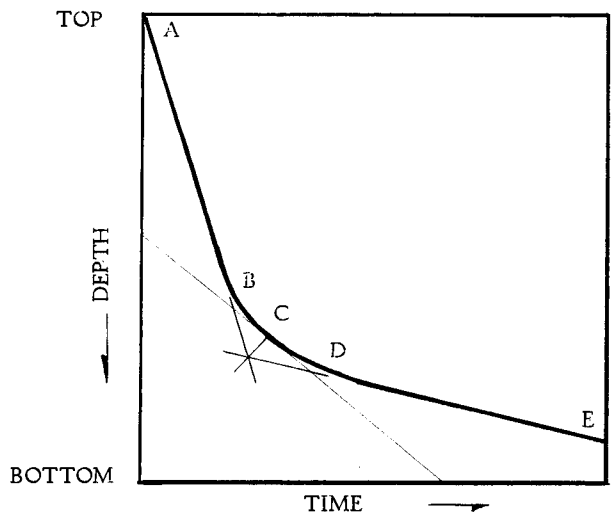


Figure 1. Graphic representation of the solid-liquid interface descend.

In Figure 1 the curve between A and B represents zone settling. At point B the transition zone is entered and the interface starts deceleration. Somewhere between B and D the settling material becomes part of the sludge deposit. This is the compression point and is shown as C. At D the solids are given mechanical support from below and are in the compression zone.

The slope of a tangent to the curve at any point is the settling velocity at that point. The compression point (C) is approximately the intersection of the settling curve and the bisector of the angle formed by the tangents of the zone settling (A-B) and compression zones (D-E). The tangent to the compression point below that point is the locus of the detention times and the corresponding sludge depth to provide a desired concentration. The concentration in the compression zone can be determined by multiplying the initial concentration by the ratio of the initial height to the sludge height.

To develop a design criteria the settling characteristics may be evaluated by batch settling tests in a graduated container. Kammermey (3, p. 7) gave experimental evidence that a minimum diameter of 1.57 inches is sufficient while Coe and Clevenger (3, p. 7) recommended a minimum of 2.5 inches and George (3, p. 7) suggested a 4 inch diameter settling tube. The results from these tests yield a curve similar to Figure 1. From this curve the settling velocity of the sludge and theoretical percent removal can be calculated

provided the initial solids concentration of the mixed liquor, as well as the solids content of the clear liquor after settling, are known.

Flotation as a method of concentrating solids has been used for over 60 years by the mining industry. In the late 1920's the Scandinavian paper industry developed a flotation process to recover paper fibers from waste water. The search for improved sewage and industrial waste treatment methods has resulted in an increasing interest in dissolved-air flotation.

In this method the air is dissolved under elevated pressure and released by removing the pressure. Minute bubbles form in much the same manner as when a carbonated soft drink is opened. The bubbles attach to the suspended solids causing them to float to the surface to be collected as a scum. Flotation aids may be used to alter the surface adsorptive properties of the suspended matter thus increasing their capacity to entrap the released air bubbles.

The amount of pressure needed to dissolve the air is a function of the detention time under pressure and mixing. Recent experiments on air solubility in water show that the pressure-solubility relationship varies from Henry's Law, depending on the constituents of the mixed liquor. Pure saturated water at 30 psig pressure will release 3.8×10^{-4} pounds of air per gallon. This decreases with an increase in concentration of dissolved matter.

Flotation is evaluated the same as zone settling sedimentation

except the direction of solids flow is reversed. The rising velocity is a function of the air-solids ratio, so by increasing the air-solids ratio the rising velocity can be increased. With this control the detention time required for a given concentration can be less for flotation than sedimentation.

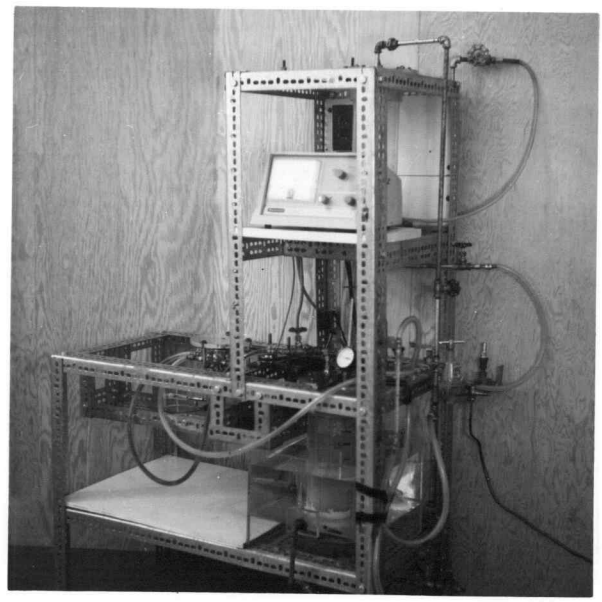
In general, a flotation system does not produce as high a quality effluent as a sedimentation system. However, in systems where the density of suspended solids is very close to that of the mixed liquor, flotation is the only practical method of separation.

METHOD OF STUDY

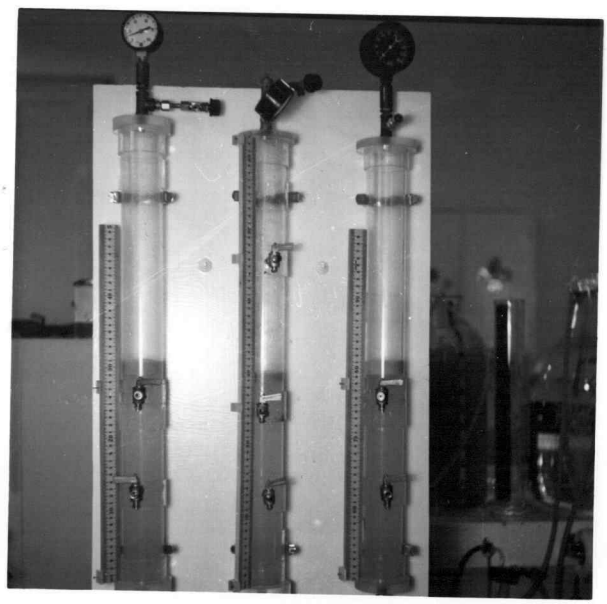
Separation characteristics of the activated sludge operated at atmospheric and 30 psig pressure in combination with zero, medium and high-shear were observed. The aeration rate, organic loading, temperature and pH were held constant. A sufficient period of time was allowed for the system to become acclimated to the particular operating conditions.

Apparatus

A laboratory activated sludge unit as shown in Figures 2 and 3 was developed for this experiment. The aeration chamber consisted of a 4 inch diameter acrylic tube 14 inches long. The bottom formed a cone with a one inch diameter porous plate for air diffusion. The entire unit was immersed in a water bath to provide temperature control. A thermometer, a sampling tube, and a pressure gauge were placed in the cover. The pressure gauge manufactured by Marshall Town Manufacturing Company was calibrated in four psi intervals. The depth of the sampling tube could be varied to facilitate withdrawing from any level in the aeration chamber. The aeration rate was measured with a Roger Gilmont Instruments flowmeter. A 2 inch by 1/2 inch mixing paddle pitched 15 degrees from vertical was located 4 inches above the bottom of the aeration chamber. Provisions



Activated Sludge Unit



Separation Tubes

Figure 2. Experimental apparatus

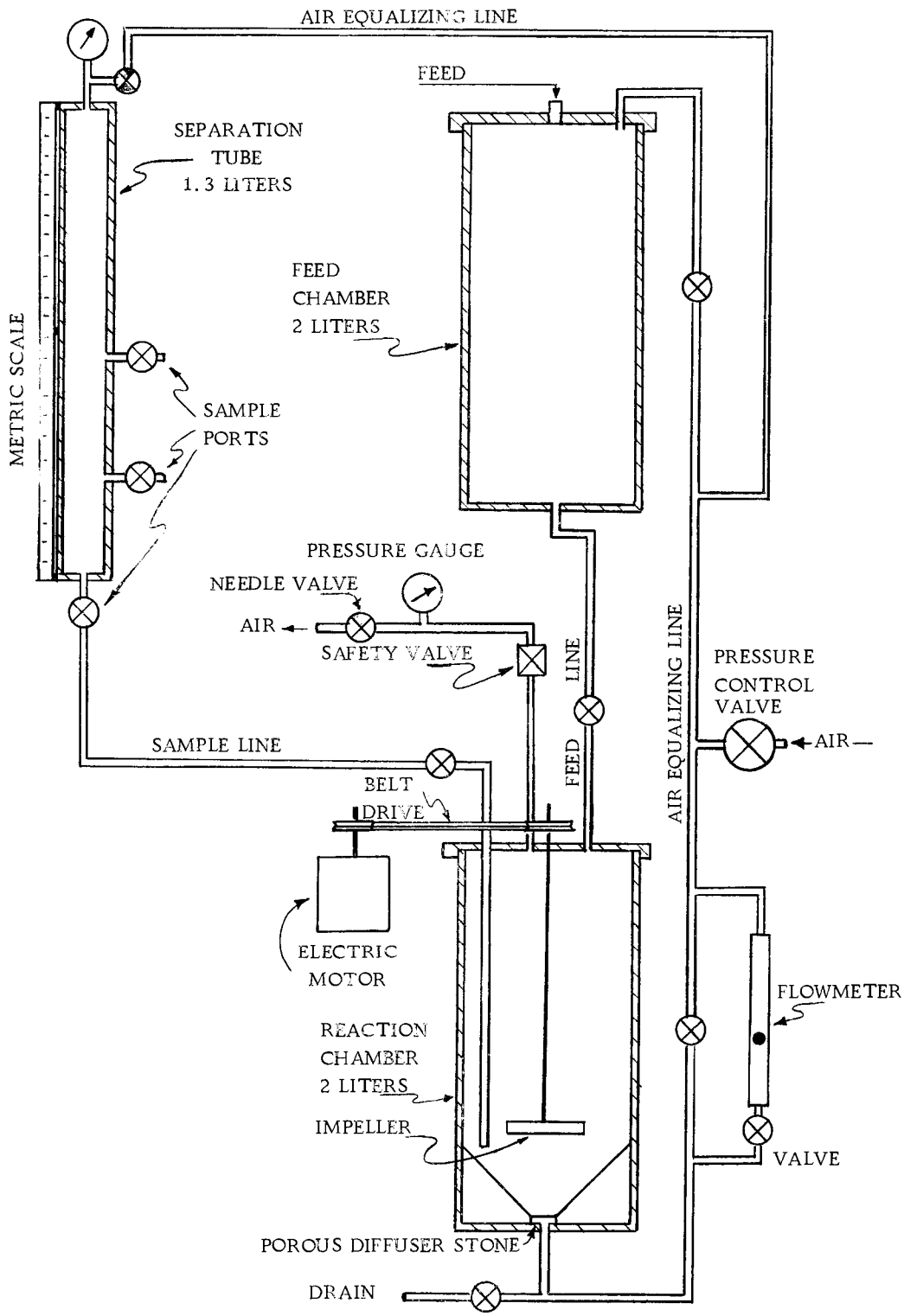


Figure 3. Experimental apparatus.

were made to drive this paddle at 500 rpm for medium-shear and 1100 rpm for high-shear.

A feed chamber, similar in size to the aeration chamber, was used to maintain the elevated pressure in the aeration chamber during feeding and clarification of mixed liquor.

The separation characteristics were studied in three, 2 inch diameter acrylic tubes 25 inches long. A metric scale was attached for measuring the solid interface height. A pressure gauge and needle valve were provided for pressure control. Sampling ports were located to facilitate sample removal from the top, the midpoint, and the bottom of the sample. This apparatus is shown in Figures 2 and 3.

Analytical Methods

Unless otherwise stated all analytical methods are those found in Standard Methods for the Examination of Water and Wastewater (1).

The five-day BOD (biological oxygen demand) was determined by the dilution method using settled raw sewage from the Corvallis sewage treatment plant as seed. The dissolved oxygen was measured by the Alsterberg (sodium azide) modification of the Winkler method. The effluent from the aeration unit was filtered through Whatman No. 40 filter paper before measuring the BOD. All samples were done in triplicate.

The standard COD (chemical oxygen demand) test using 0. 25 N potassium dichromate solution was used. The effluent from the aeration unit was filtered through Whatman No. 40 filter paper before measuring the COD. All COD samples were done in triplicate.

pH determinations were made with a Beckman glass electrode pH meter, Model No. 2. It was frequently standardized against a pH 7. 0 buffer solution.

The microscopic observations were conducted with a Spencer monocular microscope at 100 X and 430 X.

The suspended solids concentration of the activated sludge was determined by the Residue Test (Nonfiltrable Residue). A fiberglass filter pad (Hurlbut Paper Company) placed in a Gooch crucible with 25 ml of 5 gm/l suspension of Celite (Johns-Mansville Celite Analytical filter-aid) drawn through under suction, was substituted for the asbestos filter media. A 25 ml sample of the mixed liquor was mixed with 10 ml of 25 mg/l suspension of Celite and drawn through the filter media under suction. This was dried at 103° C for an hour, cooled to room temperature in a desiccator and weighed. All tests were run in duplicate.

The growth rates were determined from the daily increase in suspended solids concentration. Clarification of the effluent was determined by suspended solids samples before and after solid—liquid separation.

Experimental Procedures

The activated sludge unit, operated on a batch basis, was fed a BOD loading of 860 mg/l twice a day. The feed was a synthetic waste with approximately the same chemical composition as domestic sewage. Table I shows the formulation of the feed. In addition, a silicone defoamer, Antifoam "A" Spray, by Dow Corning was added as needed to supress foaming. Sodium bicarbonate was added to maintain alkalinity as well as providing a buffer for pH control. An air flow rate of 1,000 ml/min. measured at room temperature and operation pressure provided adequate mixing under no-shear.

TABLE I. SYNTHETIC FEED FORMULATION

Nutrient Broth	12.18 gm/l
Dextrose	17.60 gm/l
Urea	5.00 gm/l
NaCl	8.00 gm/l
KCl	4.00 gm/l
$MgSO_4$	2.00 gm/l
KH_2PO_4	1.73 gm/l
Castile Soap	2.13 gm/l

Once a day 60 ml to 250 ml of mixed liquor was wasted to determine the suspended solids and maintain the solids level as close to

3,000 mg/l as possible. The activated sludge was allowed to settle under pressure in the aeration chamber, and the clear liquor wasted until a liter remained in the chamber. Feed was then added and the system brought to volume by the addition of distilled water.

The daily suspended solids concentration of the mixed liquor was kept between 2,300 and 4,800 mg/l. When the separation characteristics were to be tested the suspended solids were adjusted to 3,000 mg/l by dilution or concentration.

The separation characteristic tests were conducted during a period three to six hours after feeding. Three or more tests were run at each condition during this three hour interval. The mixed liquor was sampled for suspended solids before each test. Sedimentation tests were conducted when the activated sludge unit was operating under atmospheric pressure and flotation tests when under 30 psig pressure.

For sedimentation tests the mixed liquor was forced into the separation columns by a five psig pressure applied to the surface of the activated sludge unit. After a height of 300 mm (606 ml) was reached in the tube the flow was stopped and the tube inverted ten times to insure complete mixing. The height of the solid-liquid interface was measured at one minute intervals until the compression zone was entered, thereafter the time intervals increased. The clear liquor was sampled for suspended solids concentration before the

solids were resuspended and returned to the aeration chamber. Thirty minutes of aeration was allowed before another test was started.

In the flotation tests the mixed liquor was released into a separation column where either atmospheric, 10, or 20 psig pressure was maintained. The flow rate was controlled to prevent undue agitation and consequently the loss of dissolved air. When the mixed liquor reached a height of 300 mm the flow was stopped. The height of the solid-liquid interface was measured at one minute intervals until entering the compression zone, whereon the time intervals increased. The clear liquor was sampled for suspended solids concentration at the end of each test. The solids were resuspended and returned to the aeration chamber where 30 minutes of aeration was allowed before the test was repeated.

RESULTS

Testing was conducted during the period from April 5 through June 6. It was originally planned to use the same culture through the entire period. Due to a build-up and subsequent sloughing of an anaerobic sludge from the cover of the chamber, the chamber had to be cleaned and new bio-mass introduced following each set of test conditions. Various difficulties were encountered in keeping the system operable. Therefore tests were made only after maintaining the system in a satisfactory operating condition for a period of one week.

Twice each week microscopic examinations were made of the bio-mass in the mixed liquor. Under conditions of no-shear and atmospheric pressure stalked ciliates, free swimming ciliates, flagellates, "water bears", and a filamentous bacterial growth were noted. Rotifers were not observed and free bacteria were few. Under conditions of no-shear and 30 psi pressure the only changes were that there was less filamentous bacterial growth and a nematode was observed. Under conditions of medium-shear and atmospheric pressure the stalked ciliates were more numerous than free swimming ciliates and a few more single bacteria were present. With the addition of 30 psi pressure the stalked ciliates and flagellates were less numerous, and the bacteria appeared in small groups rather than in filamentous masses. Under conditions of high-shear and atmospheric

pressure the biota was similar to that found at medium-shear and 30 psig pressure. The addition of 30 psi pressure showed a greater number of single bacteria and bacteria in small groups. The free swimming ciliates were scarce while the number of stalked ciliates were moderate. The varying shear conditions appeared to have a greater effect on the type of biological growth than the pressure change.

The weekly averages of growth rates, pH and temperature under the various conditions are shown in Table II. The weekly average of the daily growth rate varied from a maximum of 21.3% per day at conditions of medium-shear and atmospheric pressure to a minimum of 14.8% per day at conditions of medium-shear, and 30 psig pressure. The higher growth rates tended to be at atmospheric pressure. The daily average temperature ranged from 18° to 23° C with a weekly average of 20° C. The pH ranged from 7.9 to 8.8. The daily record showing the suspended solids concentration in the mixed liquor (SSML), the increase of SSML, pH and temperature is in Table I of the Appendix.

TABLE II. WEEKLY AVERAGES OF MLSS, DAILY GROWTH RATE, pH, TEMPERATURE, BOD AND COD REMOVALS

Shear Level	None	None	Medium	Medium	High	High
Pressure (psig)	0	30	0	30	0	30
Average MLSS (mg/l)	3753	3613	3558	2950	3700	3271
Daily Growth Rate (%/day)	16.3	18.7	21.3	14.8	20.3	15.5
pH	8.5	7.9	8.7	8.4	8.8	8.2
Temperature (°C)	20.6	20.0	20.4	19.7	20.6	20.3
BOD removal (%)	97	98	82	98	98	97
COD removal (%)	63	75	55	70	68	71

Table III summarizes the results of the sedimentation tests under the various mixing conditions. Figures 4, 5 and 6 are the settling curves of the solid-liquid interface. The results from the flotation tests under the different mixing conditions and pressure releases are shown in Table IV. The flotation curves with pressure releases of 30, 20 and 10 psi are shown in Figures 7, 8 and 9. The results of no mixing are shown in Figures 4 and 7, medium-shear mixing conditions in Figures 5 and 8. Figures 6 and 9 show the high-shear mixing conditions.

TABLE III. SUMMARY OF SEDIMENTATION TESTS

Shear Level		None	Medium	High
Settling Velocity	mm/min.	115	79	94
Suspended Solids of mixed liquor	mg/l	3296	3560	3270
Percent removal of suspended solids		98	87	92

Conventional activated sludge treatment (no mixing and atmospheric pressure) had the highest settling velocity, 115 mm/min., and the highest removal of suspended solids, 98% after 63 minutes detention. The application of medium-shear mixing provided the slowest settling velocity, 79 mm/min., and the poorest removal of suspended solids at 87% after 80 minutes detention. This can be attributed to a 27% increase in suspended solids in the 24 hours prior to testing, indicating that anaerobic sludge build-up on the cover of the aeration chamber sloughed off causing a "sick" sludge. High-shear mixing resulted in a settling velocity of 94 mm/min. with 92% removal of suspended solids after 30 minutes detention.

TABLE IV. SUMMARY OF FLOTATION TESTS
(30 psig pressure in aeration chamber)

Shear Level		None	Medium	High
Pressure Released	psi	30	30	30
Rising Velocity	mm/min.	288	137	131
Suspended Solids of Mixed Liquor	mg/l	2418	2860	3521
Percent Removal of Suspended Solids		85	85	86
Pressure Released	psi	20	20	20
Rising Velocity	mm/min.	283	134	130
Percent Removal of Suspended Solids		95	93	86
Pressure Released	psi	10	10	10
Rising Velocity	mm/min.	71	46	83
Percent Removal of Suspended Solids		82	86	82

In the flotation tests it was impossible to locate the solid-liquid interface until the transition zone was encountered. For this reason the rising velocity was taken from the slope of the line connecting the origin and the first observation.

At a pressure release of 30 psi the maximum rising velocity was 288 mm/min. and the minimum was 131 mm/min. following treatment with no mixing and high-shear mixing, respectively. Similar results were obtained following a pressure release of 20 psi with the velocities being 283 and 130 mm/min. A pressure release of 10 psi yielded a maximum rising velocity of 83 mm/min. following the application of high-shear mixing.

The maximum suspended solids removal (95%), followed treatment with no mixing and a pressure release of 20 psi. The minimum removal (82%), occurred twice when 10 psi pressure was released. The removal of suspended solids varied with time. An example of this is with a 20 psi pressure release following treatment with no shear. After 15 minutes detention, 90% removal was observed, after 20 minutes the removal was 95% and after 30 minutes it dropped to 82%.

The suspended solids concentration has a direct, proportional effect on the removal efficiency in the flotation process. Despite the care taken to have 3000 mg/l MLSS, the average values for each mixing level during testing was 2423 mg/l at no mixing, 2849 mg/l

at medium-shear mixing and 3447 mg/l at high-shear mixing. This undoubtedly caused the removal following treatment by high-shear mixing to be higher than it would have been at 3000 mg/l, and the removal following treatment with no mixing to be lower. The magnitude of this effect cannot be determined with the available data.

Solid-liquid separation by flotation consistently provided a denser sludge compared to that provided by sedimentation. Following treatment with no mixing, sedimentation provided a sludge concentration of 16,700 mg/l after 10 minutes detention and 21,500 after 15 minutes detention. Flotation following the same treatment provided 36,300 mg/l and 38,400 mg/l when 20 psi pressure was released for the same detention times and when 30 psi pressure was released the values were 33,000 and 35,000 mg/l. This also illustrates that releasing more than 20 psi pressure does not improve the results.

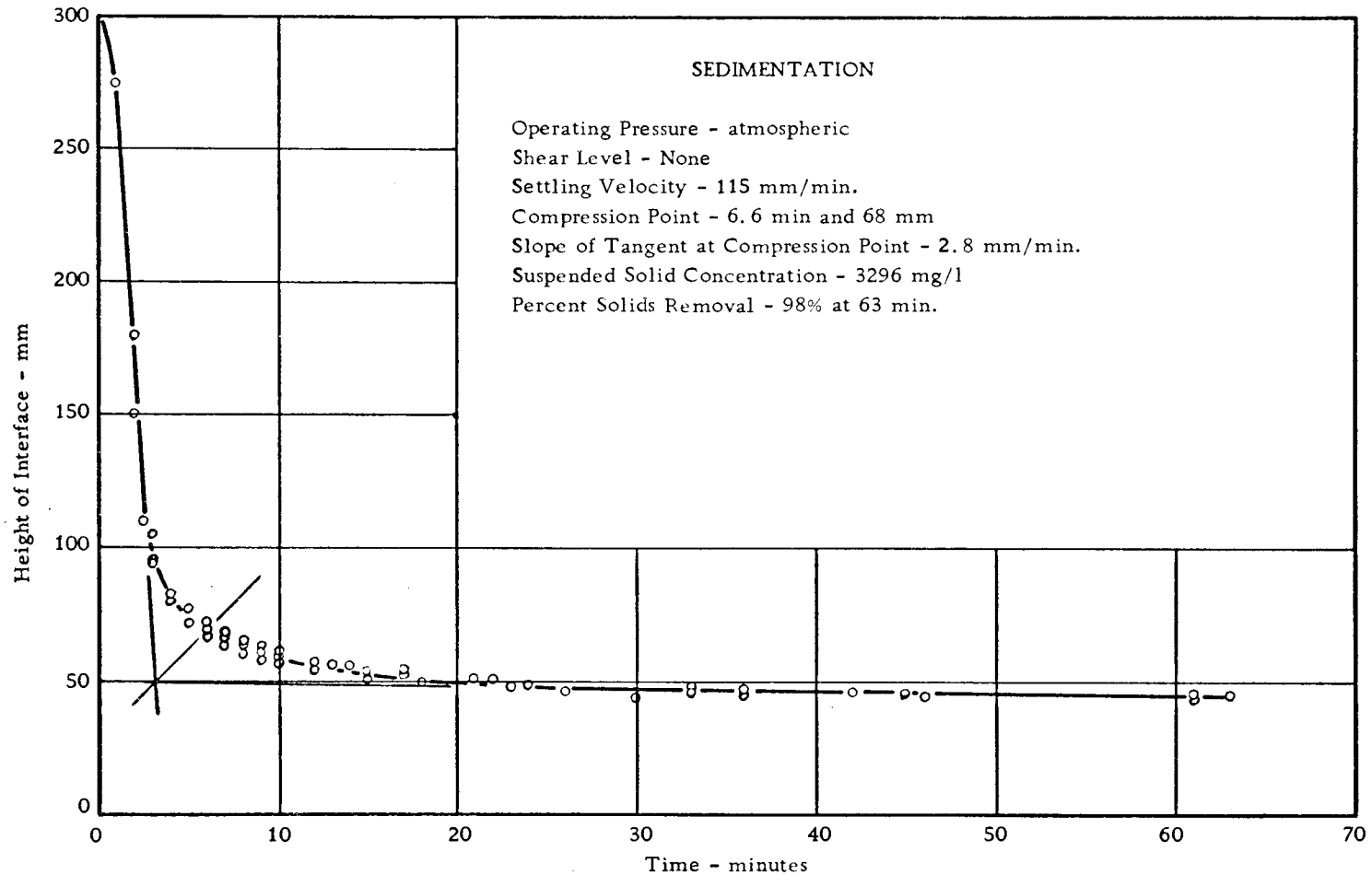


Figure 4. Sedimentation -- No mixing during treatment.

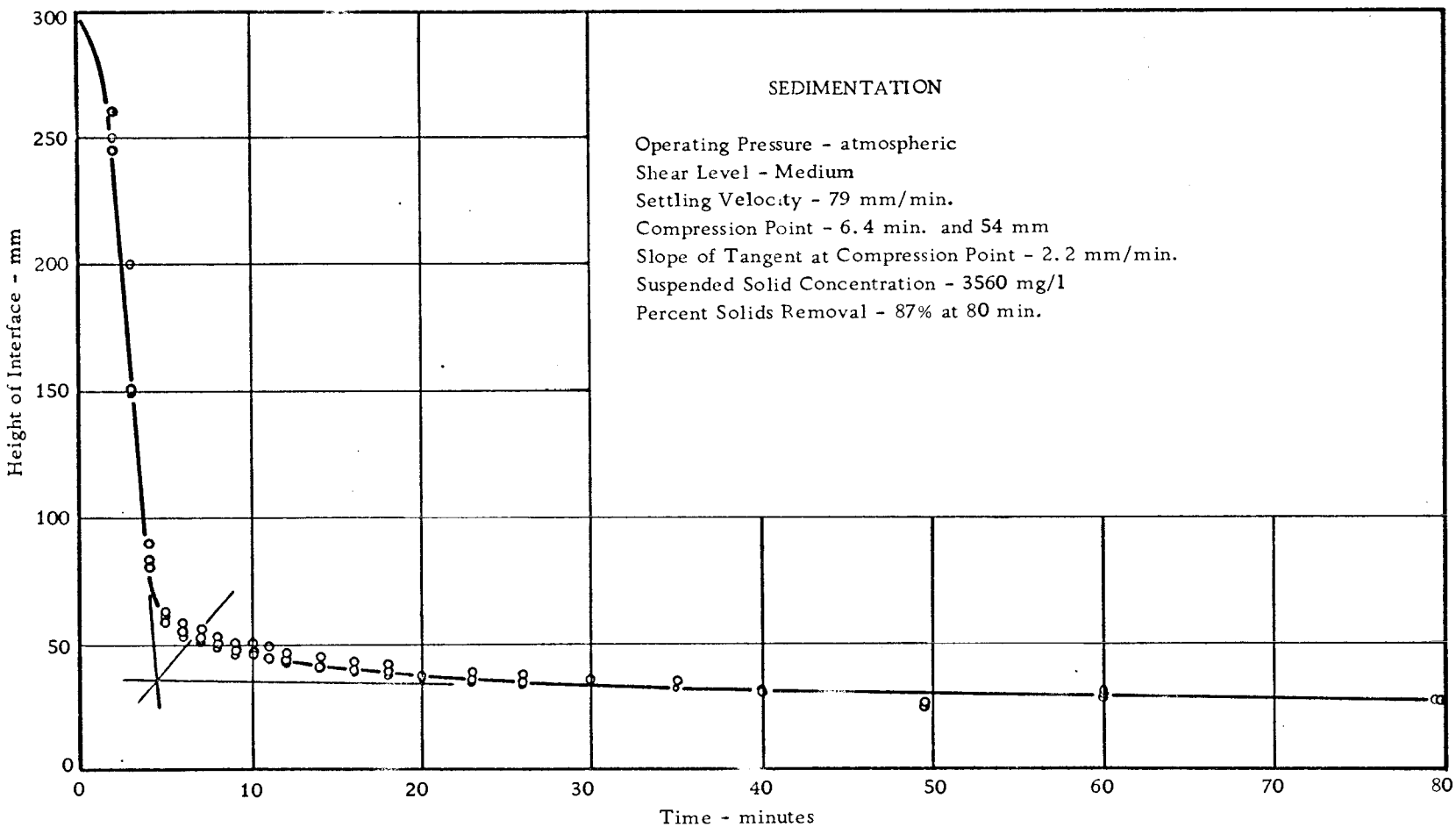


Figure 5. Sedimentation -- Medium-shear mixing during treatment.

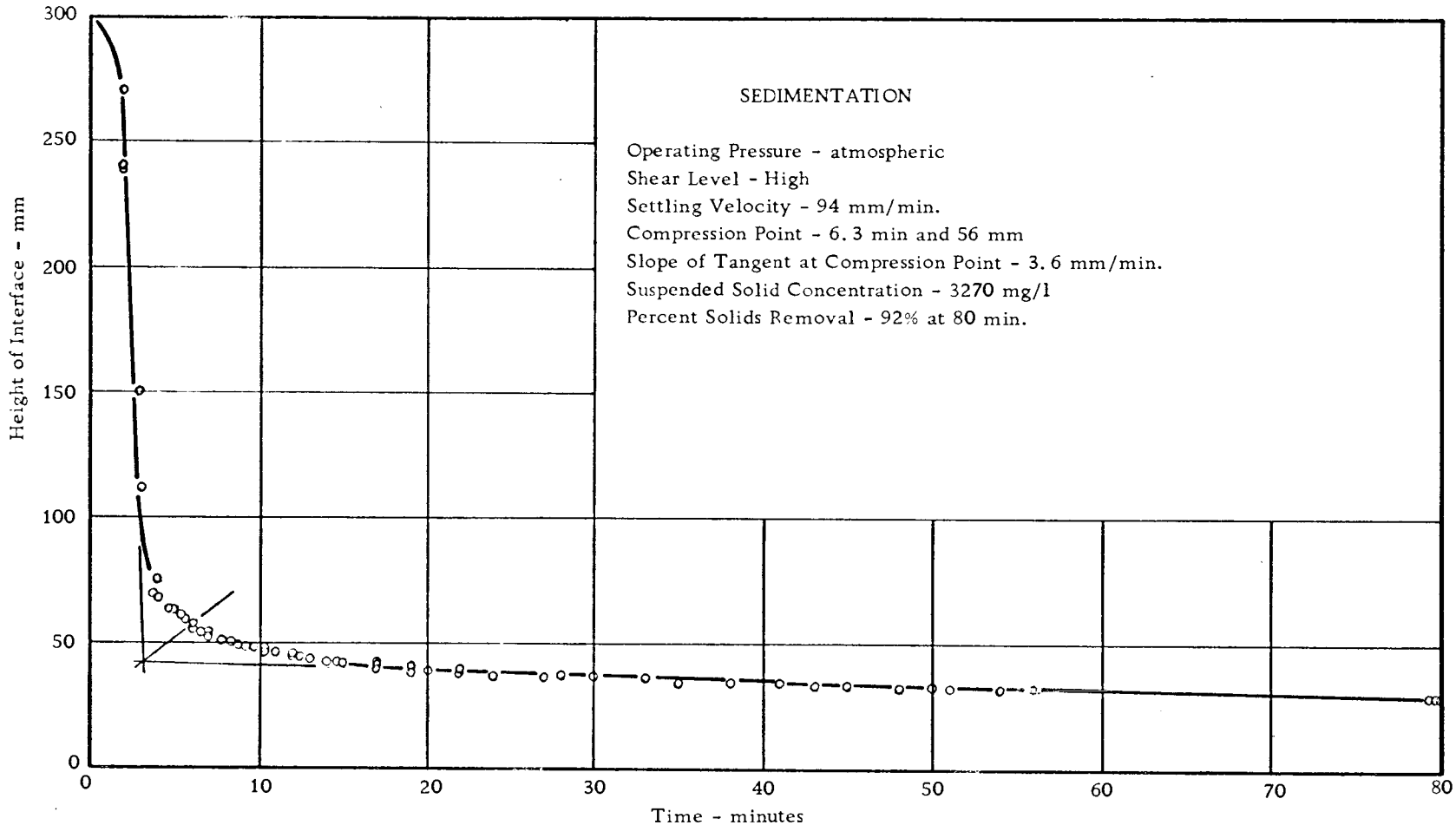
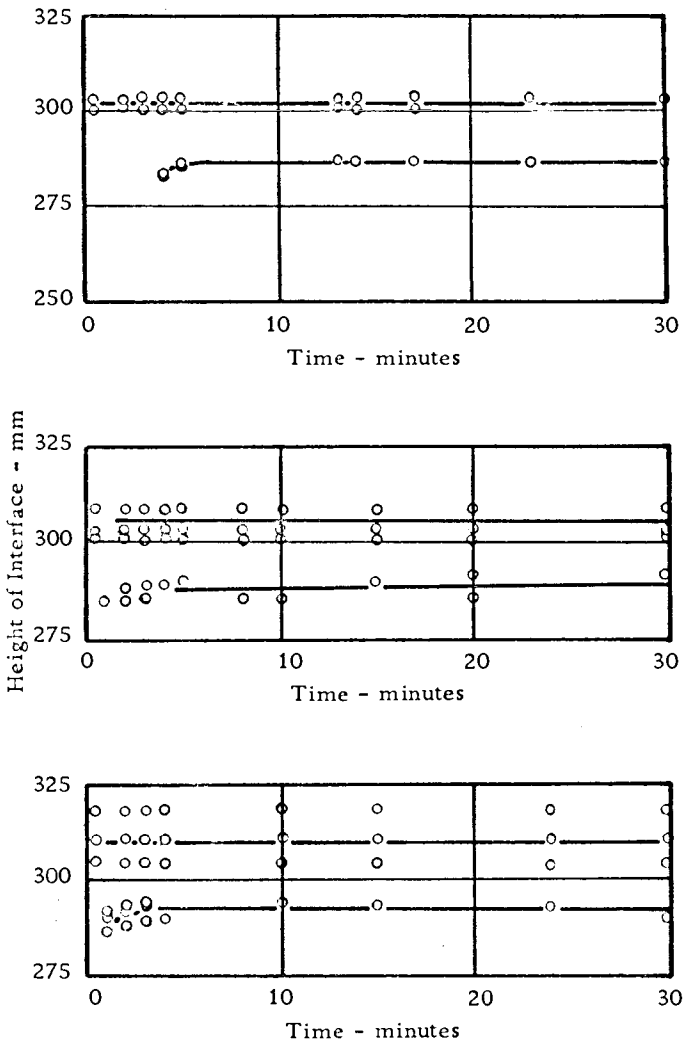


Figure 6. Sedimentation -- High-shear mixing during treatment.



Pressure released	10 psi
Rising Velocity	71 mm/min.
Suspended Solids Concentration	2426 mg/l
Percent Solid Removal	82 at 17 min. 80 at 30 min.

Pressure released	20 psi
Rising Velocity	283 mm/min.
Suspended Solids Concentration	2426 mg/l
Percent Solid Removal	90 at 15 min. - 95 at 20 min. - 82 at 30 min.

Pressure released	30 psi
Rising Velocity	288 mm/min.
Suspended Solids Concentration	2418 mg/l
Percent Solid Removal	82 at 10 min. - 85 at 24 min. - 79 at 30 min.

Figure 7. Flotation -- No mixing during treatment.

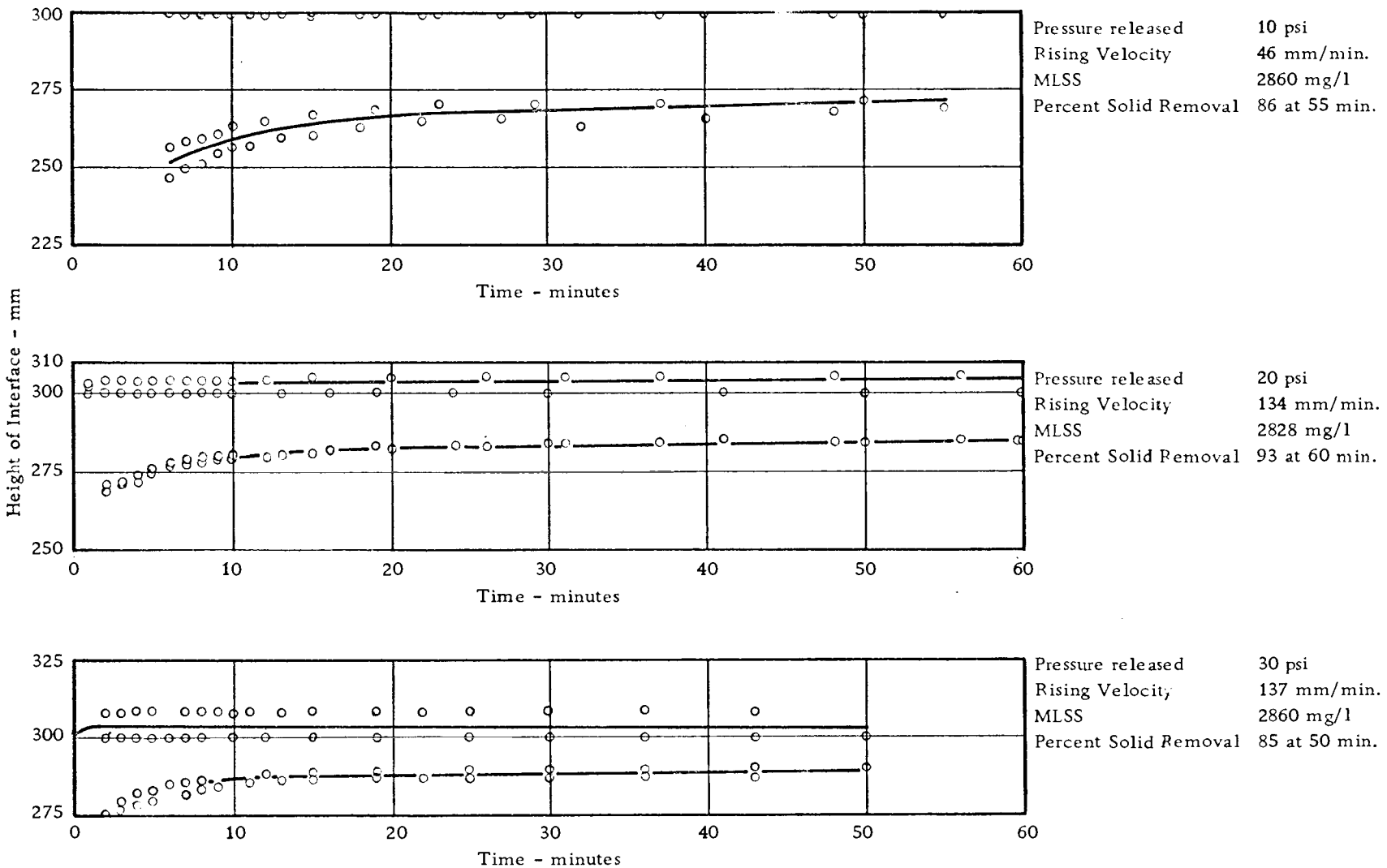


Figure 8. Flotation -- Medium-shear mixing during treatment.

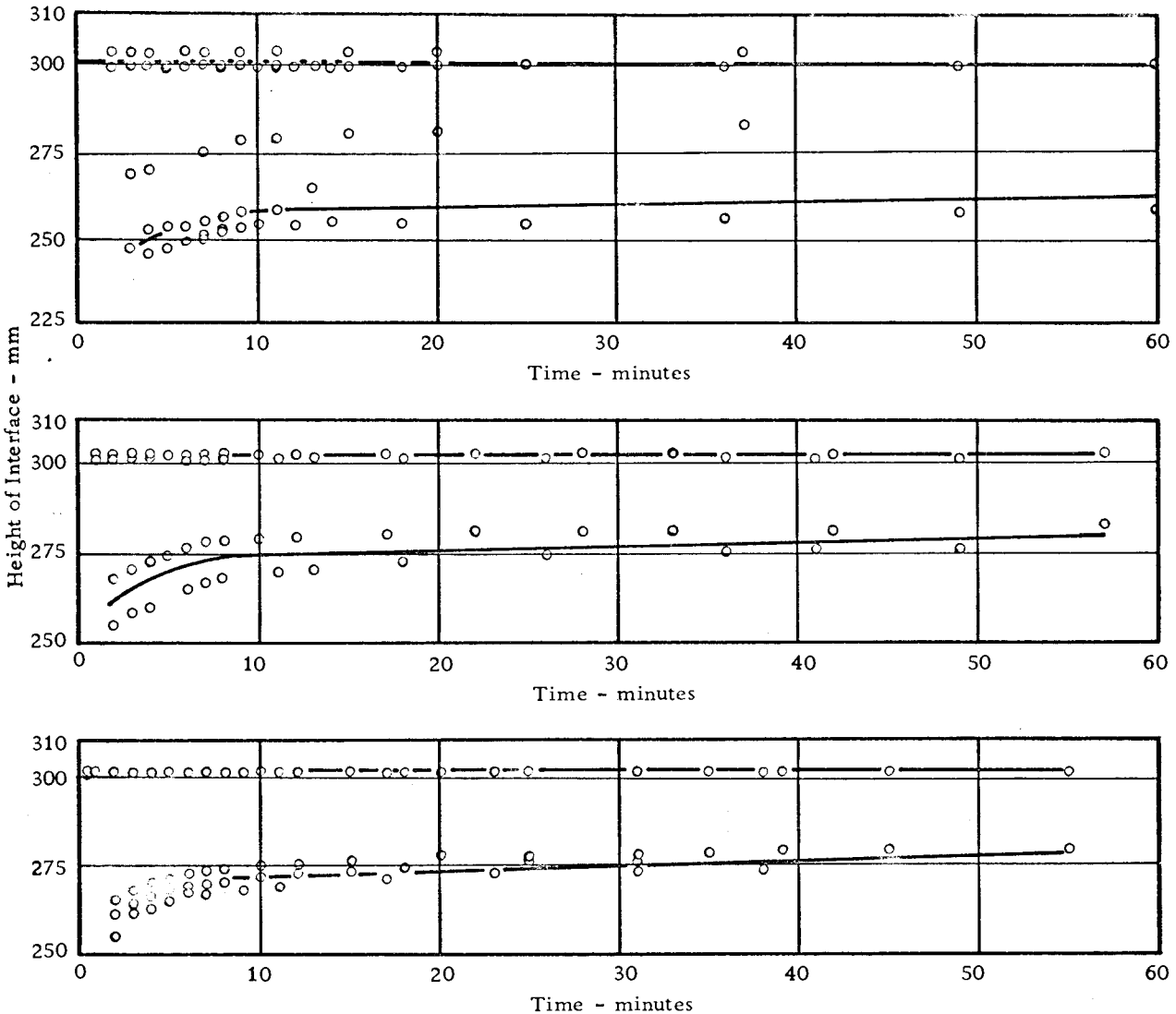


Figure 9. Flotation -- High-shear mixing during treatment.

CONCLUSIONS

1. The effluent provided by sedimentation and flotation following medium and high-shear mixing of activated sludge is not adequate for discharge to most water-courses.
2. Flotation does not yield as clear an effluent as sedimentation.
3. Suspended solids removal by flotation requires a shorter detention time than by sedimentation.
4. Flotation yields a denser sludge than sedimentation.
5. In the flotation process no advantage was found by using a pressure release of more than 20 psi.

RECOMMENDATIONS FOR FURTHER STUDY

1. Determine the clarifying ability of the combination of sedimentation and flotation.
2. Repeat the investigation at higher mixed liquor suspended solids concentrations.

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APPENDIX

TABLE I. DAILY SUMMARY OF SUSPENDED SOLIDS CONCENTRATIONS, INCREASE IN SUSPENDED SOLIDS CONCENTRATION, pH AND TEMPERATURE

Date	Operating Condition	MLSS in Morning mg/l	Increase in MLSS mg/l	pH	Temp. °C
April					
26	medium-shear	3164	864	8.6	21
27	atmospheric	3557	375	8.6	20
28	pressure	3274	1146	8.6	21
29		2500	836	8.7	20
30		3017	647	8.8	20
May 1		3406	-	8.9	20
2		-	-	9.0	21
3		3100	768	9.0	19
4	high-shear	2978	1262	8.4	22
5	atmospheric	3920	528	8.6	21
6	pressure	3710	542	8.8	20
7		3401	1027	8.8	20
8		2840	376	8.9	21
9		2740	-	8.7	21
17	medium-shear	3252	176	-	20
18	30 psig	3229	-	8.5	20
19		-	-	8.5	20
20		2740	252	8.4	20
21		2572	144	8.3	20
22		2360	1180	8.4	18
23		3000	-	8.4	20
17		2730	722	-	20
18	no-shear	3279	165	8.5	20
19	atmospheric	3275	1073	-	-
20	pressure	4130	682	8.7	23
21		4090	450	8.5	23
22		3178	582	8.5	18
23		3000	-	8.0	20
24		2817	291	8.3	19
25	high-shear	2825	791	8.4	22
26	30 psig	3104	864	8.2	21
27		3423	41	7.8	21
28		2938	538	8.1	20
29		2996	524	8.1	18
30		2864	-	8.3	21
31		-	-	-	-
June 1	no-shear	2302	598	7.5	20
2	30 psig	2683	301	8.0	20
3		1522	1026	8.1	20
4		2387	245	7.8	20
5		2485	1199	8.1	20
6		3463	-	7.8	20