A FEASIBILITY STUDY ON THE APPLICATION OF THE HYDROCYCLONE FOR THE SEPARATION OF FLOCCULENT MICROBIAL SYSTEMS

By

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1970

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
May 1971

A FEASIBILITY STUDY ON THE APPLICATION OF

THE HYDROCYCLONE FOR THE SEPARATION

OF FLOCCULENT MICROBIAL SYSTEMS

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ACKNOWLEDGMENTS

I would like to express my sincere appreciation to my major adviser, Dr. D. F. Kincannon, for his valuable time and encouragement throughout this study. Special thanks are also due Dr. W. G. Tiederman, who not only supplied his expertise of hydrocyclone technology, but also provided much of the equipment which was used in this study. I would also like to thank Dr. A. F. Gaudy for his participation on my advisory committee.

I am most grateful to my wife, Barbara, for her understanding and encouragement during this study and for her help in preparing and typing this manuscript.

Lastly, I would like to thank the Federal Water Quality Administration for providing me the opportunity of making this study through bioengineering training grant number 1T1-WP-238-01.

TABLE OF CONTENTS

LIST OF FIGURES

Figure | Page

CHAPTER I

INTRODUCTION

For years man has considered water to be an over abundant resource and has used it for every purpose imaginable. In recent years man has become more aware of the plight of his water resource and, consequently, more and more emphasis is being placed on pollution control.

Biological waste treatment has come to play an extremely large part in the abatement of water pollution. The activated sludge process is considered to be the most efficient of biological waste treatment methods known today.

The characteristic feature of the activated sludge process is that biological solids must be separated from the treated effluent for recycle back into the process. Efficient performance requires that the separation be done effectively because the solids are needed to sustain the process and because solids which escape separation impair the quality of the effluent. In addition, it is important that the solids be consolidated into a concentrated suspension before being recycled back into the aeration tank.

Unfortunately, the light, flocculent, biological solids formed in the activated sludge process usually do not settle and compact well. Hence, the effluent quality which can be achieved by activated sludge treatment as well as the size and cost of the treatment facilities are often controlled by the settling characteristics of the sludge.

In the past the majority of this separation process has been accomplished using gravity settling. However, as higher degrees of treatment are required to meet the challenges of the environmental era, gravity settling will not suffice. It has been stated by Hansen, et. al. (1) that newer and better methods of solid-liquid separation must be found and applied to provide effluents of the caliber required for the future.

The industrial hydrocyclone is an apparatus that has acquired a unique position among the various forms of separation equipment available to the present-day engineer. Rietema and Verver (2) point out that this is due to its simplicity of construction, its lack of moving parts, its large capacity, and its many applications.

This investigation was conducted to study the feasibility of applying the hydrocyclone for separation of flocculent microbial systems such as are often found in activated sludge effluents. Two existing hydrocyclones were utilized to separate activated sludge of various levels of biological solids. Three hydrocyclone systems were investigated and separation parameters were varied in an attempt to indicate direction for design of more efficient systems.

CHAPTER II

LITERATURE REVIEW

A. General

Aeration was first applied to sewage in experiments by Arden and Lockett in the early 1900's. The first large plants installed were at Houston in 1916, Milwaukee in 1920, Pasadena in 1924, and Indianapolis in 1926. Since that time, the activated sludge process has undergone many changes in the development of what it is today.

The first formal recognition of the use of separate gravity concentration tanks as part of the activated sludge process was at the Milwaukee installation in 1925. However, Hansen, et. al. (1) has stated that the techniques and equipment used in solid-liquid separation in the treatment process have changed very little since that time.

Pipes (3) has pointed out that the primary factor controlling the performance of an activated sludge plant is the separation of sludge solids to produce a good quality effluent. In agreement with this, Dick (4) has designated 2 functions of solid-liquid separation which must be considered for satisfactory design. These functions are the production of an effluent relatively free of settleable solids and the production of a highly concentrated sludge. Dick also presents the graph shown in Figure 1, which clearly shows the effect of solids removal on the efficiency as measured by BOD.

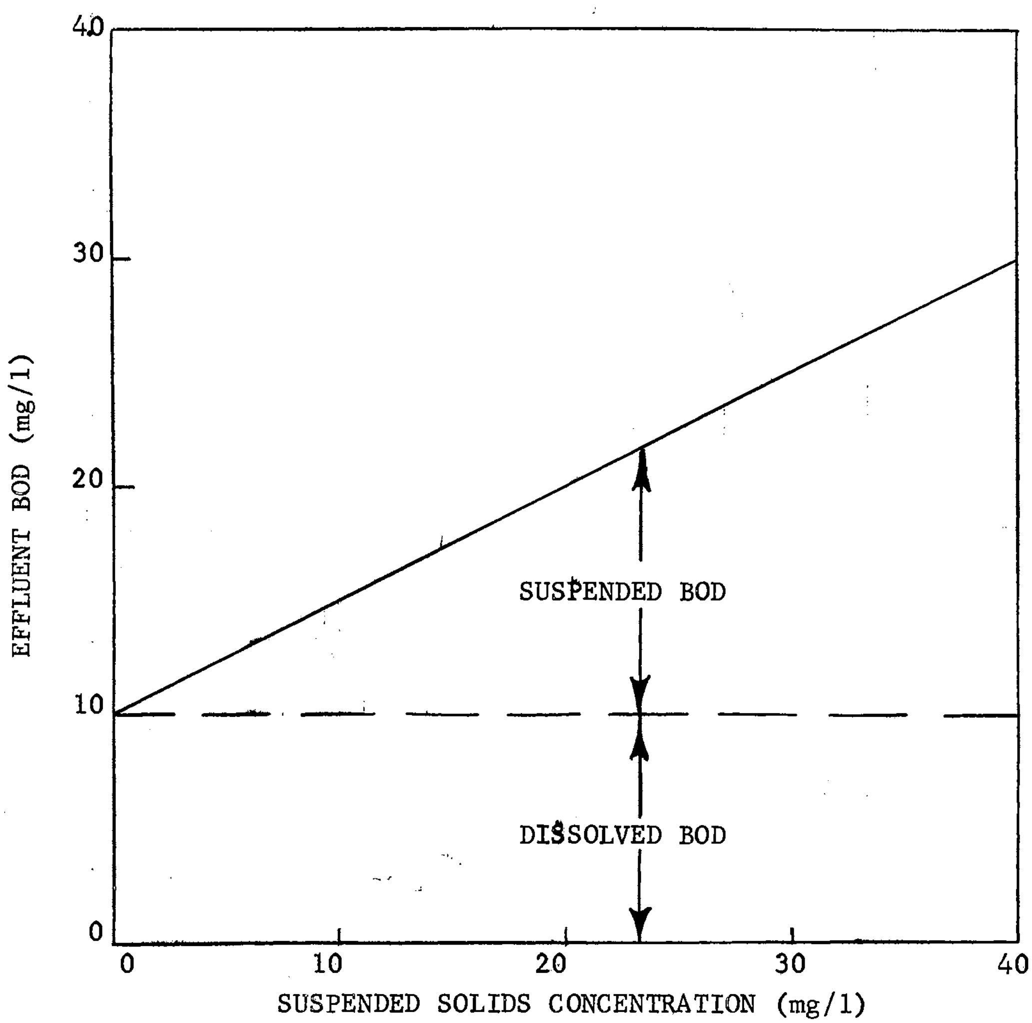


Figure 1. Effect of Suspended Solids on Effluent BOD

B. Problems in Separation

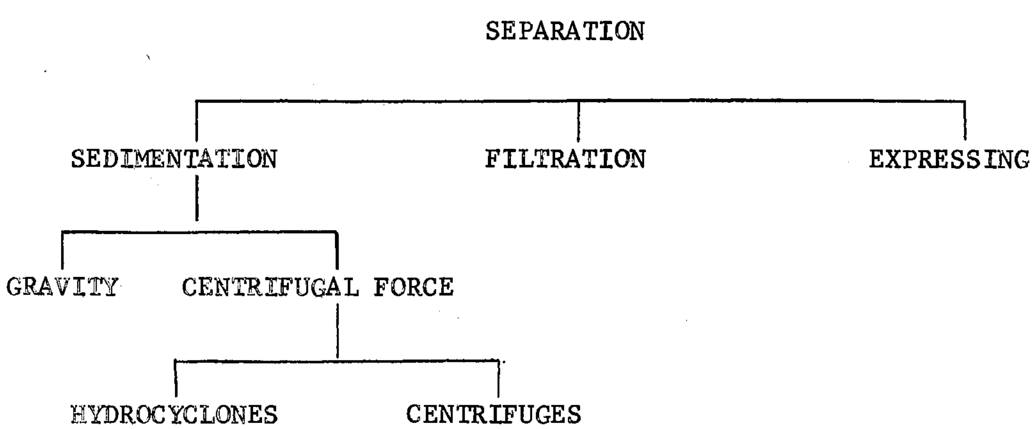
Greely (5) has stated that the principle operating disturbance in the activated sludge process is in the behavior of the sludge. In general, he refers to these problems as bulking and points out methods of controlling such problems by proper operation.

Pipes (3), however, has broken down the types of sludge which do not settle well into 9 categories and has given a detailed description of each. He further suggests that each type of sludge can be related to a specific deficiency and has proposed methods of correcting each.

Ford and Eckenfelder (6) have pointed out that floc formation in the sludge is effected by fluctuating organic loading. The most important factor controlling the formation of floc was found to be the physiological state of the floc-forming organisms.

Patterson (7) has presented a good review of the separation techniques most often employed in biological waste treatment. He includes gravity sedimentation, air flotation, centrifugation, and microscreening.

A good summary of solid-liquid separation principles has been published by Leniger (8). He has provided definitions and broken down the processes as shown below.



He further stated that separation of solids from liquid is never completed by mechanical means. The mixture is separated into two fractions -- one which contains no solids and the other with a higher concentration of solids than the original.

Coagulent aids such as organic polymers or polyelectrolytes have been utilized in improving floc formation by Woldman (9) and others (10) (11). In his studies, Woldman found that effectiveness was due to both dosage and the method of growing the cells.

Walker and Dougherty (10) determined the effects of various polyelectrolytes on the settling of activated sludge. Results indicated that no one type was universally effective.

Ries (11) has agreed that dosage is important, but states that at this time proper feeding of polymers is primarily an art.

C. The Hydrocyclone as a Separator

1. Theory

The hydrocyclone was introduced after World War II by the Dutch State Mines as a new tool to separate dispersed solid material from liquids of lower density. It has been used in many industries since that time. Unfortunately, however, the theory of the separation mechanism in the hydrocyclone is greatly lagging behind the expanding practice (12).

A great deal of work has been done on trying to determine the criteria which is important for design of more efficient hydrocyclones. Kelsall (13) determined the flow pattern and separating capabilities of several cyclones, but made no attempt to correlate these to any specific parameters.

Fontein, et. al. (14) have related the Reynolds number as being the most important variable. They also published data on the effects of variables such as pressure drop, viscosity, underflow, and roughness. One important observation in light of the present work was that high shearing forces were formed in the hydrocyclone. Hence, they concluded that floculation would be prevented and that very fine particles would always be present in the overflow.

A list of 6 variables in determining separation was presented by Fitch and Johnson (15). Included were size of feed entrance, size of cyclone, specific gravity of feed solids, quantity and size of feed solids, pressure drop, and plasticity of the feed.

Pilgrim and Ingraham (16) applied dimensional analysis to the cyclone and developed an equation of the throughput.

It has been stated by Leninger (8) that by proper selection of dimensions and operating conditions, a hydrocyclone can be made to function in such a way that the underflow contains all solid particles and the overflow is clear and constitutes the greater part of the liquid. He has stated, however, that the concentration of the underflow cannot be raised to a high value and that particles less than a few microns cannot be separated well.

It is interesting to note, however, that there are approximately 16 geometric variables in the hydrocyclone. In this survey of the literature no study was found in which all of these were simultaneously studied for their effect on separation. Thus, it appears that the design of hydrocyclones is still based on empirical relationships which cannot be extrapolated beyond the range of the original data.

2. Applications in Waste Water Treatment

The hydrocyclone is used extensively in many industries for classification and thickening of suspensions. Its economy, high capacity per unit space, and simplicity of operation indicate possible applications in the treatment of waste waters.

Patterson (7) has studied the feasibility of using the hydrocyclone for separation of dispersed microbial growths. From his work he concluded that the hydrocyclone was limited in its ability to separate the light, dispersed growth.

In experiments made by the Department of Scientific and Industrial Research in Great Britain (17) tests were made with domestic sewage. The results showed very little removal (less than 8%). An attempt was also made to separate activated sludge using the hydrocyclone which also proved unsuccessful. From this work it was concluded that the design of cyclones for sewage is very difficult due to the difficulty in defining particle size, density of the organic suspended solids, and in predicting their behavior at high velocities.

Silin (18) has described existing facilities for treating sugar wastes at the Ryzhavskii beet sugar factory in the USSR. The process included hydrocyclones as separators. His data showed removals of 33-43% of the solids. He also mentioned that more cyclones were to be added to the system.

Hollo, et. al. (19) also utilized the hydrocyclone for separation of sugar wastes. They report reaching concentrations of up to 140 times and removal of up to 97%.

Hydrocyclones have also been suggested for use as degritters in sewage treatment by Rankin (20). He prefers to utilize the cyclone on settled sludge containing grit. In other words, the primary clarifier can serve as the grit chamber and clarifier. His studies produced a grit of only 1.5% putrescible matter which is far superior to ordinary grit chambers.

CHAPTER III

MATERIALS AND METHODS

A. Hydrocyclone Systems

1. General

Two hydrocyclones were used for this study. One was designed as a 6 gallon per minute apparatus with a nominal pressure drop of 50 psi. It was originally designed by the Mechanical and Aerospace Engineering Department at Oklahoma State University for the purpose of cleaning dirty scrub water in industrial sweepers. The other was a 2 gallon per minute, 130 psi apparatus designed specifically for this study. The pump used was a roller type driven by a 1 horsepower, 220 volt a.c. motor. A bypass system (Figure 2) was set up around the pump so that the flow rate could be easily varied. These apparatus were employed in each of three different cyclone configurations.

To provide the necessary measurement of flow rate through the hydrocyclone a calibration of flow rate versus pressure drop was made for each system. This was accomplished by operating the cyclone at various pressure drops and measuring the time required for a known amount of water to pass through it.

2. Single Pass System

Single pass studies were made utilizing the system shown in Figure 3. This system consists of an inflow reservoir which contains the contaminated fluid, the hydrocyclone, an underflow reservoir to collect

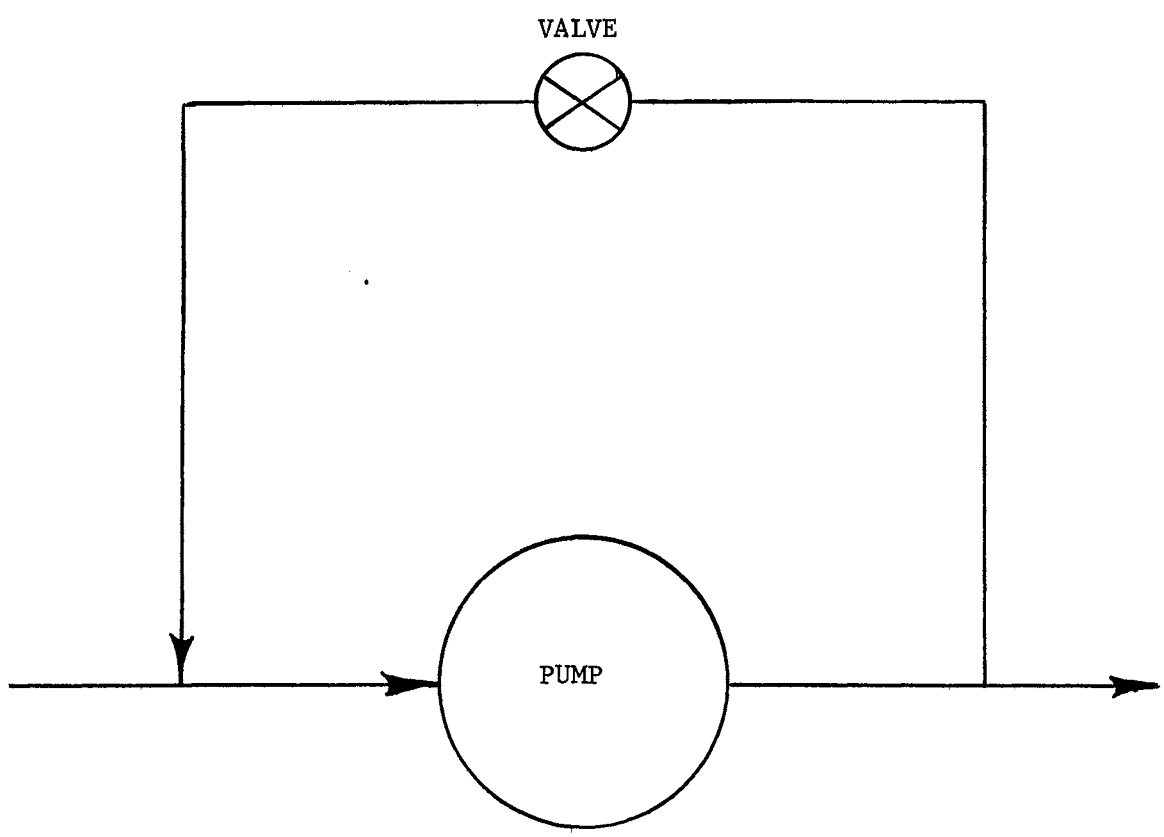


Figure 2. Pump Bypass System

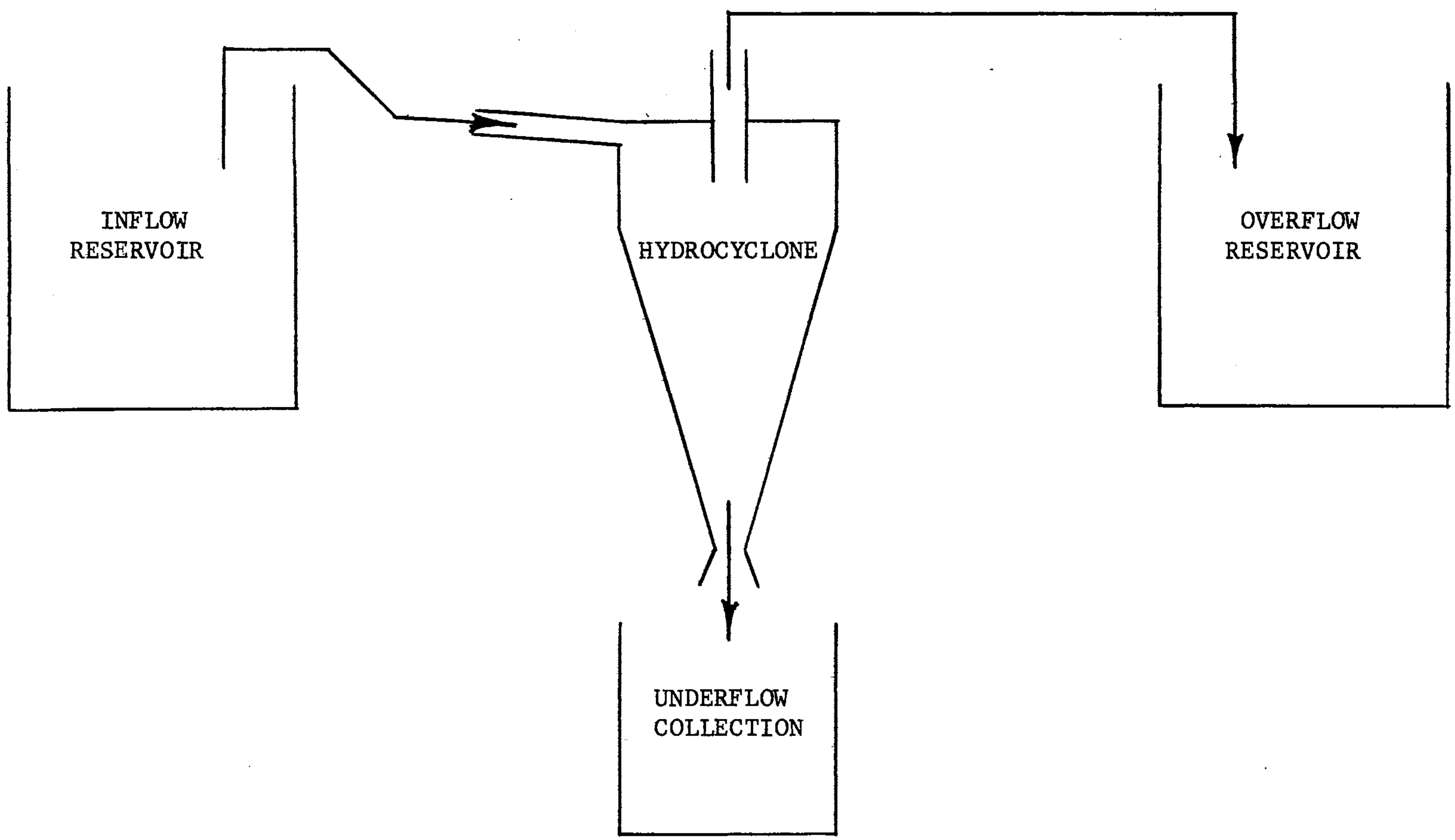


Figure 3. Open Underflow System for Single Pass Studies

the concentrated sludge, and an overflow reservoir to collect the clarified fluid. Using this system a known volume of "activated sludge" was allowed to pass through the cyclone and biological solids samples were drawn from the inflow and outflow reservoirs and the underflow to determine the concentration efficiency. The volume of the underflow was also measured so that percent underflow could be calculated and a materials balance could be made if deisred. This procedure was then repeated using the collected overflow effluent to find the effect of further passes on the condition of the slurry.

3. Continuous Recycle Systems

Studies were made on the effect of continuous recycle of the fluid through the cyclone. These studies were made utilizing two separate configurations: (1) a closed underflow hydrocyclone employing a contamination trap and; (2) a closed underflow hydrocyclone without the contamination trap.

a. Closed Underflow Employing a Contamination Trap

The Mechanical Engineering Laboratories of Oklahoma State University have developed and patented a contamination trap for use with the hydrocyclone (21). The trap consists simply of a cylindrical filter apparatus which fits into the underflow return of the cyclone and thus keeps any solid material which has reached the underflow pot from returning to the flow in the cyclone and thus contaminating the effluent.

A system (Figure 4) was arranged utilizing the contamination trap and continuous recycle studies were made. The system used consists of a reservoir and the hydrocyclone with a closed underflow. For these studies a know volume of "activated sludge" was passed through the cyclone and the effluent was returned to the inflow reservoir. Samples

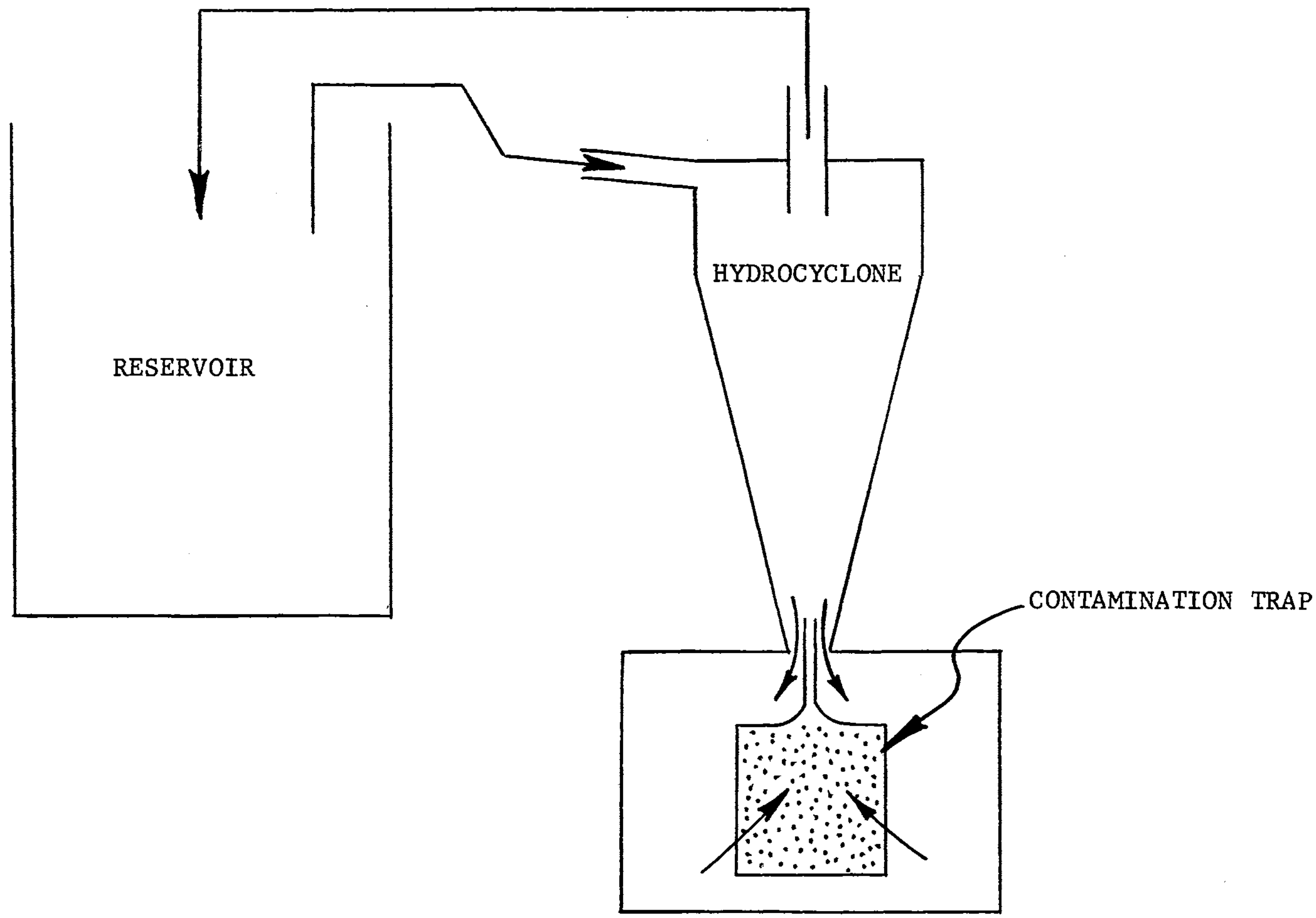


Figure 4. Closed Underflow System With Contamination Trap (Patent rights assigned to Oklahoma State University)

were drawn at 0, 5, 10, 20, 30, 40, and 50 minutes and were evaluated for biological solids.

b. Closed Underflow Without a Contamination Trap

Continuous recycle studies were also made using a closed underflow cyclone without the contamination trap. The system (Figure 5) and procedure were the same as those used for the above study involving the contamination trap with the exception of the trap itself.

B. Microbial Systems

1. General

The activated sludge used in this study was grown in batch units from an initial seed of primary settled sewage from the municipal sewage treatment plant at Stillwater, Oklahoma. The synthetic waste used as substrate for growth was the standard glucose minimal medium used in the bioenvironmental engineering laboratories at Oklahoma State University. This feed had the following chemical make-up:

Constituent	Concentration
Glucose	1000 mg/1
$(NH_4)_2 SO_4$	500 mg/1
$MgSO_4 \cdot 7H_2O$	100 mg/1
$MnSO_4 \cdot 7H_2O$	10 mg/1
$CaCl_2$	7.5 mg/1
$FeCl_3 \cdot 7H_2O$	0.5 mg/1

and was mixed and fed dry.

A phosphate buffer solution was used for pH control. The solution consisted of 52.7 gm/1 of $KH_2 PO_4$ and 107 gm/1 K_2HPO_4. 10 ml of solution were used per liter of activated sludge in the batch unit.

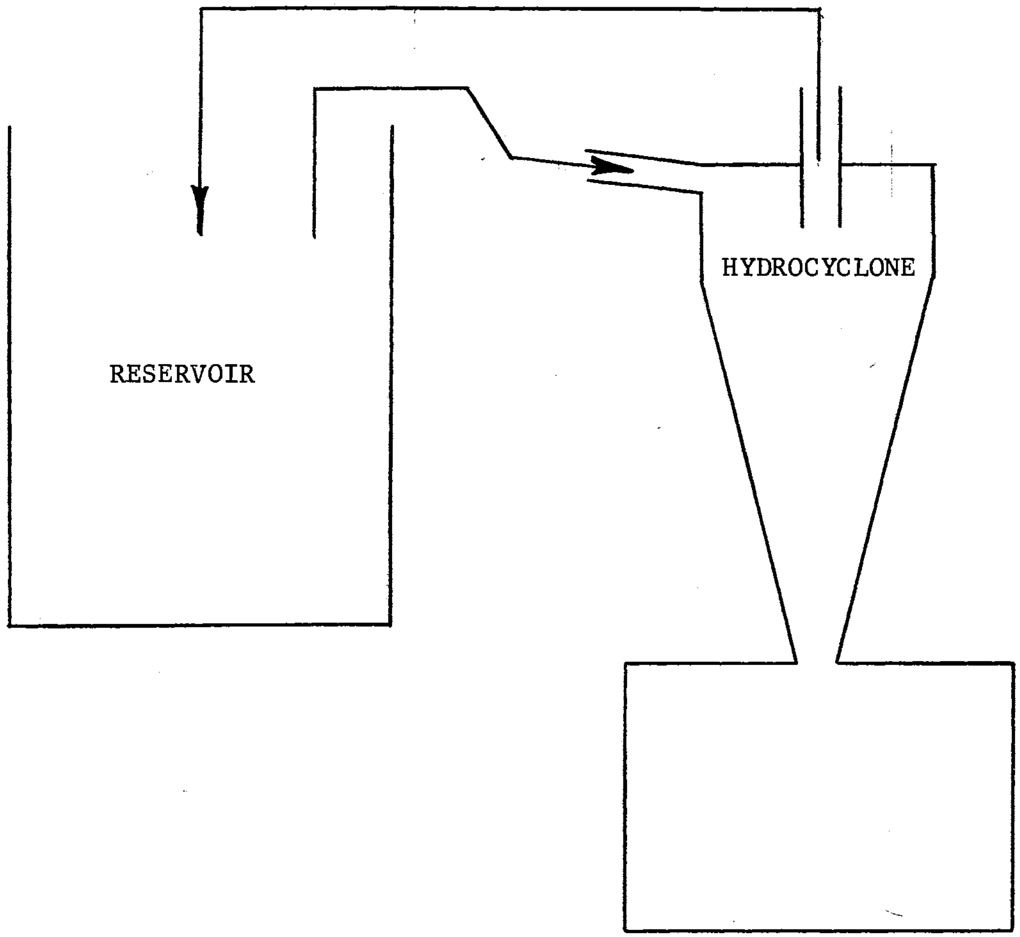


Figure 5. Closed Underflow System Without Contamination Trap

2. Low Solids Concentration

For this study, the biological solids of the activated sludge were considered to be low at concentrations between 1000 and 2000 mg/l. A growth of this type was achieved by diluting the activated sludge which was used for studies at the medium solids concentration.

3. Medium Solids Concentration

Concentrations between 2000 and 6000 mg/l were considered to be in the medium range. This was accomplished by feeding the equivalent of 1000 mg/l of glucose daily to a 30 liter reactor which had been seeded with sewage. During the dispersed growth phase 1/3 of the mixed liquor was wasted daily and replaced with tap water. After the growth became flocculent, the procedure was to waste 1/3 mixed liquor and 1/3 settled supernatant and replace with tap water. This procedure was followed until the desired concentrations were reached.

4. High Solids Concentration

In this investigation, solids concentrations greater than 10,000 mg/l were considered high. To reach this high level, the procedure for feeding the batch unit was the same as for medium solids except that no solids were wasted after flocculation had begun. The waste used, however, was raised to 30,000 mg/l of glucose and the other constituents were increased at the same ratio. The pH had to be controlled manually using a sodium hydroxide solution.

C. Analytical Procedures

1. Determination of Biological Solids

Samples of known volume were first centrifuged at 10,000 rpm and then filtered through 0.45 micron membrane filters. The technique used was that outlined in Standard Methods (22).

2. Dosages of Coagulent Aids

To determine the optimum dosage of coagulent aid to be used, 500 ml. samples were subjected to different amounts of the coagulent aid to be tested. For these tests a Phipps and Bird 6-paddle stirrer was used. The samples were rapidly mixed at 100 rpm for 1 minute and then flocculated at 25 rpm for 20 minutes. The paddles were then shut off and the settling characteristics observed. The coagulent aid used in this study was a cationic organic polyelectrolyte manufactured by Dow Chemical Company under the name of Purifloc C-31.

CHAPTER IV

RESULTS

A. 6 GPM Hydrocyclone

1. Flow Calibration

The 6 gpm hydrocyclone was calibrated for flow rate versus pressure drop. Figure 6 shows the straight line relationships which were obtained. It can be observed that a flow of 6 gpm is reached at a pressure drop of 56 psi whether the contamination trap is present in the system or not. At lower pressures, however, there is some difference in the flow rates obtained. These relationships were used to convert direct readings of pressure drop into flow rates.

2. Continuous Recycle Studies

a. General

Experiments were run to determine the effect of pressure drop and/or flow rate on the removal efficiency of the cyclone. Figure 7 shows that the efficiency tends to increase linearly in the range shown. No experiments were made at pressure drops higher than 60 psi because the pump being used had reached full capacity and the design flow for the hydrocyclone had been obtained. As a result of this study, all further experiments were made at a pressure drop of 60 psi.

b. Low Solids System

Figure 8 shows the results of four experiments made in the low solids range. Without the use of a coagulent aid, a removal of 26% was

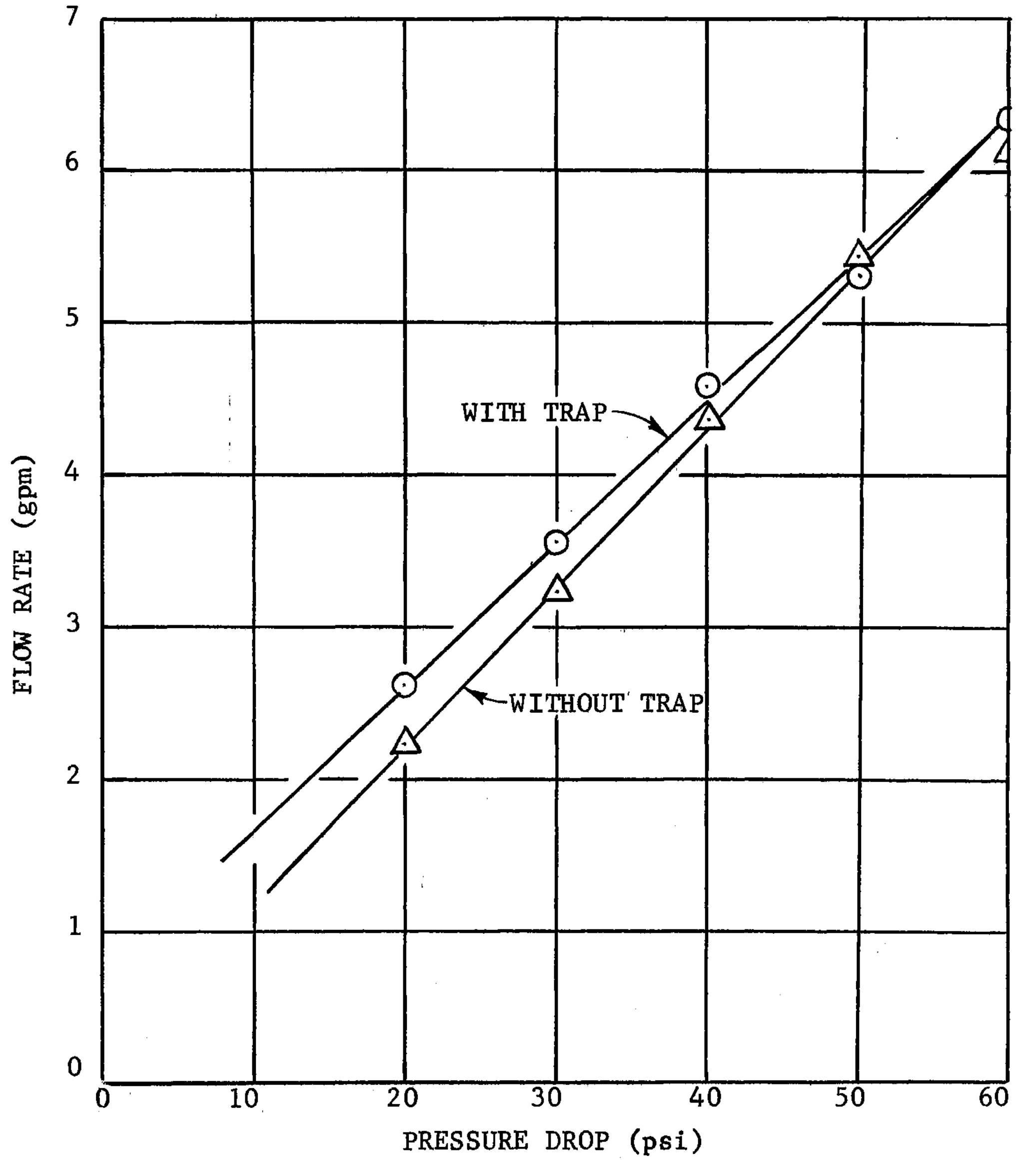


Figure 6. Calibration Curve for 6 GPM Hydrocyclone.

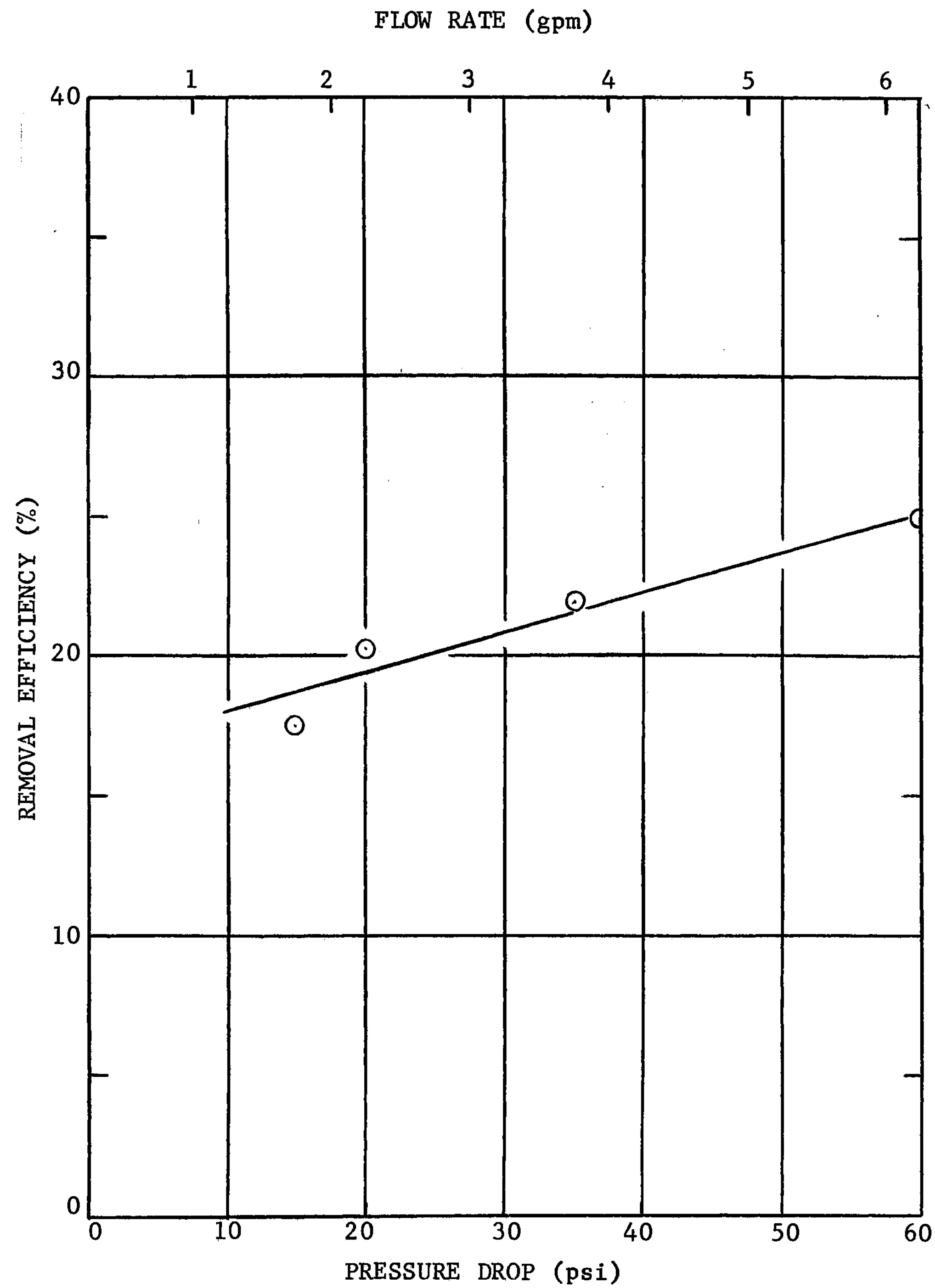


Figure 7. Effect of Pressure Drop and/or Flow Rate on Removal Efficiency.

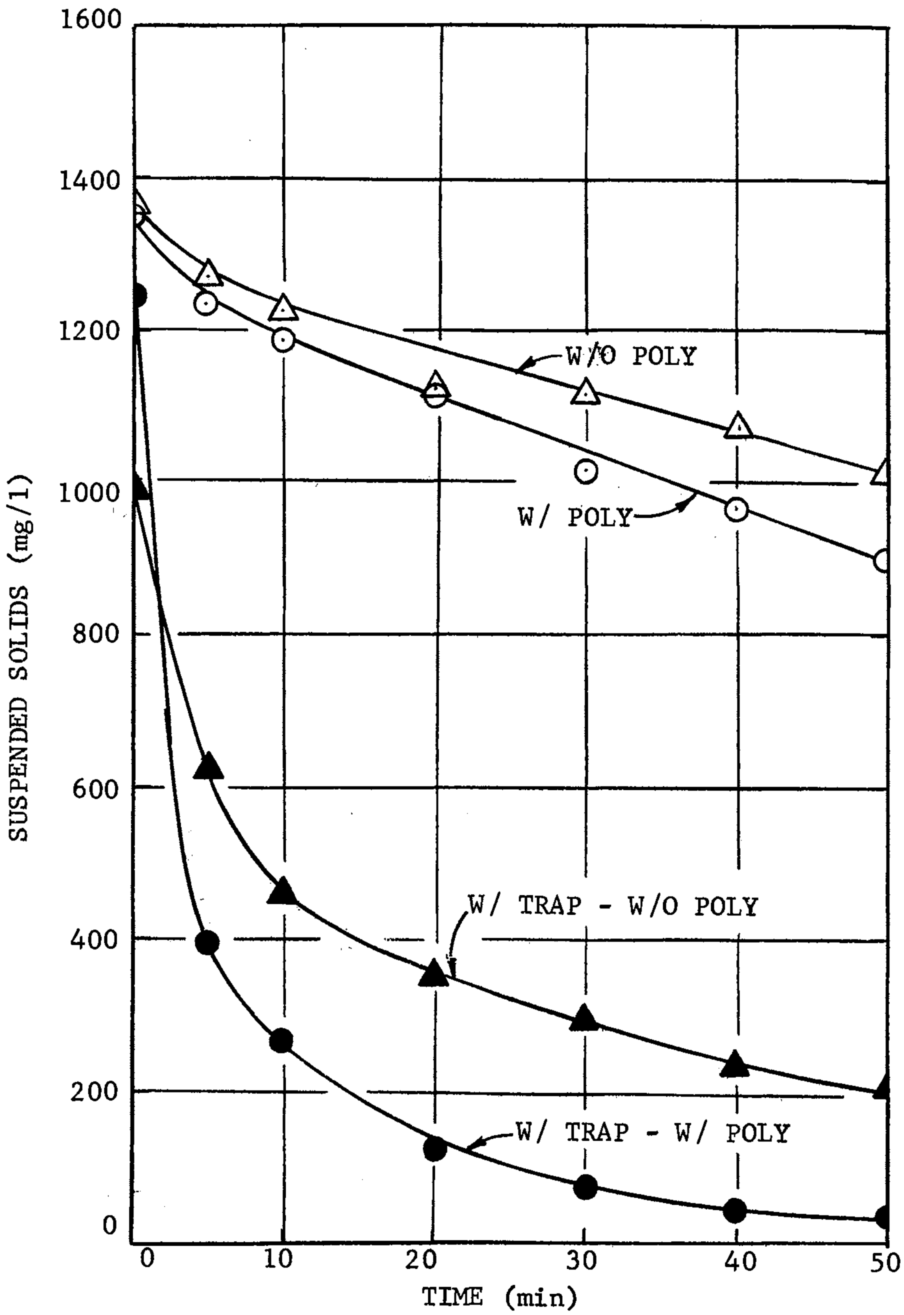


Figure 8. Continuous Recycle Studies at Low Solids Level.

accomplished in 50 minutes. However, with the addition of 50 mg/1 of C-31 polyelectrolyte a removal of 33% was obtained in the same amount of time. In both cases removal occurred at a higher rate in the first five minutes and then continued at a lower constant rate. The removal rate for the linear portion of the curve in the experiment using polyelectrolyte is higher than was obtained without polyelectrolyte. This is apparent from the slopes of the two lines.

It is very interesting to notice the effect of adding the contamination trap to the system. Without the use of polyelectrolyte a removal of 79% was achieved in 50 minutes while in the same amount of time 97% removal was obtained using coagulent aid. These curves are of a different shape than was noted without the use of the contamination trap. It is important again to notice that the removal rates are much higher in the first 5 minutes in both cases. With the use of polyelectrolyte and the contamination trap, 69% of the suspended solids were removed in the first 5 minutes as compared to 37% when the coagulent aid was not used. However, when the trap is in the system there is no apparent period of constant removal rate as was found before. The rate of removal tends to be continually decreasing.

c. Medium Solids System

The results of continuous recycle studies made in the medium solids range are found in Figure 9. As was seen at the low solids concentration, when the contamination trap was not utilized, a diphasic removal curve was obtained. Again, with, or without, polyelectrolyte, the curves exhibited an initial phase of higher removal efficiency followed by a second phase of constant removal rate. Without coagulent aid, a removal of 28% was obtained in 50 minutes. Within this same amount of

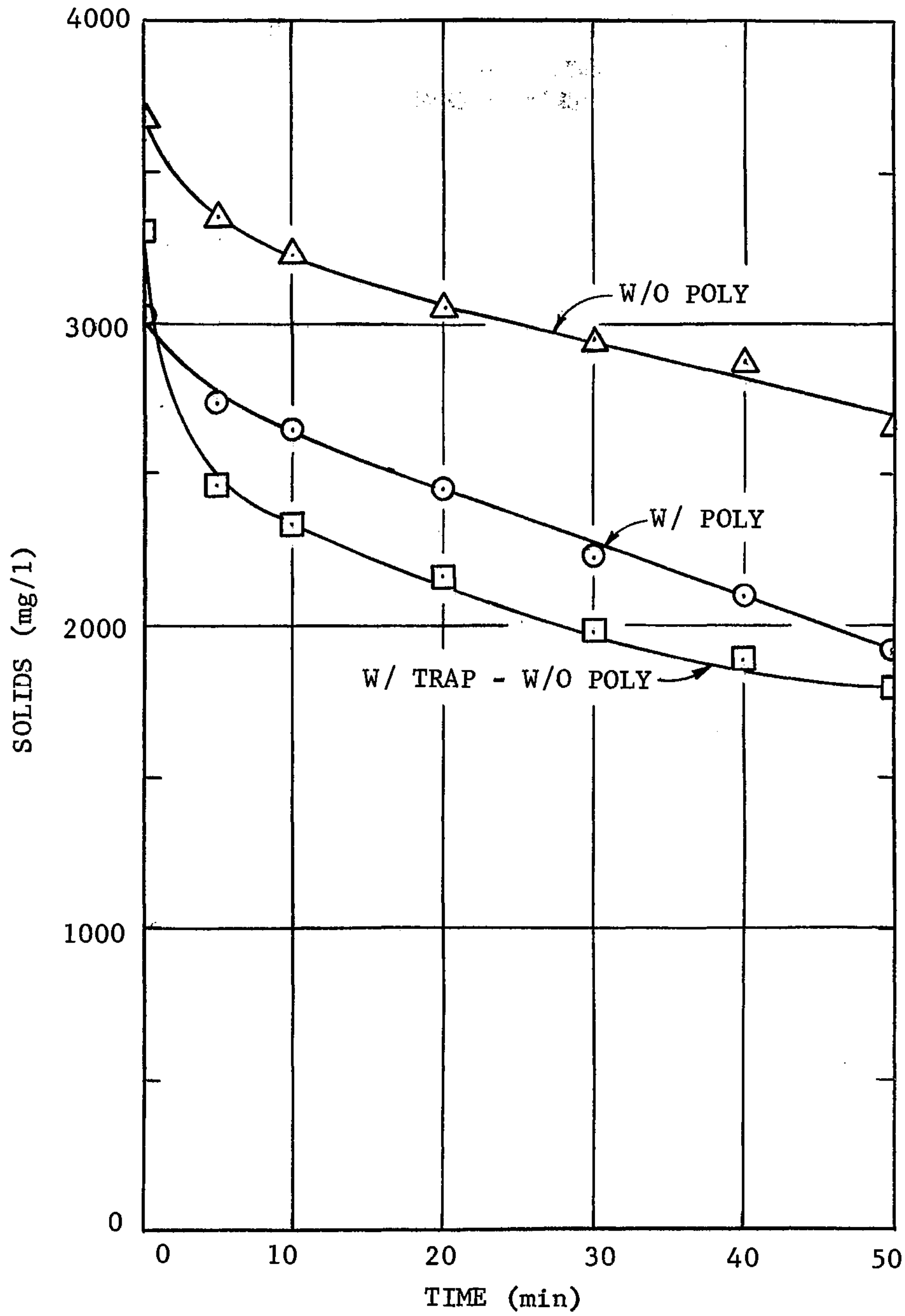


Figure 9. Continuous Recycle Studies at Medium Solids Level.

time the system, utilizing the polyelectrolyte, achieved 37% removal. It is apparent again that the constant removal rate when polyelectrolyte is used is slightly higher than that obtained without it.

The results shown for the experiment utilizing the contamination trap are somewhat different from what was obtained at the low solids level. An initial removal of only 20% was achieved in the first 5 minutes followed by continuously decreasing rates of removal. A total removal of only 45% was exhibited in 50 minutes. It was apparent from this fact and the shape of the removal curve that the contamination trap was becoming plugged and thus was affecting the removal efficiency. It was therefore decided that the multi-layered paper filters being used did not have the capacity for microbial systems in the medium and high solids ranges. For this reason, no further studies were made utilizing the contamination trap.

d. High Solids System

As seen in Figure 10, very unique data was obtained at the high solids level. When no coagulent aid was used, an initial removal of 42% occurred in 10 minutes, but after that time the suspended solids in the reservoir increased back to a value only 16% less than existed originally. The addition of 200 mg/l of polyelectrolyte produced a constant removal rate which achieved a total removal in 50 minutes of only 19%. Visual observation of the collection pot revealed a possible reason for these unique results. It was observed that without polyelectrolyte the solids which entered the underflow pot did not settle well and as the pot became filled, were forced back into the cyclone. The addition of polyelectrolyte appeared to greatly improve the settling of the solids once they had entered the underflow pot. Thus, less contamination of

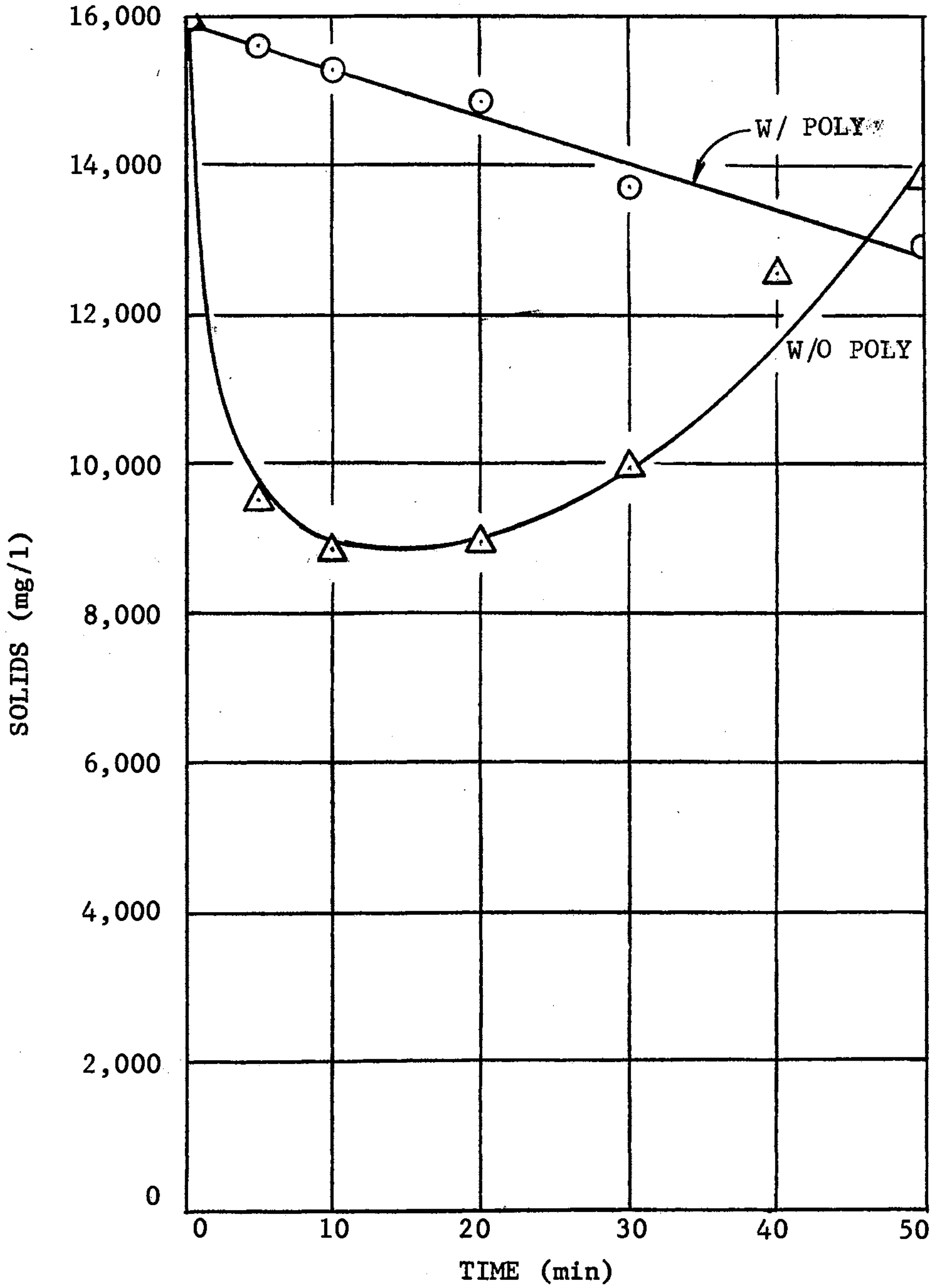


Figure 10. Continuous Recycle Studies at High Solids Level.

the effluent was observed.

3. Single Pass Studies

a. General

A number of single pass studies were made to determine the removal accomplished in each pass and to determine the separation and concentration efficiencies produced in each case. Separation efficiency was calculated by dividing the difference in concentration of the inflow and the overflow by the concentration of the inflow. Concentration efficiency was determined by dividing the difference of the underflow and inflow concentrations by the inflow concentration. It is important to note that the average underflow volume was measured to be about 16% of the inflow for the 6 gpm hydrocyclone.

b. Low Solids System

Removal curves for studies made in the low solids range are shown in Figure 11. By the results exhibited in Figure 11-A, it is safe to say that essentially no removal or concentration occurred when polyelectrolyte was not used. However, with the addition of polyelectrolyte, Figure 11-B, some removal and concentration were accomplished. The extent of this difference is shown in Figures 12-A and 12-B. These results further point to the fact that without polyelectrolyte no concentration or separation was obtained. The application of coagulent aid, however, brought about an increase in concentration efficiency to 100% and increased the separation efficiency to approximately 20% in the first pass. The concentration efficiency then dropped abruptly to 20% and remained there in the next two passes. The separation efficiency remained at approximately 20% during the second pass but then dropped to 4% in the third pass.

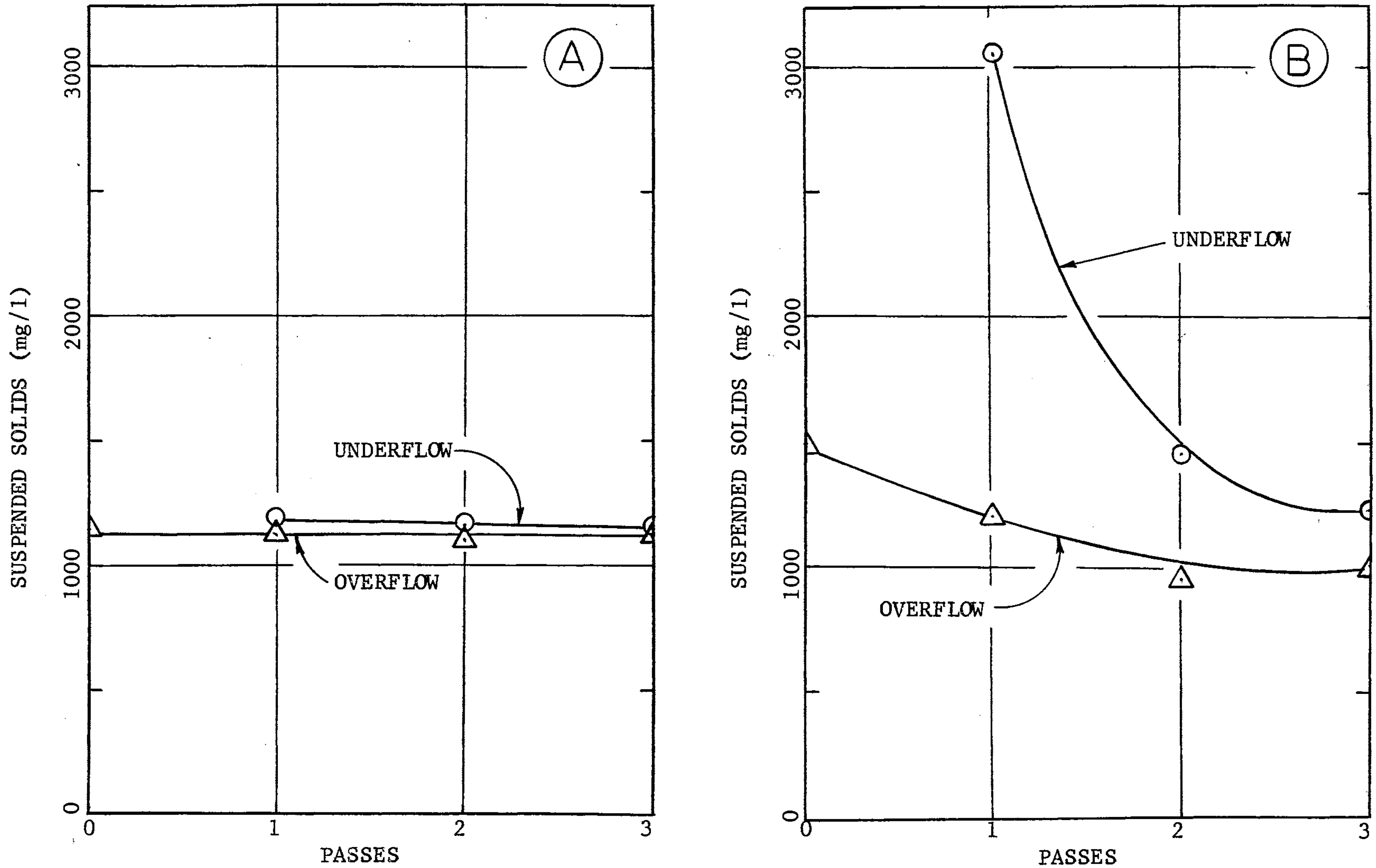


Figure 11. 6 GPM Single Pass Studies at Low Solids Level, (A) Without Polyelectrolyte, (B) With Polyelectrolyte.

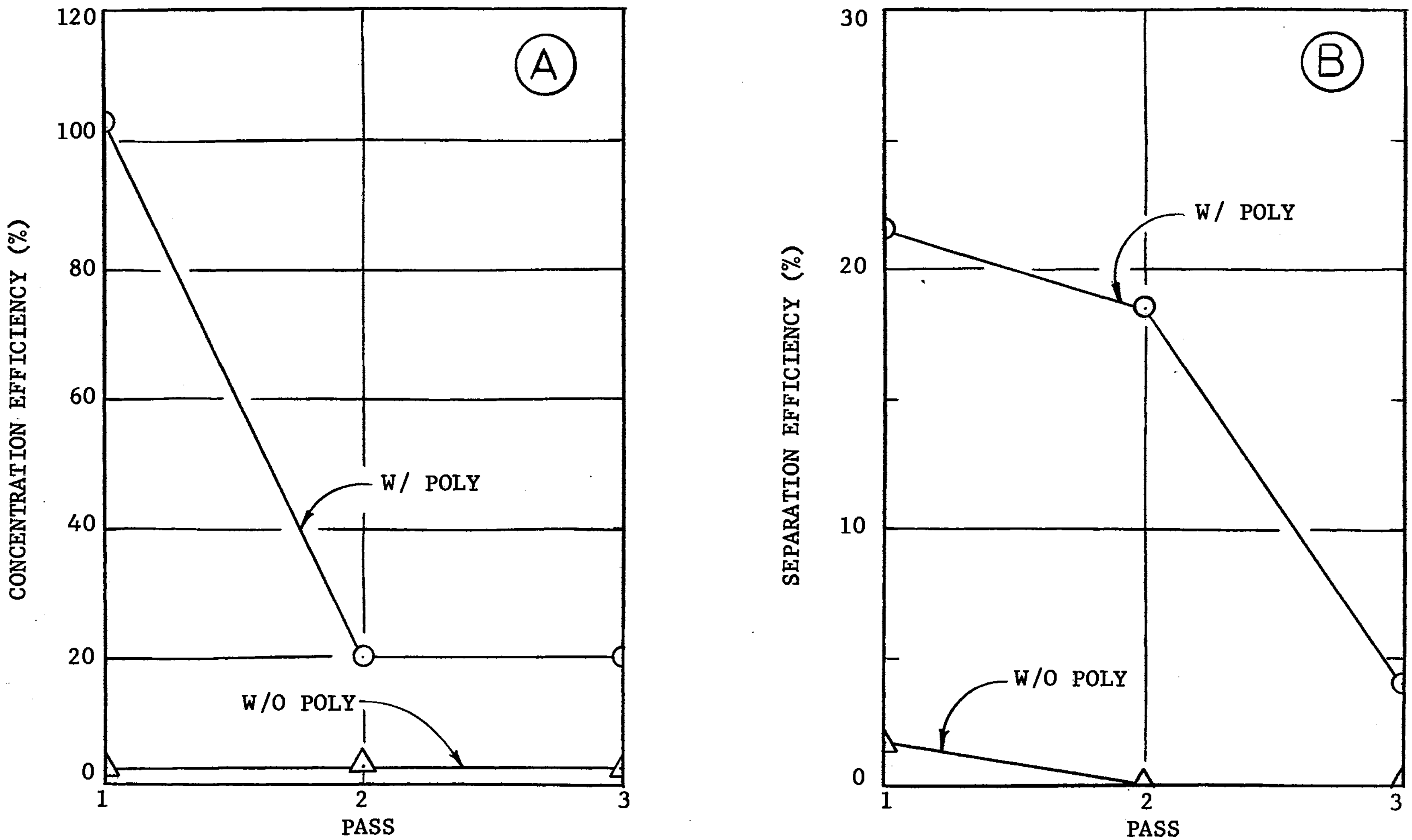


Figure 12. 6 GPM Single Pass Studies at Low Solids, (A) Concentration Efficiency, (B) Separation Efficiency.

c. Medium Solids System

Figure 13 shows the results of single pass experiments in the medium solids range. Without polyelectrolyte, Figure 13-A, very little removal was accomplished in three passes, but the underflow was concentrated somewhat. This effect was increased considerably by the addition of 50 mg/1 of C-31 polyelectrolyte, as shown in Figure 13-B. Figure 14-A depicts the effect the addition of polyelectrolyte had on the concentration efficiency. Without polyelectrolyte, the concentration efficiency was about 50% in the first pass and then decreased to 30% and 25% in the next two passes. When the coagulent aid was utilized the concentration efficiency was increased to 100% in the first pass but returned to the same values as without polyelectrolyte in the second and third passes. The separation efficiencies, Figure 14-B, behaved somewhat differently. The addition of polyelectrolyte appeared to increase the separation efficiency by about the same factor in all three passes.

d. High Solids System

Figure 15 shows the results of experiments at the high solids level. Again, it can be seen that without polyelectrolyte, Figure 15-A, very little removal or concentration occur. Figure 15-B points out once more that the addition of polyelectrolyte increases the efficiency of the operation. The concentration and separation efficiencies shown in Figures 16-A and 16-B, respectively, show that this effect is only significant in the first pass. The concentration efficiency was increased from 9% to 32% in the first pass by addition of coagulent aid. However, in the second pass very little difference was observed, and in the third pass the sludge containing polyelectrolyte did not concentrate as well as that without. The separation efficiencies followed this same trend

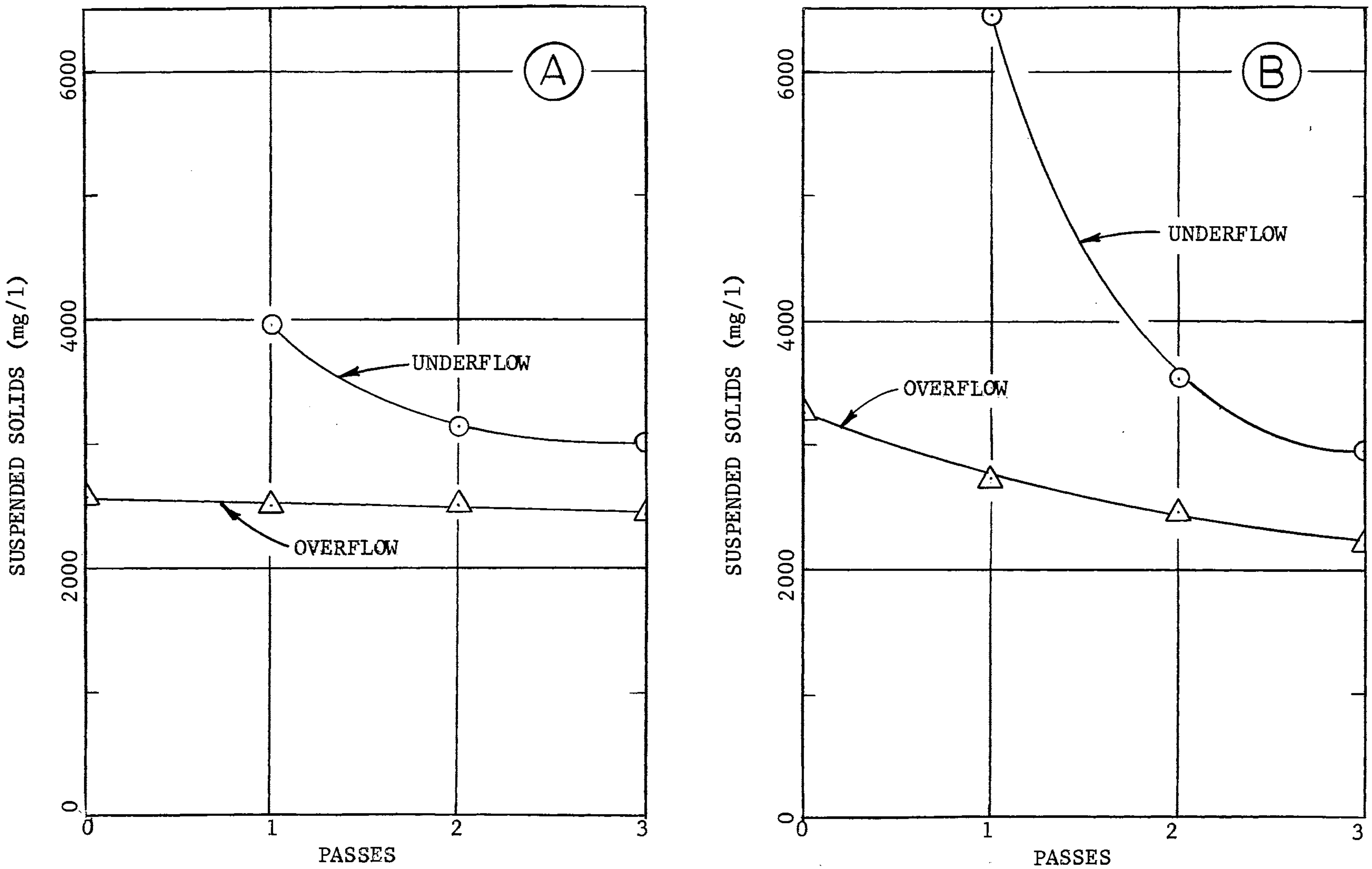


Figure 13. 6 GPM Single Pass Studies at Medium Solids Level, (A) Without Polyelectrolyte, (B) With Polyelectrolyte.

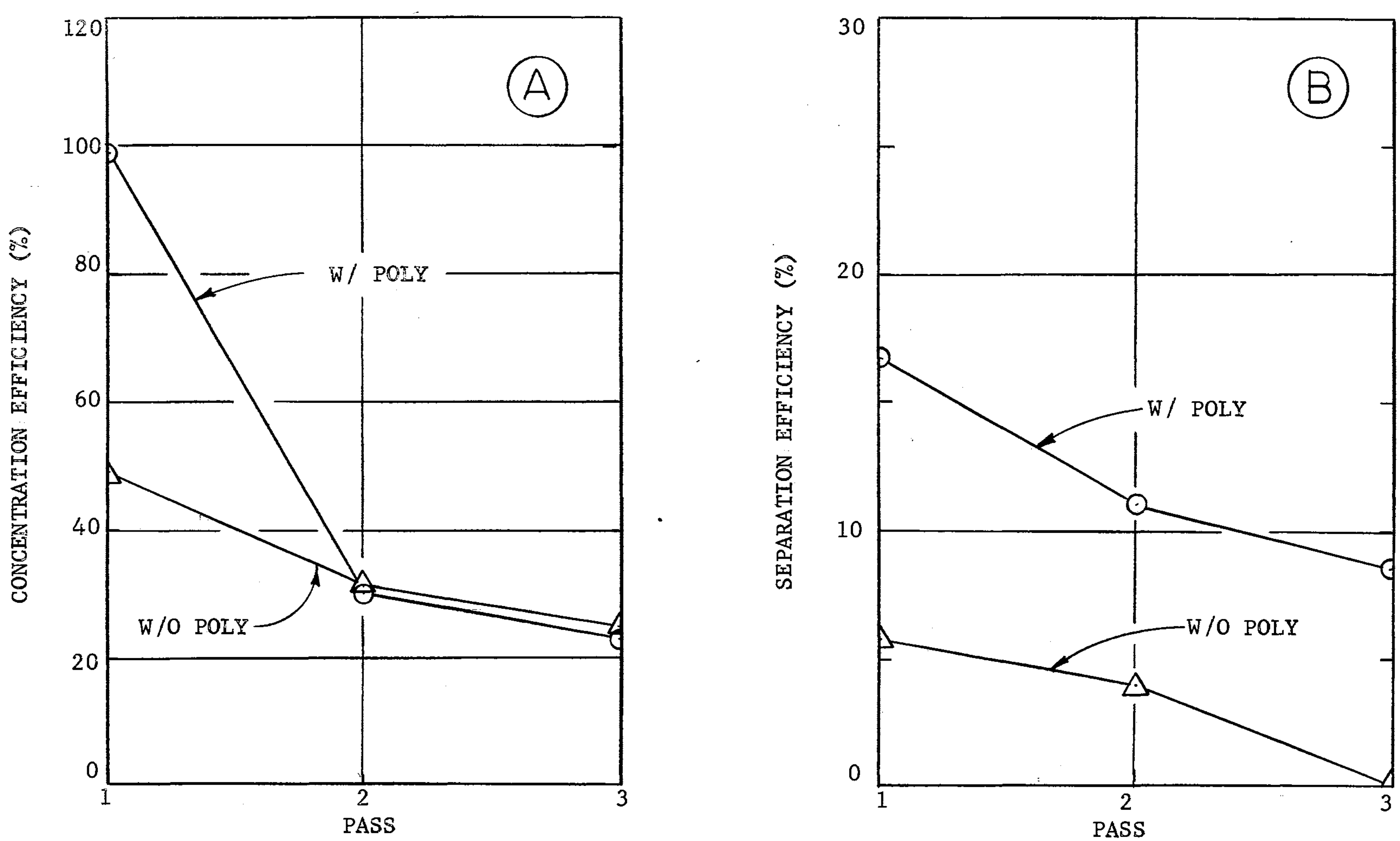


Figure 14. 6 GPM Single Pass Studies at Medium Solids, (A) Concentration Efficiency, (B) Separation Efficiency.

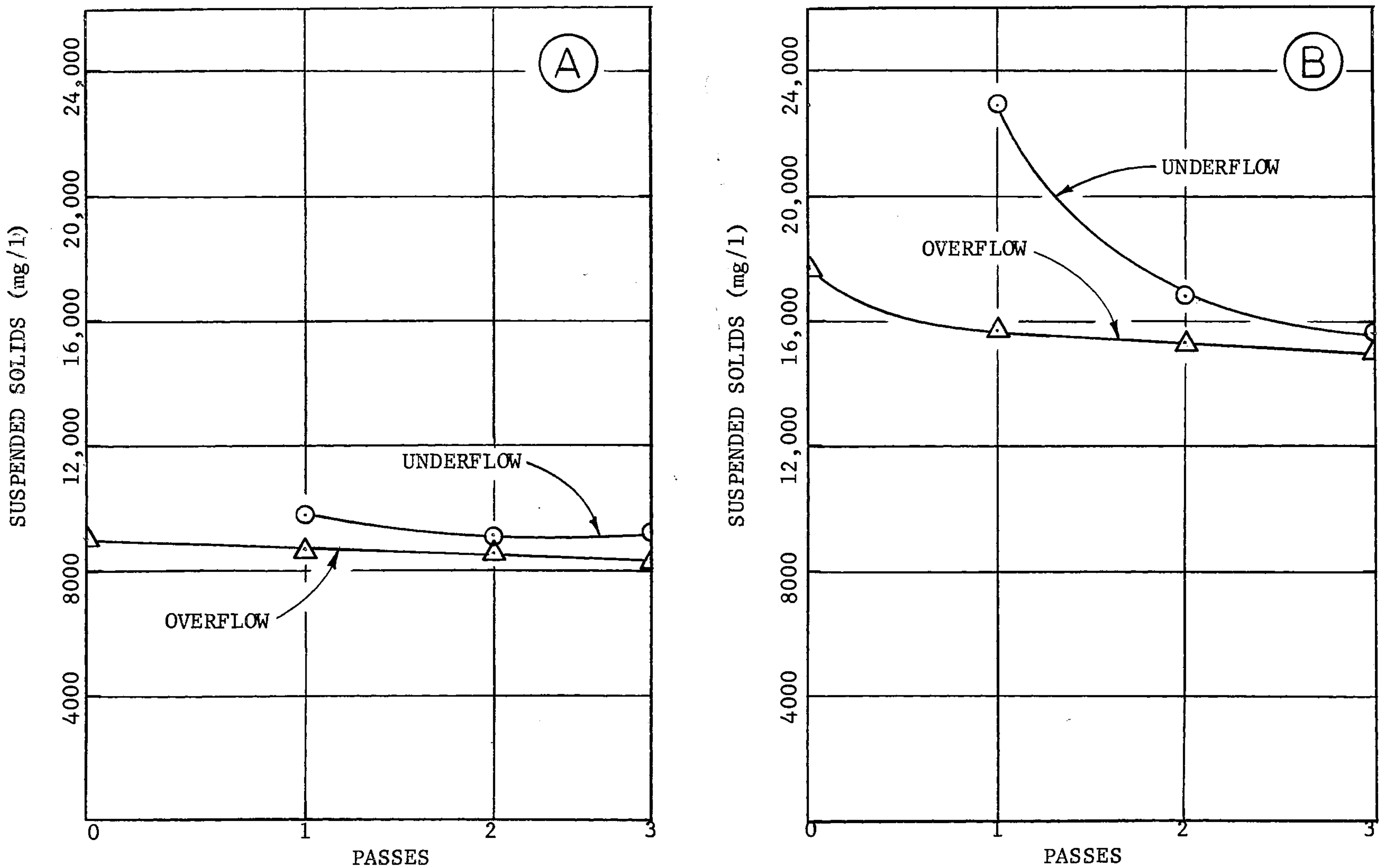


Figure 15. 6 GPM Single Pass Studies at High Solids Level, (A) Without Polyelectrolyte, (B) With Polyelectrolyte.

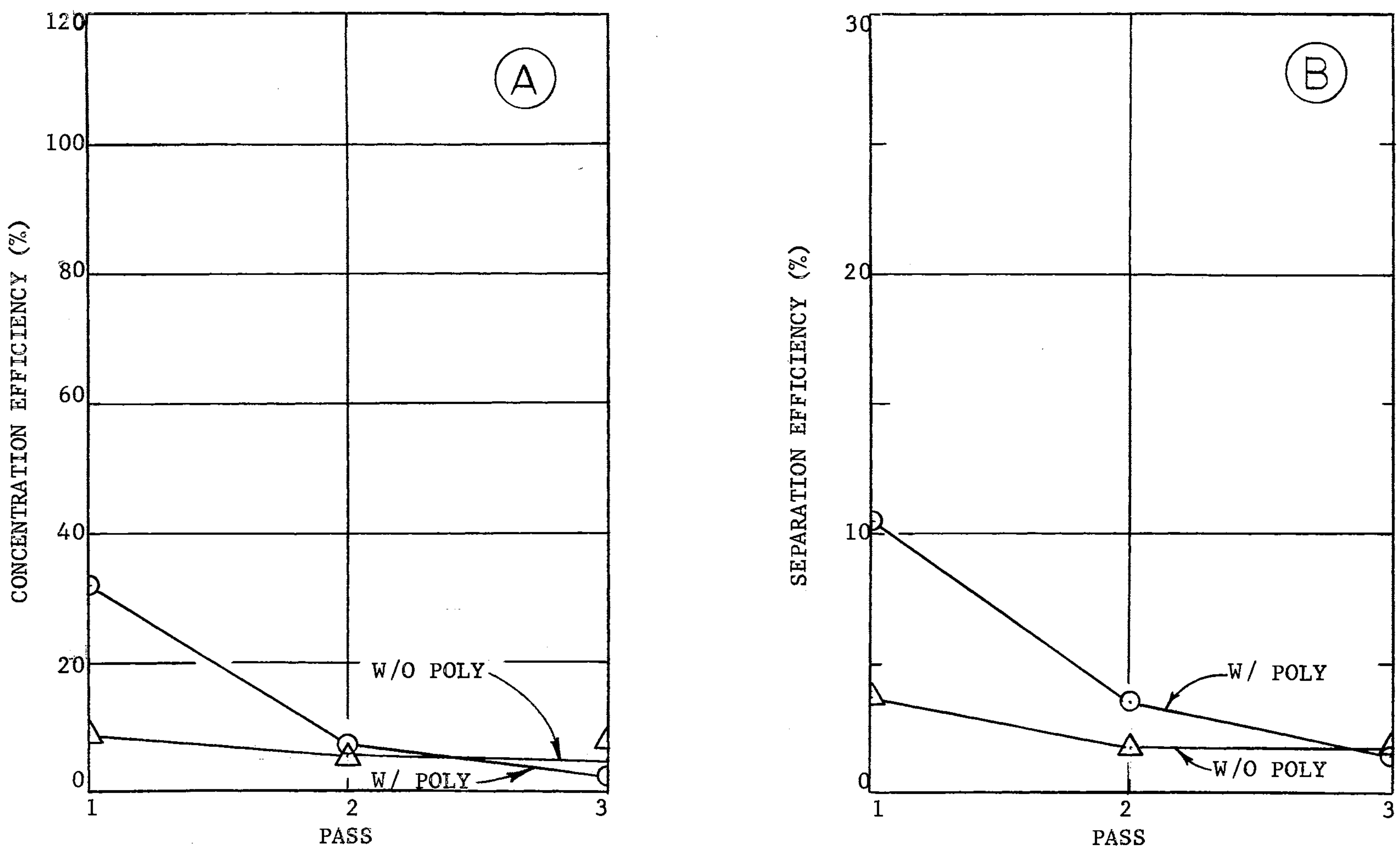


Figure 16. 6 GPM Single Pass Studies at High Solids, (A) Concentration Efficiency, (B) Separation Efficiency.

with the polyelectrolyte increasing the separation from 4% to 11% for the first pass, and then showing little or no effect in the second and third passes.

B. 2 GPM Hydrocyclone

1. General

Two studies were made using a single pass configuration with the 2 gpm hydrocyclone. The purpose of these experiments was to see if any modifications in the direction of smaller, higher pressure, cyclones might improve efficiency. The hydrocyclone was operated at 130 psi which was found to produce the design flow rate of 2 gpm. The average underflow volume for this unit was measured to be about 7% of the inflow volume.

2. Single Pass Studies

a. Low Solids System

Results of an experiment using a low solids microbial system without coagulent aid are shown in Figure 17. It is apparent that essentially no removal occurred in the effluent, yet some concentration was measured. From Figure 18-A it can be seen that the concentration efficiency dropped from 90% in the first pass to only 35% in the second pass and 25% in the third. This is compared to separation efficiencies, Figure 18-B, of only 1 or 2%. The reason for high concentration efficiencies and little or no separation is that the underflow is such a small amount of the total flow that the solids removed have little effect on the effluent concentration.

b. High Solids System

Figure 19 shows the results of an experiment made using a high solids microbial system with no coagulent aid. The figure shows that

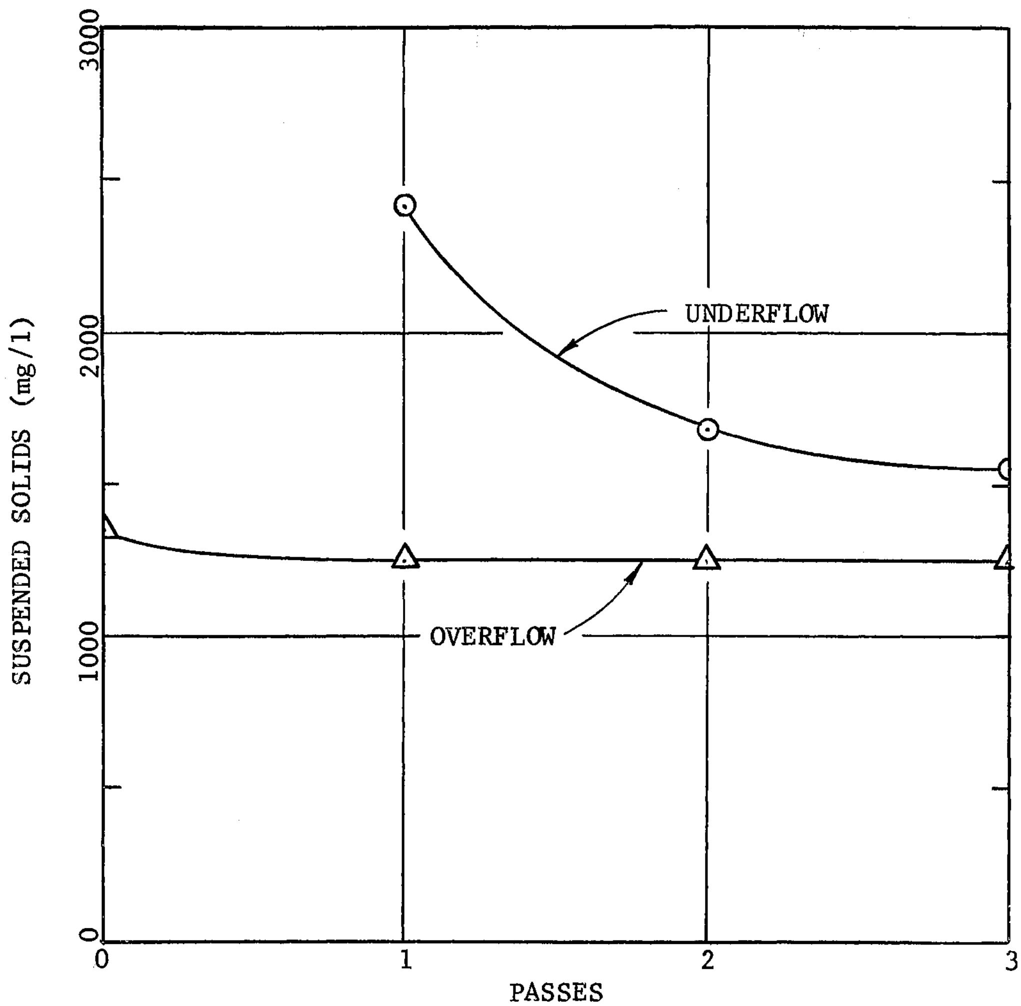


Figure 17. 2 GPM Single Pass Study at Low Solids Level Without Polyelectrolyte.

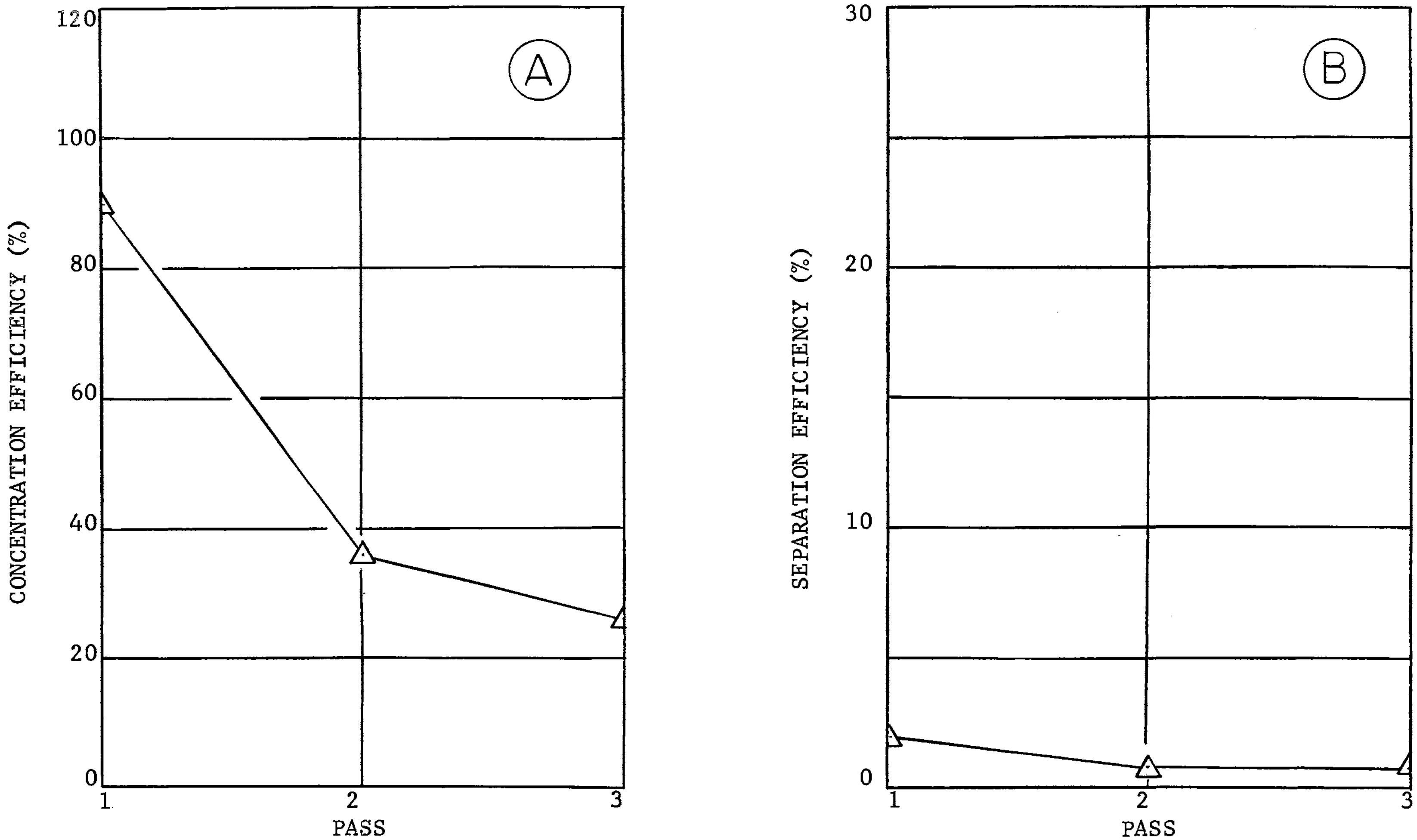


Figure 18. 2 GPM Single Pass Studies at Low Solids, (A) Concentration Efficiency, (B) Separation Efficiency.

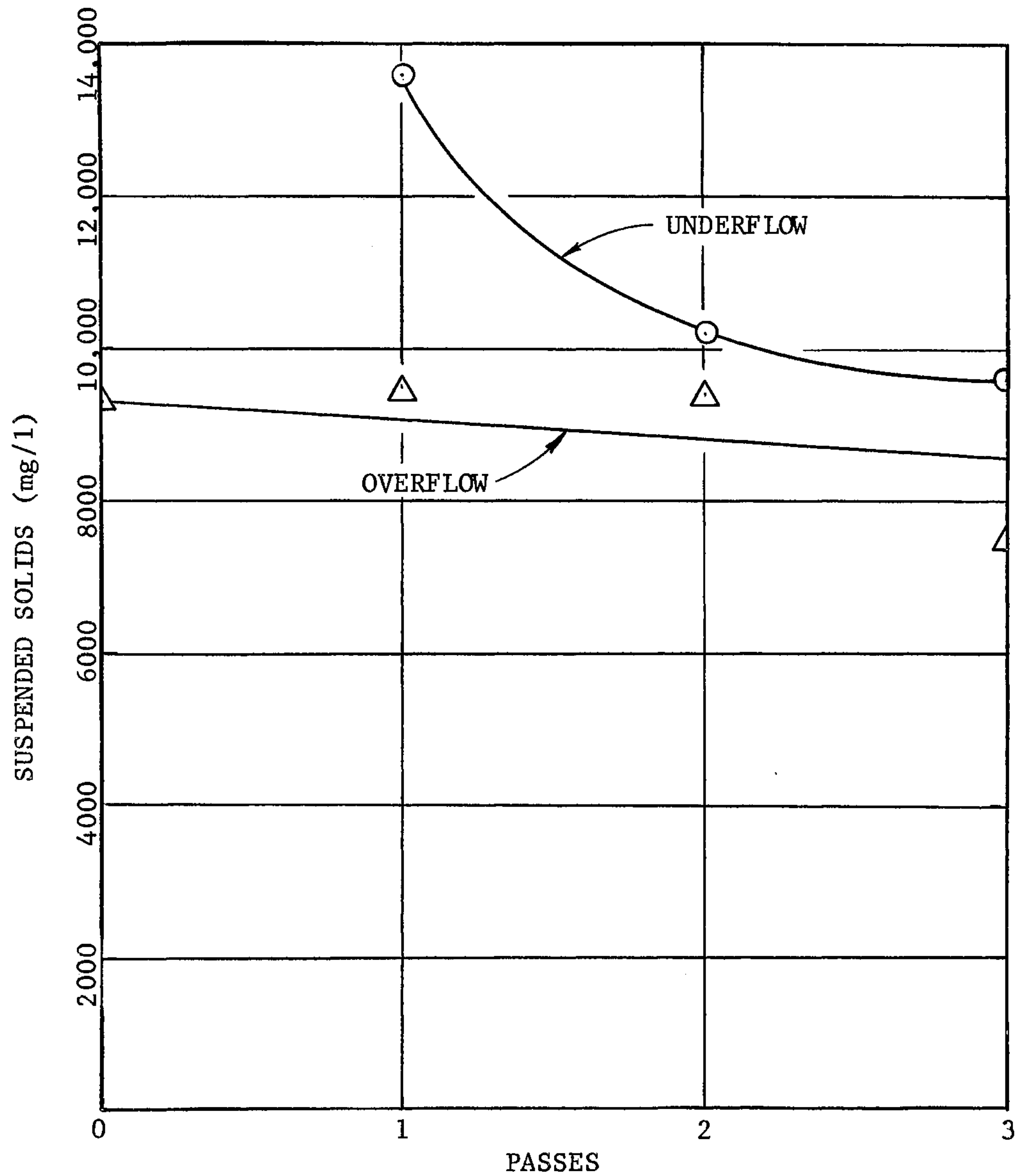


Figure 19. 2 GPM Single Pass Study at High Solids Level Without Polyelectrolyte.

again no removal was measured in the effluent, but concentration occurred in the underflow. Figure 20-A shows that a maximum concentration efficiency of 46% was obtained in the first pass. The efficiency then dropped to around 10% in the next two passes. The separation efficiency again was only 1 or 2% for all three passes as shown in Figure 20-B. The reason for this difference in concentration and separation efficiency is the same as for the low solids system -- low volume underflow.

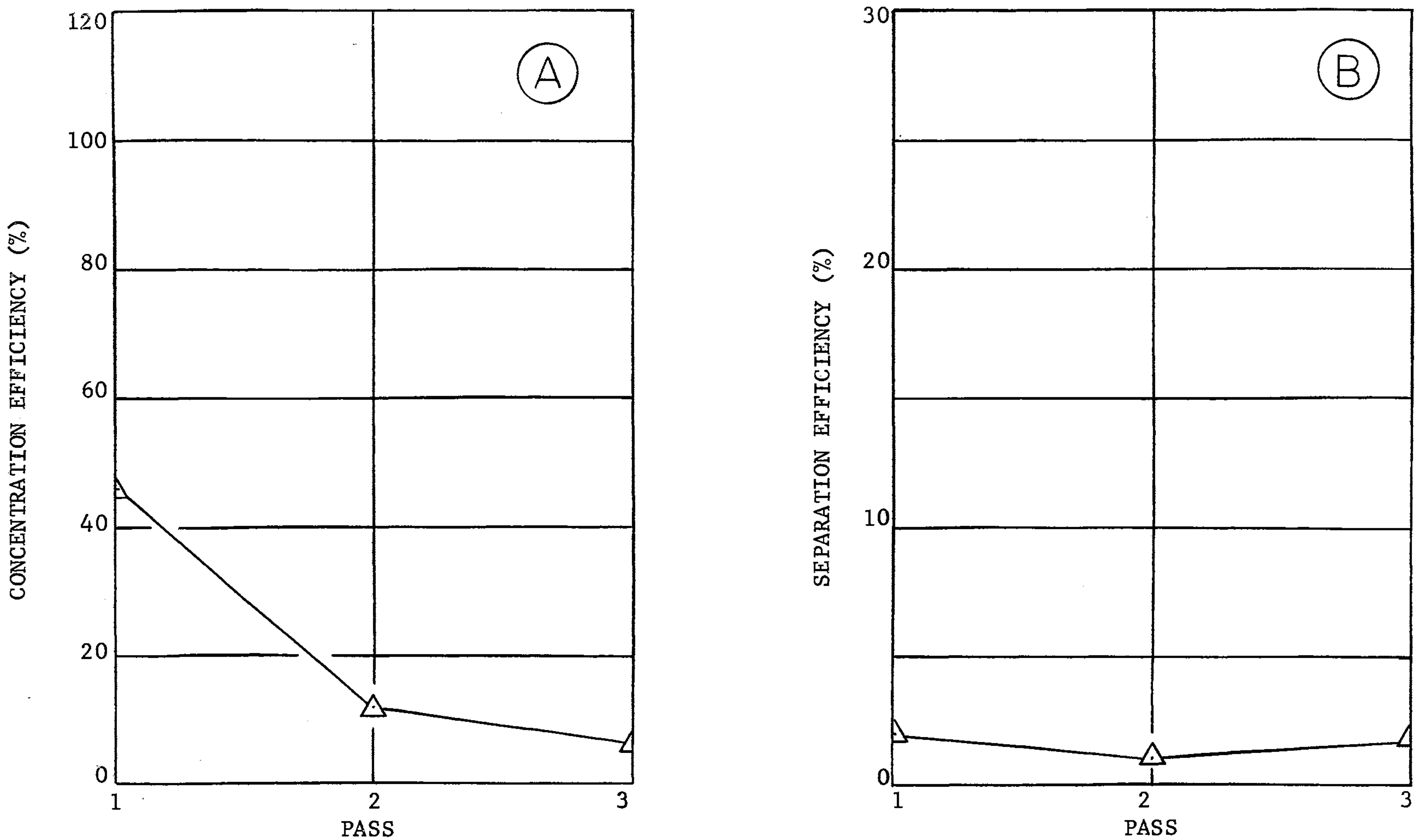


Figure 20. 2 GPM Single Pass Studies at High Solids, (A) Concentration Efficiency, (B) Separation Efficiency.

CHAPTER V

DISCUSSION

This investigation was conducted to study the feasibility of applying the hydrocyclone for separation of flocculent microbial systems. Three hydrocyclone systems were investigated and separation parameters were varied in an attempt to indicate direction for design of more efficient systems.

The most obvious result obtained is that systems utilizing the closed underflow without the contamination trap are not at all efficient for the separation of microbial suspensions. This result supports the finding of Patterson (7), who attempted to separate dispersed bacterial suspensions utilizing this same configuration. It is interesting to note, however, that for the suspensions used by Patterson, no separation was achieved. Whereas, in this study up to 37% of the suspended solids were removed by the cyclone system without the use of the contamination trap. This would lead one to believe that the older, flocculated cells are separated more easily than young, dispersed systems.

Utilization of the contamination trap in the closed underflow configuration seemed to show the most promise for the separation of microbial systems using the hydrocyclone. The effect of employing the trap in the system is very vivid in Figure 8. However, the primary problem of this type of system becomes visible in Figure 9. The problem is that the filters available at this time for use with the hydrocyclone become clogged quickly and efficiency is lost. The study of other types of filters which would have higher holding capacities and which would backwash easily might show further application of this type of system.

The open underflow configuration used in the single pass studies showed very little effect when no coagulent aid was applied. However, with the addition of polyelectrolyte separation efficiencies of up to 20% were obtained in a single pass. This is by no means good removal, but it was an improvement.

It is very important to note the effect of adding a coagulent aid to the suspension. In all cases the addition of polyelectrolyte improved the efficiency of the hydrocyclone. It is visible from the single pass studies, however, that this effect caused by the coagulent aid was only significant in the first pass. In subsequent passes the flocs evidently become so badly beaten up by the shear forces in the cyclone that coagulation becomes ineffective. This is in line with earlier works done by Leniger (8) and Fontein, et. al. (14), which pointed out the fact that high shear forces in the cyclone would prevent flocculation and consequently would prevent removal of small, light particles. The important thing to realize is that a coagulent aid can help relieve this inherent disadvantage of the hydrocyclone. The development of coagulent aids which are extremely resistant to shear would be a great break-through for this process.

In all experiments which employed the contamination trap, an improvement in removal was observed. This was most effective when a low volume of solid material was in the system. Other than the problem of filter-clogging, one other question was brought to mind. How much of the material removed was simply filtered by the trap? In other words, does the cyclone do any concentrating of what goes through the filter?

Patterson (7) presented calculations showing that concentration factors of about 2.3 to 3.0 were obtained using the same 6 gpm hydrocyclone as was used in this study. These calculations were based on the assumption that only 2% of the total flow entered the underflow collection pot. This assumption was based on experiments made by Tiederman (23) who physically measured this flow in another existing hydrocyclone of the same type. This was accomplished by employing a hot wire anamometer at the underflow of the hydrocyclone.

Single pass experiments in the current study showed that concentration factors of only 1.03, 1.50, and 1.08 were obtained when no coagulent aid was employed. Assuming these same concentration factors could be applied to closed underflow experiments, and assuming that the trap was 100% efficient, calculations were made to determine the portion of the total flow which would pass through the underflow to produce the measured efficiency. These calculations indicated underflows of 13.5%, 4.0%, and 11.7% of the total flow. These flow rate percentages disagree with the results obtained by Patterson. For this reason, it is felt that an experimental measurement of the underflow in the current hydrocyclone would be beneficial to clarify exactly how much of the flow passes through the contamination trap.

An effort was made to determine if the biological solids concentration of the sludge had any direct effect on the concentration and separation efficiencies. Figure 21 shows that the hydrocyclone seemed to be more effective for the medium solids range than for the high or low range. It is important to note that in Figure 21-B, the polyelectrolyte was much more effective at the low and medium solids levels than at the

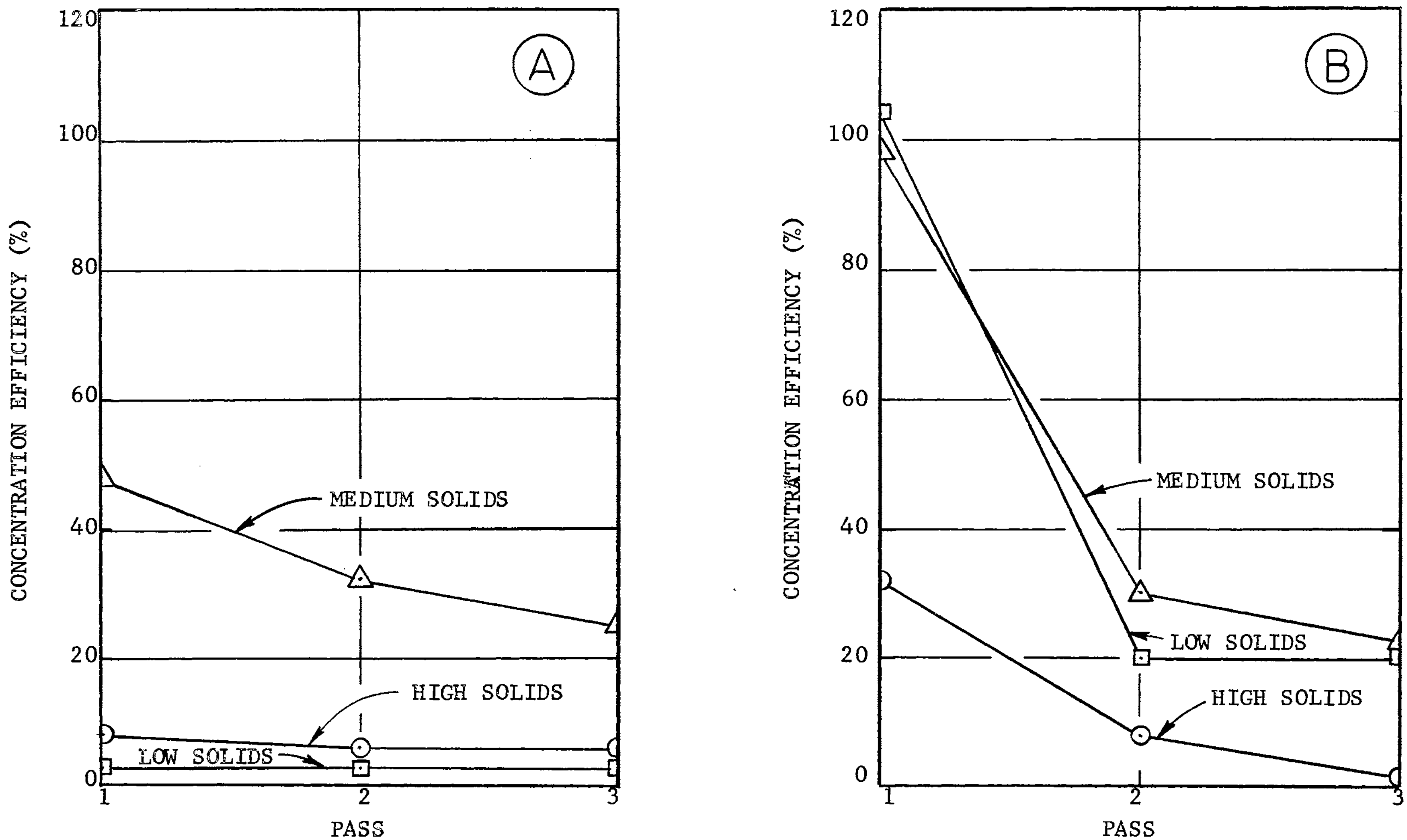


Figure 21. Concentration Efficiencies for 6 GPM Single Pass Studies, (A) Without Polyelectrolyte, (B) With Polyelectrolyte.

high level. This was expected as the jar studies made to determine the optimum dosage of coagulent aid to be used showed very little effect of polyelectrolyte on the high solids system.

The poor results obtained by the 2 gpm hydrocyclone brought about another question. Why is the 6 gpm hydrocyclone more effective than the 2 gpm unit? A possible solution to this question is that the shear forces developed in the 6 gpm hydrocyclone were lower and therefore the floc was not completely broken up to discreet particles. This belief is supported by calculations of the average shear forces developed in each cyclone. It was found that the 2 gpm hydrocyclone inlet produced shear forces more than three times higher than were produced in the 6 gpm inlet. This conclusion also helps explain why the 6 gpm hydrocyclone with trap removed the flocculent systems used in this study better than the dispersed systems used by Patterson. This is shown graphically in Figure 22. In other words, even without polyelectrolyte, some flocs were strong enough to withstand the shear in the 6 gpm hydrocyclone, and since the hydrocyclone separates larger particles more effectively than small particles, flocculation therefore played a part in the separation.

The author feels that the lack of effectiveness of the 2 gpm hydrocyclone is not due only to the size of the particles or their failure to flocculate, but also to the specific weight of the particles involved. This belief is supported by results obtained by Cobb (24) who utilized the same 2 gpm cyclone for the separation of clay colloids from water. The results of that work showed 83% removal of solids within 5 passes. The clay suspensions used contained many particles as small, or smaller than, the bacteria used in the present study. It is therefore apparent

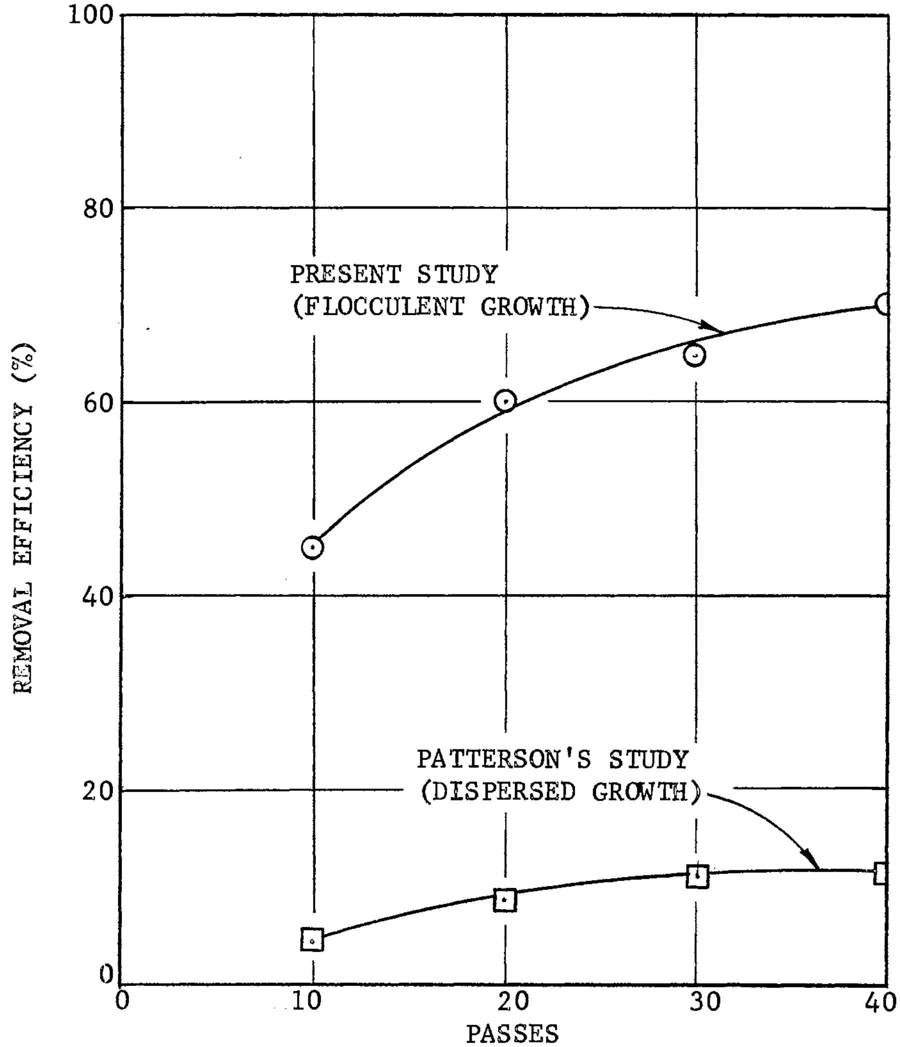


Figure 22. Comparison of Results Obtained by Patterson to Those Obtained in the Present Study for the 6 GPM Hydrocyclone with Trap.

from this study that smaller, high pressure cyclones should not be used for separation of bacterial suspensions.

This work, being a feasibility study, indicates that, for the hydrocyclone to be used efficiently for the removal of biological solids from activated sludge, two problems must first be solved. A shear resistant coagulent aid must be found, and a contamination trap, which has a high holding capacity and can be backwashed easily, must be developed.

CHAPTER VI

CONCLUSIONS

The results of this study support the following conclusions:

(1) The closed underflow hydrocyclone configuration without the contamination trap is not an efficient separator for microbial suspensions.

(2) Some promise is shown for the application of the closed underflow configuration when the contamination trap is employed. This promise depends upon the development of a more practical filter apparatus.

(3) The open underflow configuration has only limited application for the separation of microbial systems.

(4) Coagulent aids, such as polyelectrolytes, are effective in improving hydrocyclone efficiency for removal of biological solids.

(5) Hydrocyclones which produce high shear forces are not practical for the separation of flocculent microbial systems.

CHAPTER VII

SUGGESTIONS FOR FUTURE STUDY

Based on the findings of this study, the following suggestions are made for future study of the application of the hydrocyclone for separation of microbial systems:

(1) Development and investigation of better contamination traps.

(2) Development and investigation of shear resistant coagulent aids.

(3) Simultaneous study of the effect of all hydrocyclone variables on removal.

(4) Physical measurement of the amount of fluid which enters the underflow of the hydrocyclone and passes back through the contamination trap.

SELECTED BIBLIOGRAPHY

(1) Hansen, S. P., Culp, G. L., and Stukenburg, J. R., "Practical Application of Idealized Sedimentation Theory in Wastewater Treatment." Jour. Water Pollution Control Federation, 41, 8, 1421-1443 (1969).

(2) Rietema, K., and Verver, C. G., ed., Cyclones in Industry, Elsevier Publishing Co., (Netherlands, 1961).

(3) Pipes, W. O., "Types of Activated Sludge which Separate Poorly." Jour. Water Pollution Control Federation, 41, 5, 714-723 (1969).

(4) Dick, R. I., "Role of Activated Sludge Final Settling Tanks." Jour. San. Engr. Div., ASCE, 96, SA2, 423-436 (1970).

(5) Greely, S. A., "The Development of the Activated Sludge Method of Sewage Treatment." Sewage Works Journal, 17, 6, 1135 (November 1945).

(6) Ford, D. L., and Eckenfelder, W. W., "Effect of Process Variables on Sludge Floc Formation and Settling Characteristics." Jour. Water Pollution Control Federation, 39, 1850-1859 (1967).

(7) Patterson, K. E., "The Primary Application of the Hydrocyclone for the Separation of Biological Solids from Dispersed Bacterial Systems." Unpublished Master's Thesis, Oklahoma State University, Stillwater, Oklahoma (1971).

(8) Leniger, H. A., "General Remarks on Phase Separations and Classification." Cyclones In Industry, Ed. by Rietema and Verver, Elsevier Publishing Co., (Netherlands, 1961).

(9) Woldman, M. L., "Effects of Selected Organic Polyelectrolytes on Biological Systems." Unpublished Master's Thesis, Oklahoma State University, Stillwater, Oklahoma (1967).

(10) Walker, J. F. H., and Dougherty, J. H., "Use of Polyelectrolyte to Enhance Settling Characteristics of Activated Sludge." Proceedings of the 20th Industrial Waste Conference, Purdue University, Engr. Ext. Ser. 118, 715-723 (1965).

(11) Ries, K. M., "Application of Polymers in Existing Municipal Sewage Treatment Plants." Water and Sewage Works, 115, R195-R197 (1968).

(12) Mizrahi, J., "Separation Mechanisms in Dilute-Pulp Hydrocyclone Classifiers." British Chemical Engineering, 10, 10, 686-692 (1965).

(13) Kelsall, D. F., "A Further Study of the Hydraulic Cyclone." Chemical Engineering Science, 2, 6, 254-272 (1953).

(14) Fontein, F. J., VanKooy, J. G., and Leniger, H. A., "The Influence of Some Variables upon Hydrocyclone Performance." British Chemical Engineering, 7, 6, 410-421 (1962).

(15) Fitch, E. B. and Johnson, E. C., "Controlling Separation in Liquid-Solid Cyclones." Chemical Engineering, 59, 6, 172-173 (1952).

(16) Pilgrim, R. F., and Ingraham, T. R., "Resolution of the Operating Variables of a Small Hydrocyclone." Canadian Journal of Chemical Engineering, 40, 169-172 (1962).

(17) Water Pollution Research 1963, Department of Scientific and Industrial Research, H. M. Stat. Office, London, 1964, 71-73.

(18) Silin, P. I., "The Use of Hydrocyclones for Clarification of Flume Wash-Waters." Sugar Industry (Moscow), 9, 33-35 (1962). Abstracted in Water Pollution Abstracts, 36, 2072.

(19) Hollo, J., Toth, J., and Blum, A., "Clarification of Flume Wash-Waters in the Sugar Industry by Means of Hydrocyclones." Rep. Sugar Beet Conf. Prague, 2, 1051-1063 (1955). Abstracted in Water Pollution Abstracts, 32, 699.

(20) Rankin, R. S., "Replacing Conventional Grit Chambers." Public Works, 90, 1, 68-72 (1959).

(21) Maciula, L. A., and Reed, R. E., Assignors to Oklahoma State University, Stillwater, Oklahoma, Patent 3,529,724.

(22) Standard Methods for the Examination of Water and Wastewater, 12th Ed., APHA, (New York, 1965).

(23) Tiederman, W. G., Personal Contact, October 14, 1970.

(24) Cobb, T. J., "A Study of Hydrocyclone Separation in Water Clarification." Unpublished Master's Thesis, Oklahoma State University, Stillwater, Oklahoma, (1971).

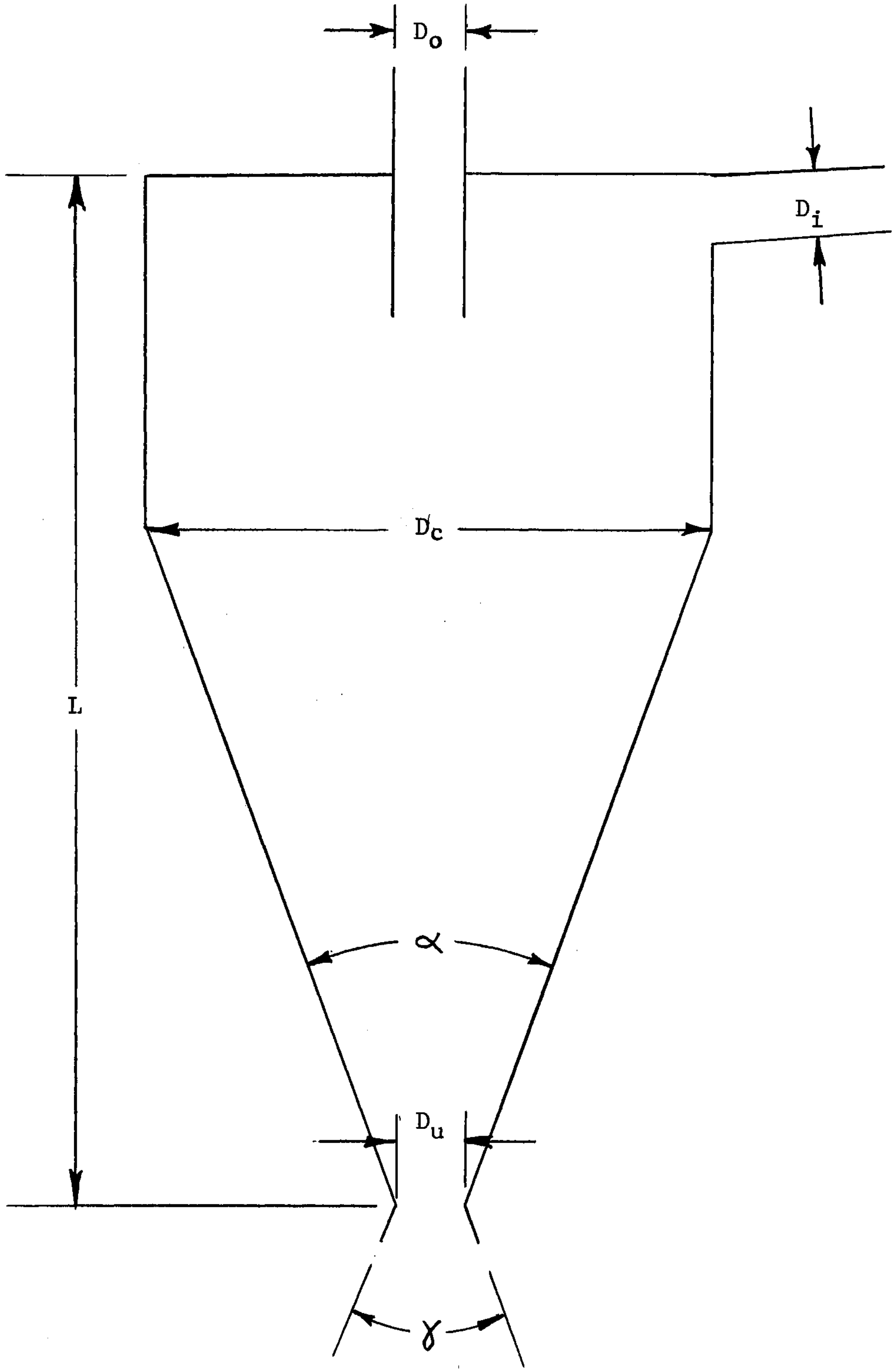


Figure 23. Hydrocyclone Without Contamination Trap

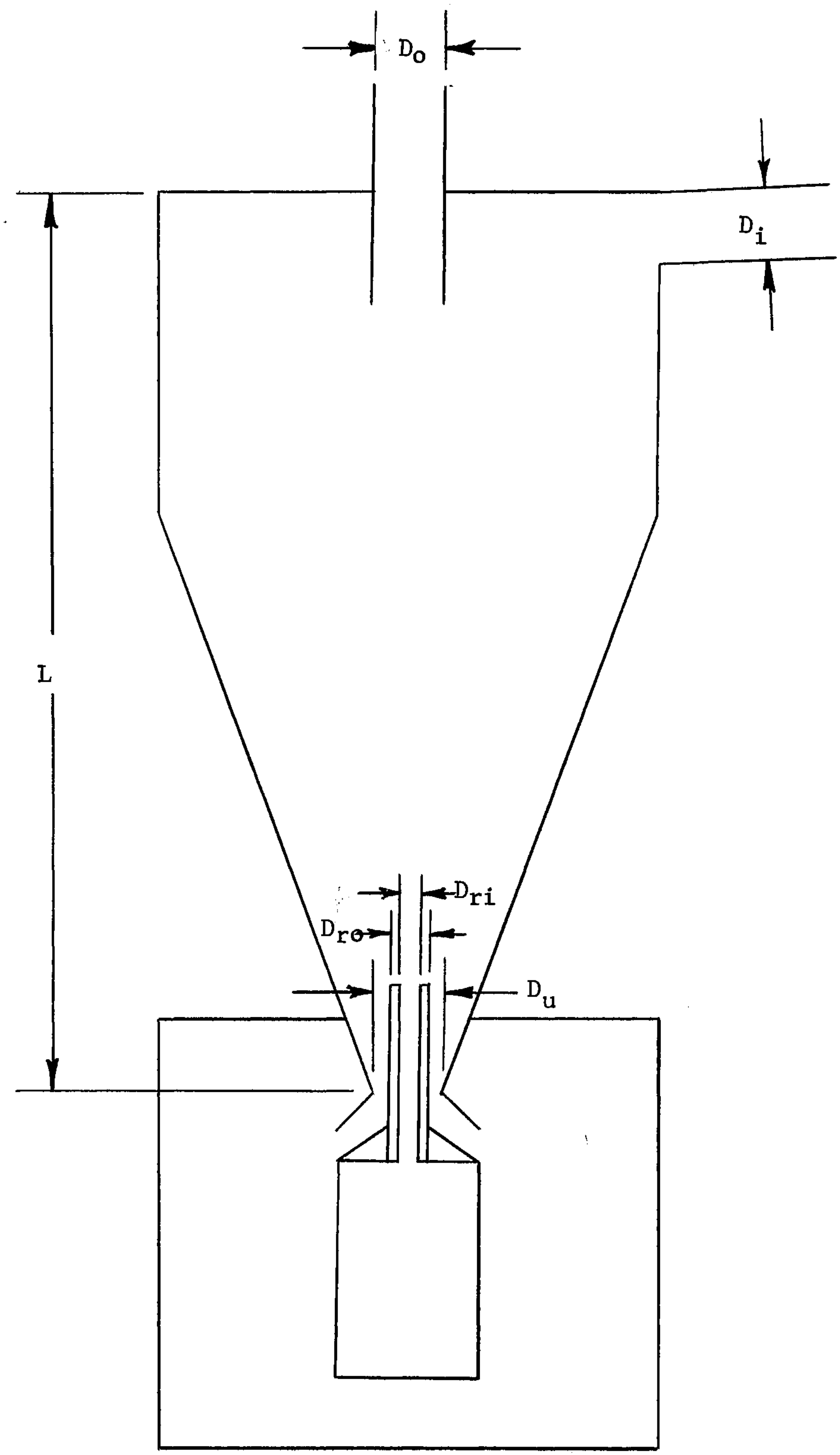


Figure 24. Hydrocyclone With Contamination Trap

CRITICAL FLOW DIMENSIONS OF THE HYDROCYCLONES

Parameter	6 GPM Hydrocyclone Without Contamination Trap	6 GPM Hydrocyclone With Contamination Trap	2 GPM Hydrocyclone Without Contamination Trap
D_c	2.460	2.460	1.000
D_i	0.215	0.215	0.114
D_o	0.375	0.375	0.138
D_u	0.172	0.308	0.061
α	20^o	20^o	20^o
γ	34^o	34^o	- -
L	11.720	11.150	6.000
D_{ri}	- -	0.153	- -
D_{ro}	- -	0.216	- -
L_r	- -	1.500	- -

Values are given in inches, (α and γ in degrees).

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