APPLICATION AND DEVELOPMENT OF HYDROCYCLONES FOR CLARIFICATION IN SYNTHETIC KITCHEN WASTE WATER TREATMENT

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CHAPTER I

INTRODUCTION

It is well recognized that solids-liquid separation is one of the major problems in waste water treatment. Most waste water treatment systems depend heavily on solids-liquid separation by gravity sedimentation. This system proves very inefficient at the best. When considering mobile waste treatment facilities, one major disadvantage is that gravity clarification takes a great deal of space. The hydrocyclone has been proven as an effective separator for other systems and could prove to be an effective separator for waste waters. It offers several advantages. It is compact and has no moving parts. Therefore it would have a low space requirement and would be simple to operate.

This study was conducted to determine the feasibility of using a hydrocyclone for the solids-liquid separation of army kitchen wastes. The hydrocyclones were designed by reserachers from the School of Mechanical and Aerospace Engineering, Oklahoma State University. Nine different designs were tested. Eight of these were a first generation design and the last unit tested was a design based upon the results of the testing of the first eight.

CHAPTER II

LITERATURE RESEARCH

A. Hydrocyclone

The most widely used method for separation of solids from liquids is gravity sedimentation. Problems associated with gravity separation gave rise to investigations towards other methods. Hirsch (1) reported that various hydraulic phenomena would produce undesirable settling conditions. Tube Settling (2) (3) techniques are the more recent attempts to incorporate shallow depth settling principles to improve sedimentation basin performance. Due to the shallow depth of the tubes the detention time is reduced with improved performance. One advantage of the tube settling is that the sludge is automatically withdrawn, but a disadvantage which occurs at the same time, is that diluted sludge is withdrawn from the tank (4). The hydrocyclone is the other method widely investigated. Cobb (5) reported that the closed pot configuration without contamination trap is not feasible, and that the closed pot with contamination trap and the open underflow configuration shows considerable promise in water treatment. The medium used by Cobb were Kaolinite, Permian Red Clay, and Roger Mills Gray Clay in water.

Patterson (6) concluded that the hydrocyclones tested has limited ability to separate the biological solids from a dispersed bacterial system. Hunt (7) also concluded that the closed underflow with contamination trap was found to offer some promise for use in sewage treatment. The other conclusion from the Bioenvironmental Engineering laboratory at Oklahoma State University is that a very shear resistant coagulant aid must be found and a more practical contamination trap must be developed. Kelsall (8) had a thorough discussion on hydrocyclone's performance in relation to design variables such as: feed pressure, feed diameter, shape of feed openings, overflow diameter, votex finder length, underflow diameter. He concluded that hydrocyclones with a feed diameter of 1/4" to 5/16" is optimum for a 3" diameter hydrocyclone. He hepothetically assumed that at this critical feed diameter the average velocity of entry and the tangential velocity are apporximately equal. Fontein VanKooy and Leniger (9) stated that among many design variables Reynold's number is the most important. They reported that a maximum efficiency occur at the optimum Reynold's number for each single set of configurations. Designing the critical flow dimensions corresponding to the optimum Reynold's number was suggested. Piligrim (10) developed a relationship among the pressure drop, the throughput of the hydrocyclone, the density, and the viscosity for a hydrocyclone of fixed geometry and opening sizes by application of dimensional analysis with the assumption that a simple power relationship exists between the variables. Fitch and Johnson (11) reported that the significant variables in determining the separation efficiency are the size of the feed entrance, votex finder, major diameter of the cone, specific gravity of feed solids, quantity and size distribution of feed solids, pressure drop and plasticity of feed. They concluded that the smaller the cyclones the finer the separation, increasing coarseness of the solids increases the separation, increasing pressure gives finer separation, and the higher the percent solids in the underflow the sharper the separation.

B. Filtration

Bele (12) in his studies of diatomite and sand filtration reported that water produced by the diatomite filtration process had a more acceptable clarity and consistently met bacteriological standards with no more than a 0.2 mg/l chlorine residual. The filters were operated in a range of 0.5 to 3 gpm/sqft. He concluded that a decrease in the filtration rate brought about a substantial increase in the throughput per cycle. This resulted in a decrease in filter aid costs, but an increase in capital investment cost. Camp (13) developed a theory of water filtration. He reported that an increase in Reynold's number with decrease in porosity during filtration and that for effective and economical filtration the pretreatment must produce floc particles that are samll enough to penetrate into the bed, and that the rate of increase in head loss is greatest at the end of filter runs. Hudson (14) stated that the desired rate of filtration requires consideration of the desired effluent quality, the character of applied water, the size of the sand to be used, the depth of the filter bed, and the condition of the filter bed. He developed an expression for floc strength index which is hd^3/L. Where h is headloss and L is bed thickness and d is the effective size of the bed particles. A high index is associated with low penetration of floc and vice versa. For diatomaceous earth filtration studies he found that the specific permeability, which was defined as gpm/sqft/ft loss of head, was decreased with time. With increases of head loss with time there were decreases in the total volume of output observed. He stated that indiscriminate adoption of filtration rates above 2 gpm/sqft should not be encouraged. Fraser (15) discussed that in order to prevent rapid clogging, smaller quantities of diatomaceous earth in the form of slurry are introduced into the raw water as filtration takes place. He concluded that the density of the slurry depends entirely on the conditions of the raw water, and head losses exceeding 30 psi are subject to failure. He reported that an installation of 4 diatomaceous earth filters with total filtering area of 612 sqft followed by chlorination produced an acceptable effluent at the 1.75 MGD intermittant water supply plant at Tupper lake N. Y..

The quantity of diatomaceous earth used was 560 lbs/MG, and the quantity used as precoat was 2 oz/sqft of area of the filter elements. Baylis (16) discussed that the filtration rate does not have to be maintained at or near 2 gpm/sqft, since the length of filter run is almost inversely proportional to the filtration rate. From his experiments, filters operated at 4 gpm/sqft may be maintained in service 97,9 percent of the time, provided the filters are washed and returned to service with reasonable speed. He found that the turbidity of water filtered at rates of 4-5 gpm/sqft is not measurably greater than that of water filtered at 2 gpm/sqft rate and that the bacteria removal efficiency of filters operated at 5 gpm/sqft is equal to that of filters operated at 2 gpm/sqft. High rate filters should be introduced only when there is evidence that such rates will not decrease plant efficiency. He also reported that the filter performance which is defined as the volume of water filtered per ft of increase in loss of head, is greater for the high rate filters than for the 2 gpm/sqft filters. Diaper and Ives (17) reported that the principle of graded filtration utilizing anthracite, sand and garnet sand can be applied in downflow filtration. The system was operated successfully giving the expected improved results compared with a normal rapid-sand filter. This three layer filter retained its proper stratification after backwashing on several occassions.

CHAPTER III

MATERIALS AND METHODS

A. Hydrocyclone Systems

1. General

The hydrocyclones used in this study were 4 gallon per minute units of nine configurations. Eight of which were the first generation, while the last configuration unit 10 belongs to the second generation. They were all designed and constructed by the School of Mechanical and Aerospace Engineering at Oklahoma State University. The critical flow dimensions and pressure drops at operation for the nine hydrocyclones used in this study are given in chapter IV.

The pump used in this study was a roller type with a bypass system driven by a 1 horsepower, 220 volt a.c. motor. A valve was placed at the bottom of the collection pot to regulate the underflow and facilitate sampling procedure.

2. Single Pass System

Single pass studies were made using each hydrocyclone design. Ten gallons of waste were passed through the cyclones. For each test on the nine designs the underflow rate Q_u was kept at 5 percent of the inflow, which is 0.2

gallon per minute. Two runs were made on each unit of both the first and second generation designs. The single pass system is shown in Figure 1. It consists of an inflow reservoir which has two baffles installed at the periphery to assure horizontal and vertical mixing, the hydrocyclone, an underflow reservoir to collect the concentrated waste, and an overflow reservoir to collect the clarified fluid. Samples were collected at the inflow and overflow reservoir, Suspended solids are determined from samples collected.

Five single passes were made on the most efficient unit of the first generation design which is unit 9, and the second generation design unit 10. This was conducted by transferring the effluent in the overflow reservoir resulting from previous passes to the inflow reservoir. The underflow was wasted for each pass made.

Suspended solids were determined on samples drawn from the inflow and overflow reservoir for each passes.

3. Continuous Recycle System

Studies were made on the effect of continuous recycle of the synthetic kitchen waste through the hydrocyclone. The system included a contamination trap. In these studies two types of contamination trap were used. They were a diatomaceous earth filter and a rapid sand filter.

The system (Figure 2) consists of a reservoir which will hold the inflow as well as the recycled return flow, the contamination trap which keeps suspended solids from

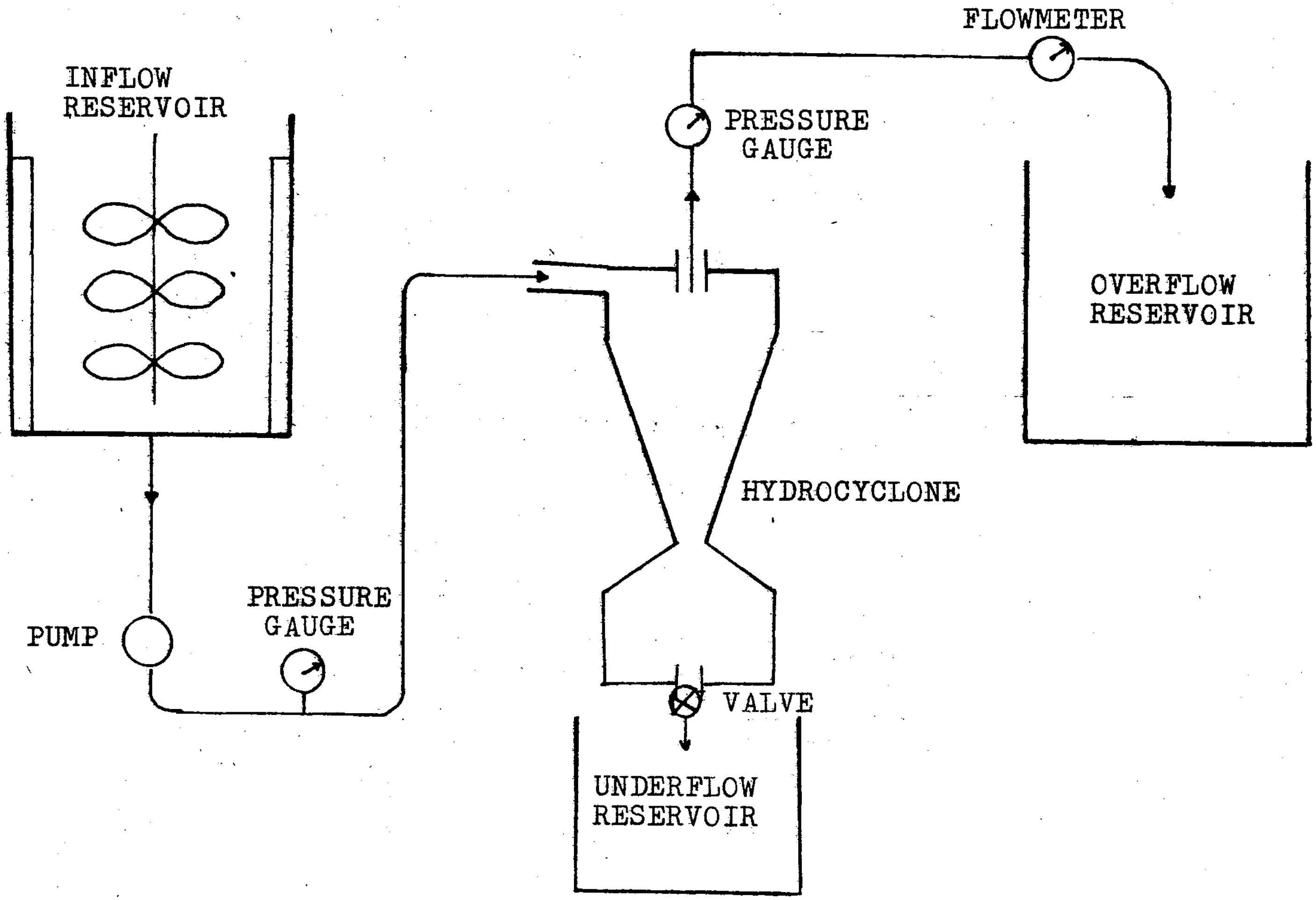

Figure 1. Open Underflow System for Single Pass Studies

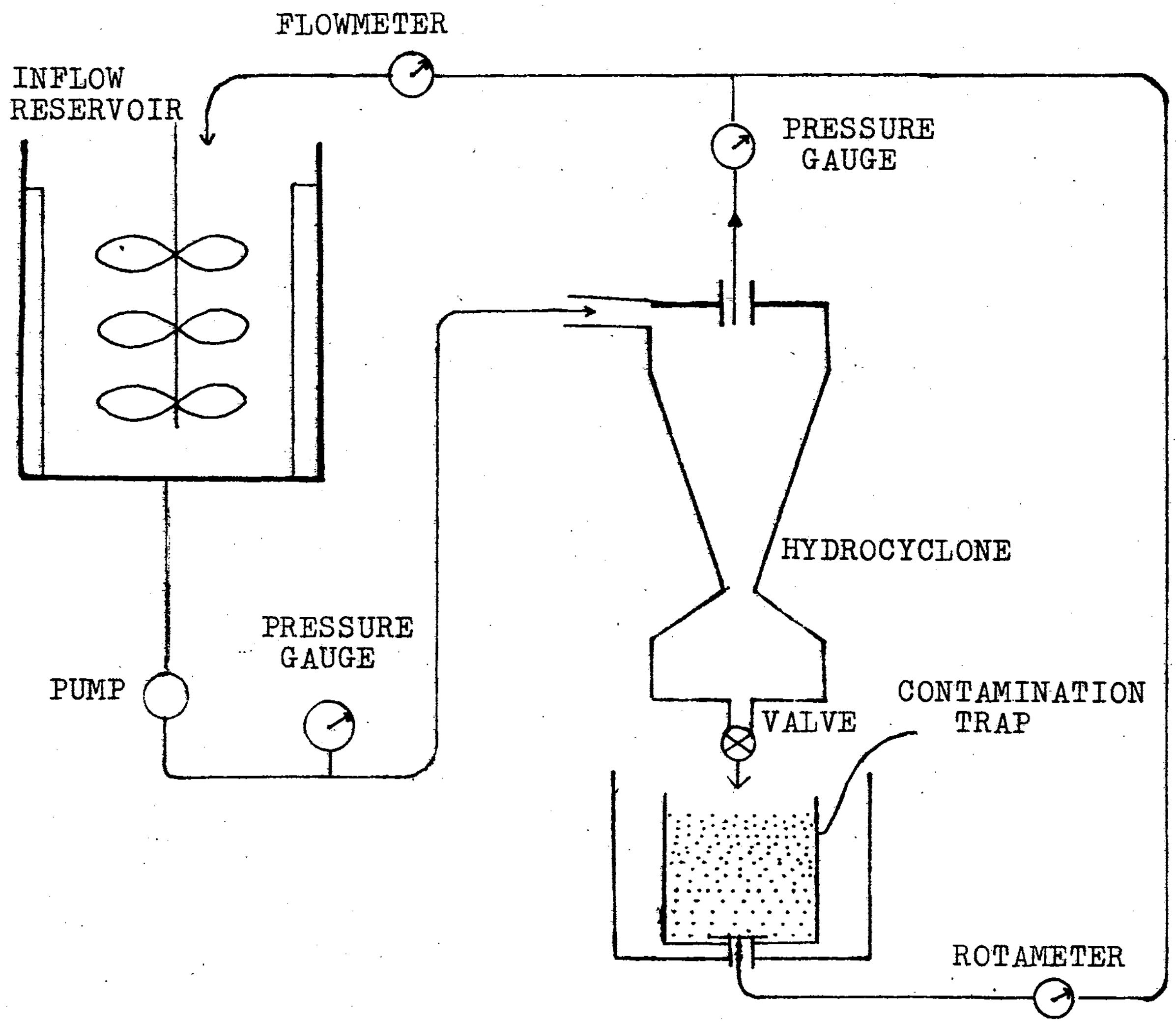

Figure 2. Open Underflow System for Continuous Recycle Studies

returning to the effluent, a roller type pump driven by 1/4 horsepower 110-220 volt a.c. motor for pumping filtered underflow waste back to the effluent reservoir, a flow rotameter for metering the recycling flow.

The cylindrical diatomaceous earth filter was a nylon fiber material. The diatomaceous earth slurry was added continuously while a roller type pump was pumping the filtered water back to the trap to keep the diatomaceous earth coated on the nylon fiber. Waste was not passed through the cyclone until the filter was coated well with diatomaceous earth. The filter used in this study was a cylinder of diameter 4.75", height 6" and total filtering area of 0.625 sqft.

The sand filter contamination trap had a diameter of 7.87", total filtering area of 0.338 sqft and depth of 7.25". It was a single medium sand filter with gravel at the bottom. The sand used had a uniformity coefficient of 1.7 and an effective size of 0.5 mm. The filter was backwashed each time before using.

Investigations were made on unit #9 with a 5% underflow rate through the diatomaceous earth contamination trap. Additional investigations were made on unit #10. Ten gallons of synthetic kitchen waste was passed through unit #10 and 2.5, 5.0, and 7.5 percent of the inflow was the underflow rate through the two contamination traps mentioned above.

Every run lasted 30 minutes. Both suspended solids and chemical oxygen demand were determined on samples drawn from the reservoir, underflow nozzle, combined overflow discharge, and downstream of the contamination trap at 0, 5, 10, 15, 20, and 30 minutes after operation began.

B. Synthetic Kitchen Waste

The synthetic kitchen waste used throughout this investigation had the following make-up shown in Table I.

TABLE I

SYNTHETIC KITCHEN WASTE
BATCH VOLUME - 10 GALLONS

1. Detergent (Dash)	71.4 gm
2. Sparkleen (Sani-flush)	57.1 gm
3. Scouring Powder (Blue Dot Ajax)	7.1 gm
4. Soap, Grit, Hand (Lava)	3.3 gm
5. Grease (Wilson Bake Rite)	3.8 gm
6. Vegetable Oil (First Pick Salad Cooking Oil)	5.7 gm
7. Suspended Solids (dog food - Dash)	45.4 gm
8. Temperature	110.0 F

The constituents were weighed and mixed on a wet weight basis. Before mixing the dog food was broken apart by adding water to it and stirring. The hand soap, grease, and vegetable oil were well dissolved in hot water before being added to the influent reservoir.

C. Analytical Procedures

The techniques used for the determination of suspended solids and chemical oxygen demand were the same as that outlined in Standard Methods (18). Jar tests (19) were conducted for the determination of dosages of coagulant aids. Alum, lime, ferric sulfate were utilized as coagulant, coagulant aids produced by Dow Company and Calgon Company were also tested.

Gravity separation studies of the synthetic kitchen waste were conducted in order to compare with the results of hydrocyclone's clarification. A batch of 10 gallons of the waste was mixed and stirred at 60 rpm in a reservoir with two baffles at the periphery. Samples were drawn at 0, 5, 10, 15, 20, 30 minutes after the mechanical stir was stopped. Suspended solids and chemical oxygen demand were determined from the samples drawn.

The efficiencies of each single pass were calculated by means of the following formula:

$$E = (I-O)/I,$$

where

I = concentration in inflow,

O = concentration in outflow.

CHAPTER IV

RESULTS

A. General

The experimental results are divided into six main sections. The first section presents the single-pass results obtained from two runs made on each of the first generation and second generation units.

The second section gives the results of chemical treatment of the synthetic kitchen waste after passing through hydrocyclone.

The third section displays the results of hydrocyclone #9, the one with the highest pressure drop. Single-pass studies were made and the underflow was regulated at 5 percent. Continuous recycle studies with a diatomaceous earth contamination trap and an underflow rate of 5% are also presented.

The fourth section presents the results of the second generation design unit #10, in two parts. One part gives the result of sigle-pass studies and the other presents the continuous recycle results. Both the diatomaceous earth contamination trap and sand filter trap were utilized and the recycled underflow rate was varied from 2.5%, 5% to 7.5%.

The fifth part of the results presents the effects of different underflow rate on continuous recycle hydrocyclone system.

The sixth part of the results describe the settling characteristics of the synthetic kitchen waste in comparison with the performance of the optimum continuous recycle hydrocyclone system.

B. Preliminary Studies

The resultant efficiency of single-pass studies of the nine configurations of both first generation and second generation hydrocyclones, along with the critical flow dimensions, initial solids of each test, and pressure drops are shown in Table II. The efficiencies displayed are average of two runs made on each unit.

TABLE II

CRITICAL FLOW DIMENSIONS, SOLIDS REMOVAL EFFICIENCIES, INITIAL SOLIDS AND PRESSURE DROPS OF THE HYDROCYCLONES

Hydrocyclone	D_i	D_o	D_c	L	E	I_s	P
#2	0.30"	0.36"	1.5"	9"	25%	578	14.5
#3	0.28"	0.24"	1.0"	6"	32%	651	28.0
#4	0.42"	0.36"	1.5"	6"	23%	652	11.5
#5	0.20"	0.34"	1.0"	6"	22.5%	765	41.0
#6	0.30"	0.51"	1.5"	6"	21%	714	13.0
#7	0.28"	0.34"	1.0"	4"	22.5%	699	30.0
#8	0.42"	0.51"	1.5"	9"	20%	664	7.0
#9	0.20"	0.24"	1.0"	6"	38.5%	677	74.0
#10	0.30"	0.36"	1.5"	6"	33%	717	20.0

By definition

D_i = Feed inlet diameter,

D_o = Overflow outlet (Vortex finder) diameter,

D_c = Maximum cone diameter,

L = Total axial length from inlet to underflow,

E = Suspended solids removal efficiency,

I_s = Initial solids in mg/l,

P = Pressure drop in psi.

It can be seen that generally as the pressure drop increases the separation efficiency increases. The best efficiency was obtained by hydrocyclone #9. This unit had a pressure drop of 74 psi. However, it can also be seen that the efficiency of this unit is not much greater than some of the lower pressure drop units.

Hydrocyclone #10 came from a second generation design with the concept of obtaining maximum efficiency with the lowest possible pressure drop. Table II shows that hydrocyclone #10 had an efficiency of 33 percent with a pressure drop of only 20 psi. The efficiency of unit #10 is not quite as high as unit #9, however there is a very great reduction in required pressure drop.

C. Chemical Treatment

For all of the jar studies conducted with synthetic kitchen waste, there was an optimum dosage which would yield the best flocculation of the kitchen waste, provided that the waste was acidified to PH 3 by sulphuric acid.

The dosage was ferric sulphate 1500 mg/l + Calgon 2630 8 mg/l. The dosage was very high and it appears that it is not economically feasible to chemically treat the synthetic kitchen waste. In addition, there was no improved efficiency observed after passing through the hydrocyclone.

D. Performance of Unit #9

1. Single-Pass Studies

Figure 3 shows the results of single-pass studies made on unit #9. The initial solids concentration is 745 mg/l and it was reduced to 379 mg/l on the first pass and to 361 mg/l on the second pass. Very little separation was achieved after the second pass. A removal of 47% was accomplished on the first pass. Note that the removal efficiency obtained from the preliminary studies (see Table II) on unit 9 was 38.5%. The difference in these two efficiencies is attributed to differences in the initial solids of the tests. This point will be discussed further in chapter V.

2. Continuous Recycle Studies

Performance of unit 9 with 5% underflow rate is shown in Figure 4. Two experiments were conducted with diatomaceous earth contamination trap in order to investigate the consistency. In both tests the greatest solids removal occurred in the first 5 minutes. The original solids concentration were 745 and 707 mg/l for experiment #1 and #2 respectively and they are lowered to 389

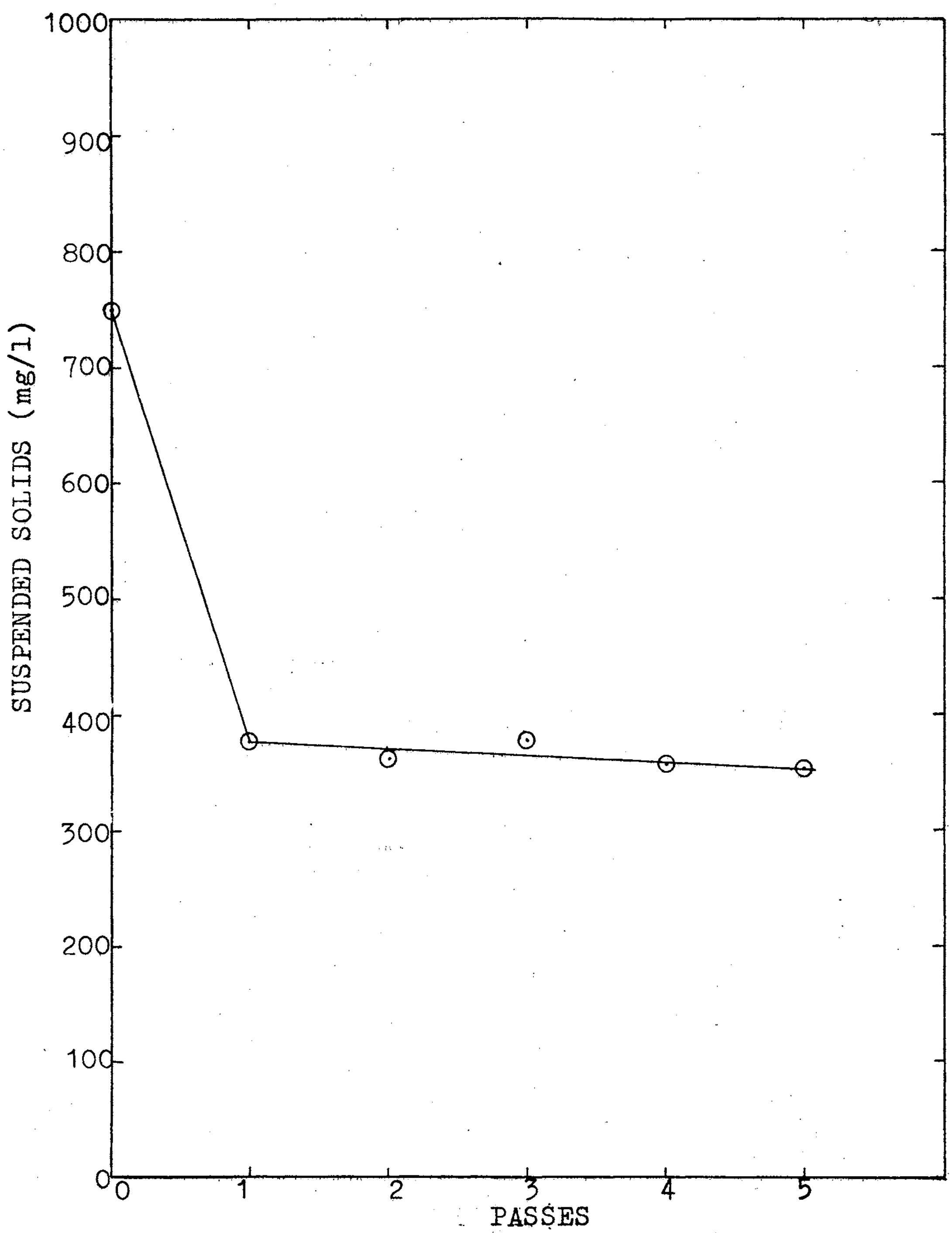

Figure 3. Hydrocyclone #9, Suspended Solids Removal of Single Pass Studies, $Q_u = 5\% \; Q$

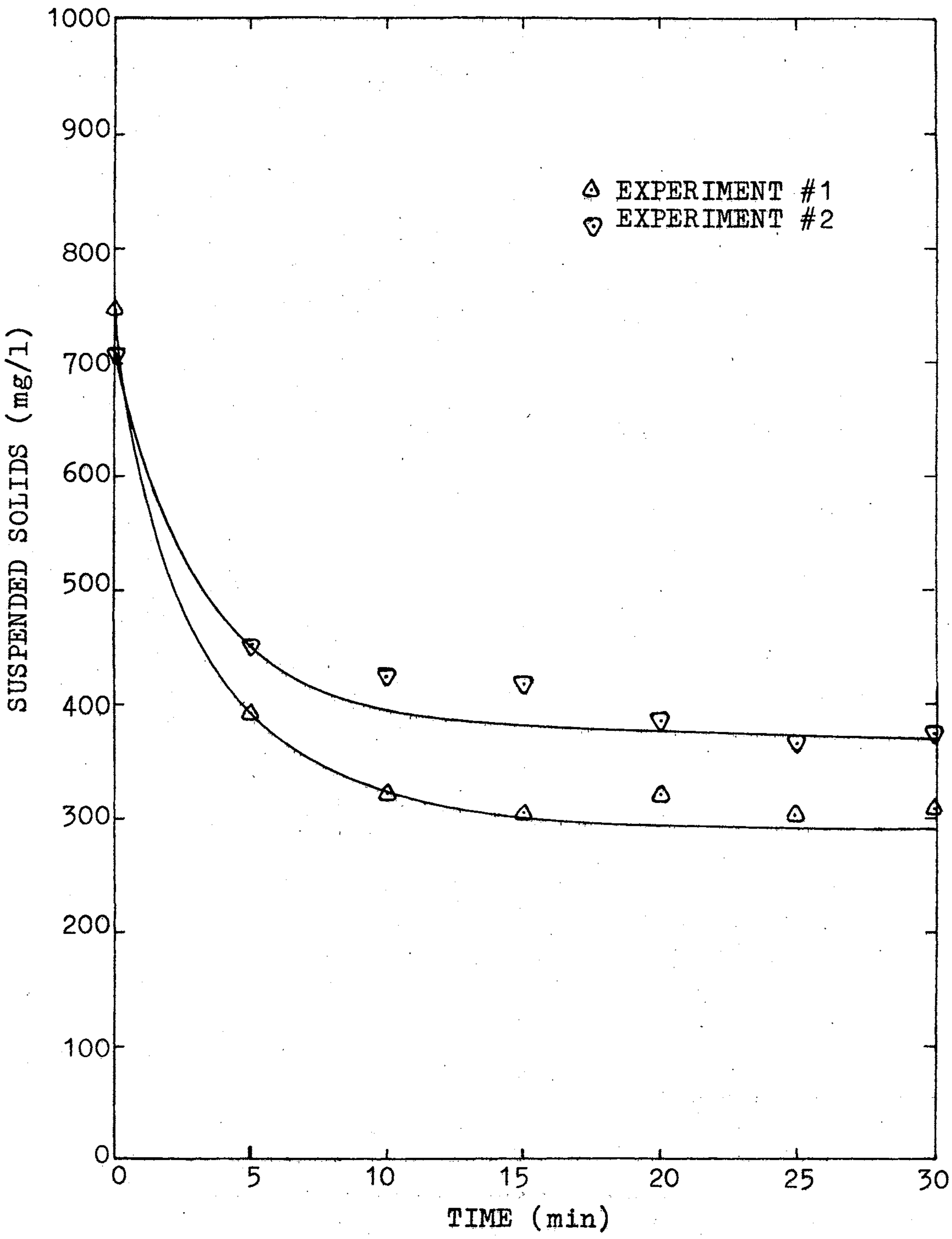

Figure 4. Hydrocyclone #9, Suspended Solids Removal of Continuous Recycle Studies, Q_u = 5% Q, with Diatomite Filter Trap

mg/l and 448 mg/l after five minutes. The rate of removal decreased gradually from 5 minutes to 15 minutes. After 15 minutes the solids removal efficiency was 57% for experiment #1 and 42% for experiment #2. After 15 minutes there was essentially no removal.

E. Performance of Unit #10

1. Single-Pass Studies

Figure 5 shows the results of single-pass studies made on unit #10 with the underflow rate regulated at 5%. The original suspended solids was 728 mg/l and was lowered to 464 mg/l by the first pass and to 416 mg/l by the second pass. The efficiencies were 36% for the first pass and 43% for the second pass. There is essentially no removal of solids after two passes.

2. Continuous Recycle Systems

(a) Diatomaceous Earth Contamination Trap

i. 2.5% Underflow

Figure 6 and Figure 7 show the results of experiments conducted using unit #10 with 2.5% of the total flow Q through the underflow diatomaceous earth filter trap. Figure 6 shows a solids removal of 23% after 5 minutes. The original solids was 643 mg/l and is lowered to 490 mg/l after 5 minutes, 425 mg/l after 10 minutes and 370 mg/l after 20 minutes. Figure 7 shows that hydrocyclone unit #10 removed 17% of the COD after 5 minutes of operation. The original COD was 1780 mg/l and it was lowered to 1516 mg/l after 5 minutes, 1440 mg/l after 10 minutes,

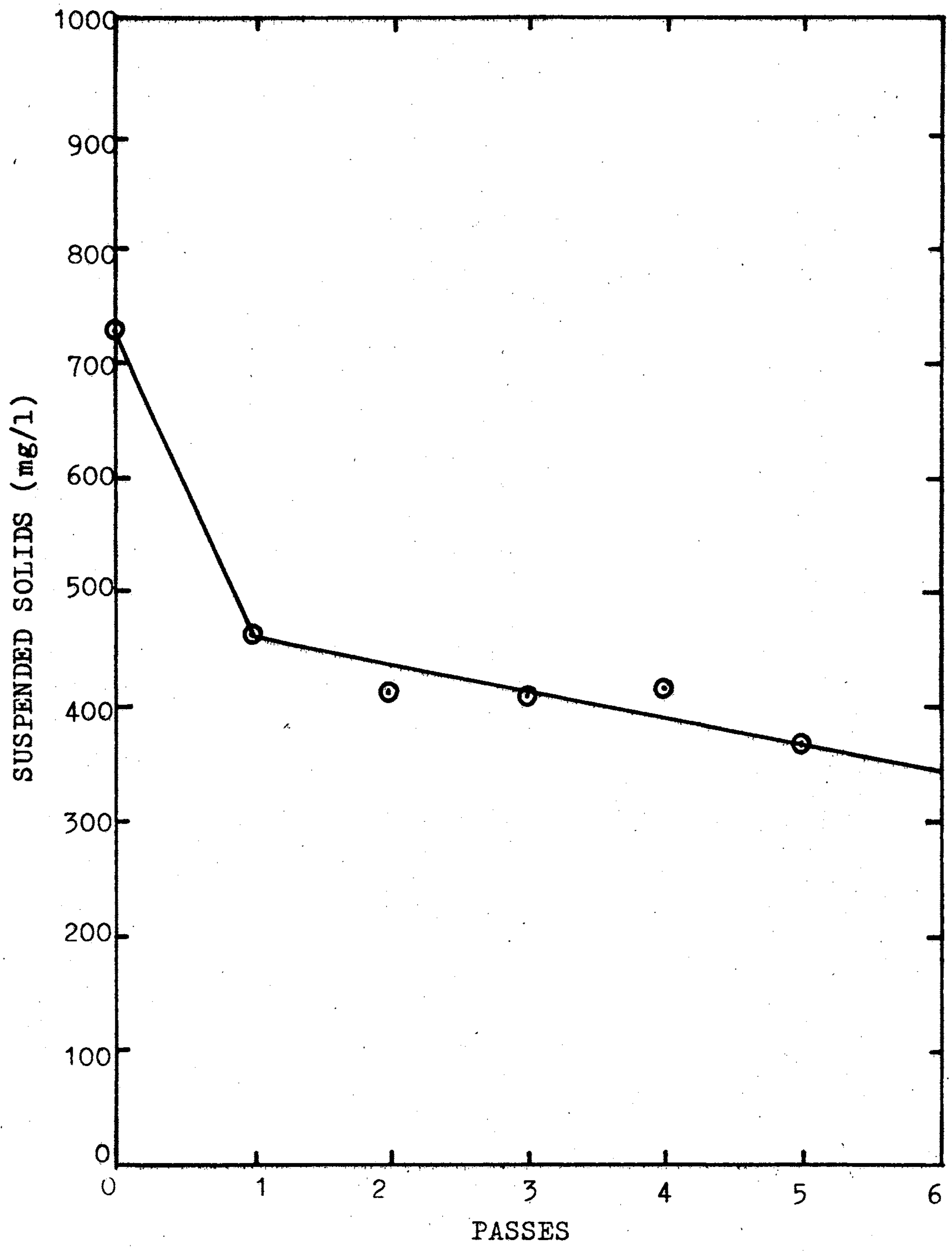

Figure 5. Hydrocyclone #10, Suspended Solids Removal of Single Pass Studies, $Q_u = 5\% \ Q$

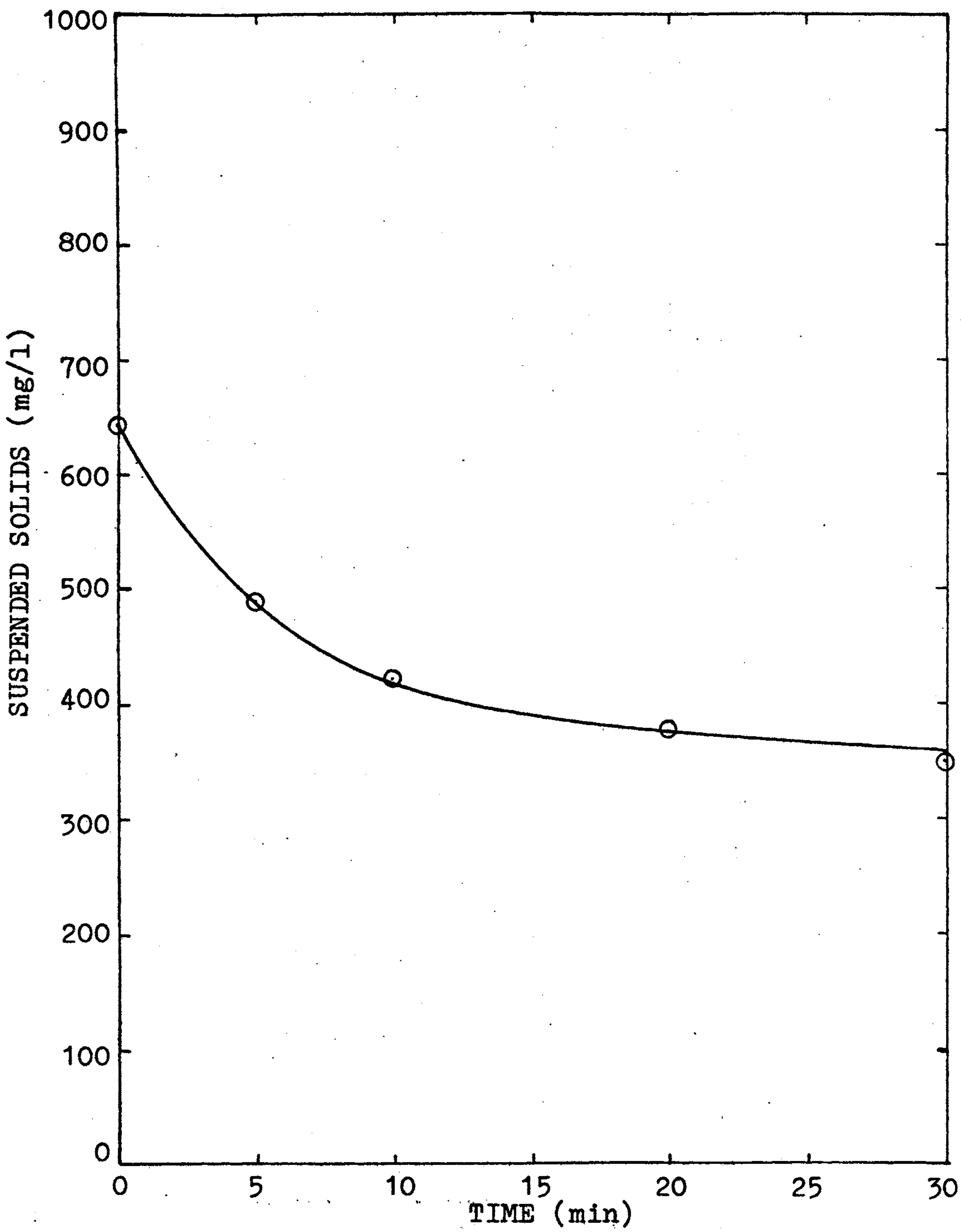

Figure 6. Unit #10, Continuous Recycle Results, Removal of Suspended Solids, with Diatomite Filter Trap, $Q_u = 2.5\%\ Q$

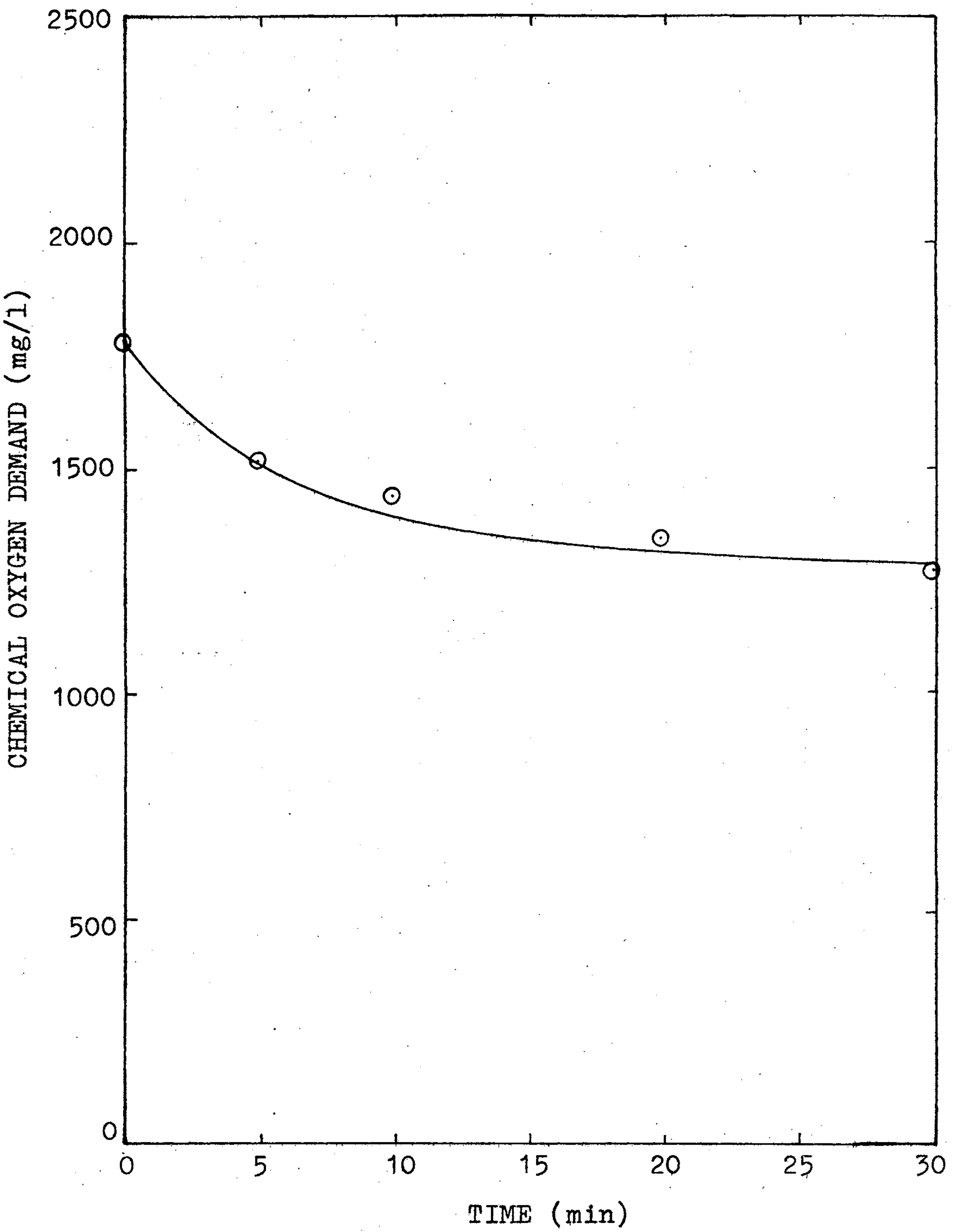

Figure 7. Unit #10, Continuous Recycle Results, Removal of COD, with Diatomite Filter Trap, Q_u = 2.5% Q

and 1350 mg/l after 20 minutes. A cumulative solids removal of 41% and COD removal of 31% was accomplished in 20 minutes.

ii. 5% Underflow

Figure 8 and Figure 9 show the results of the experiments made on unit #10 with 5% of the total flow passing through the underflow contamination trap and the diatomaceous earth filter. Figure 8 shows the original solids concentration was 585 mg/l and is lowered to 315 mg/l after 5 minutes. A removal efficiency of 44% was achieved. After 5 minutes a lower constant removal rate was observed until the end of operation. A total solids removal of 58% was achieved after 20 minutes. Figure 9 shows that the initial COD concentration of 1913 mg/l was reduced to 1310 mg/l after 5 minutes. A removal efficiency of 30% was obtained. The same type of removal as with solids was obtained. In both cases removal occurred at a higher rate in the first five minutes and then continued at a lower constant rate. A COD removal of 42% was accomplished at the end of 20 minutes.

ii. 7.5% Underflow

The results of suspended solids and COD removal are shown in Figure 10 and Figure 11. Figure 10 shows that a original solids concentration of 808 mg/l was decreased to 378 mg/l after 5 minutes. A solids removal efficiency of 49% was obtained. From 5 minutes to 30 minutes the removal rate continually decreased. A total solids removal

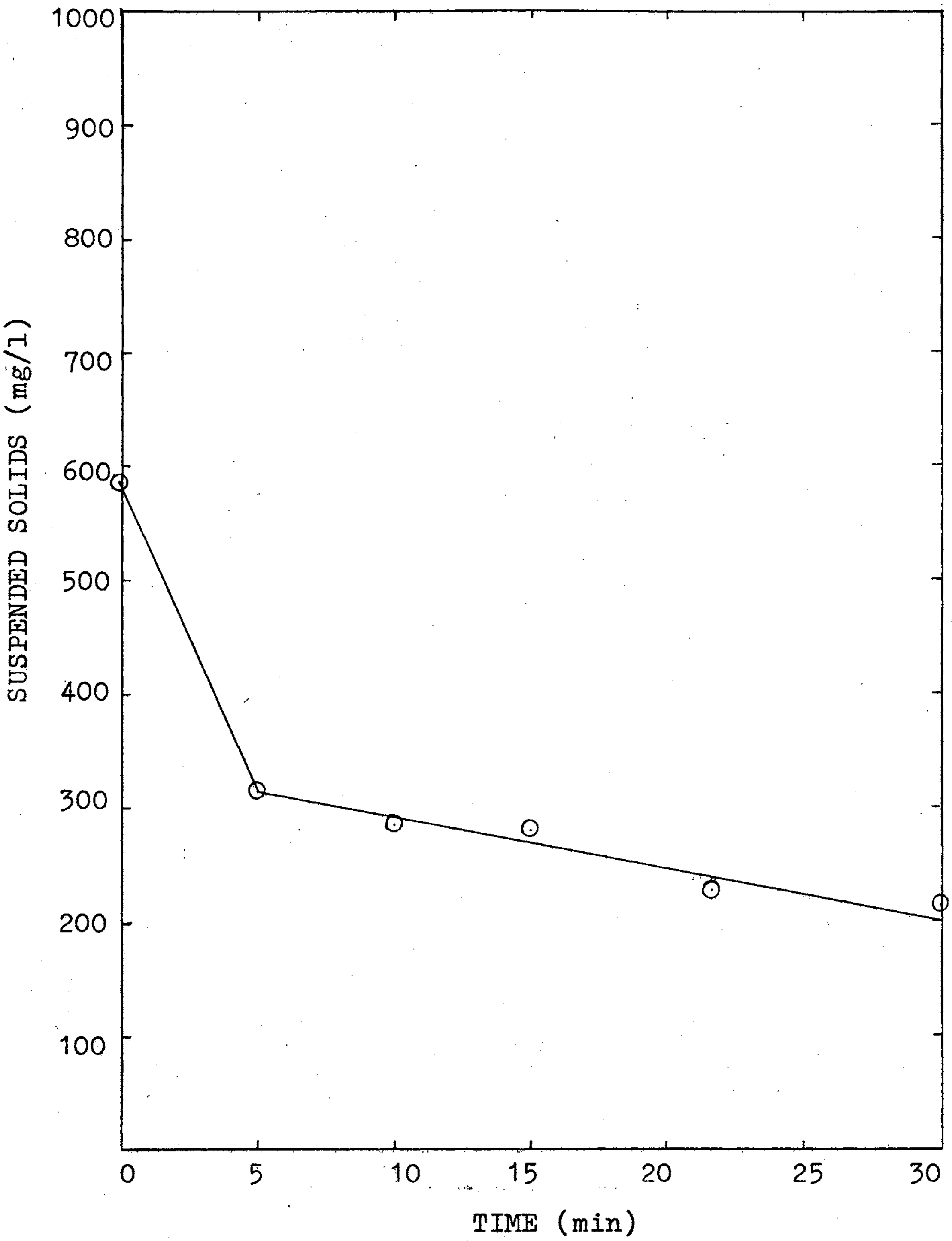

Figure 8. Unit #10, Continuous Recycle Results, Removal of Suspended Solids, with Diatomite Filter Trap, Q_u = 5% Q

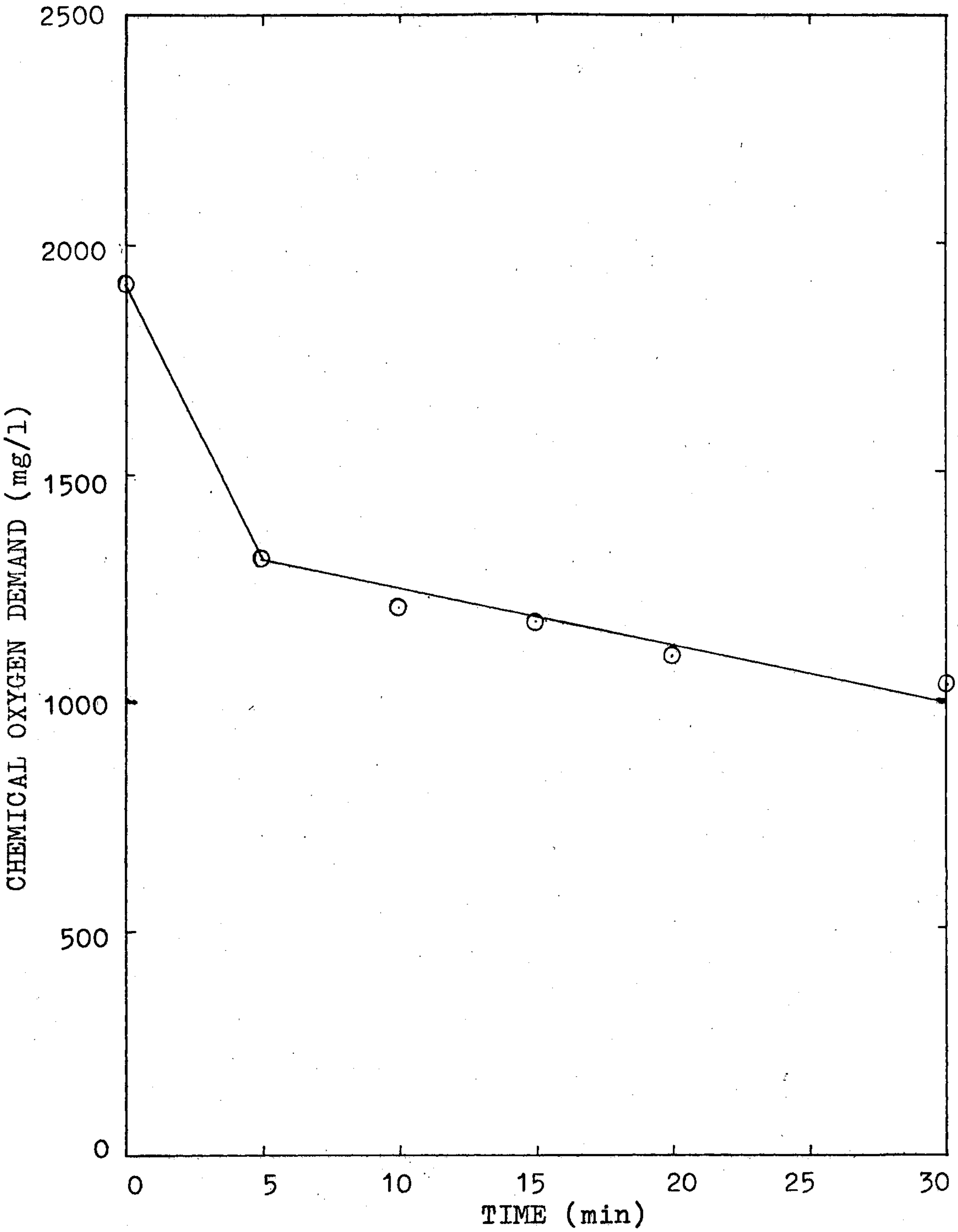

Figure 9. Unit #10, Continuous Recycle Results, Removal of COD, with Diatomite Filter Trap, Q_u = 5% Q

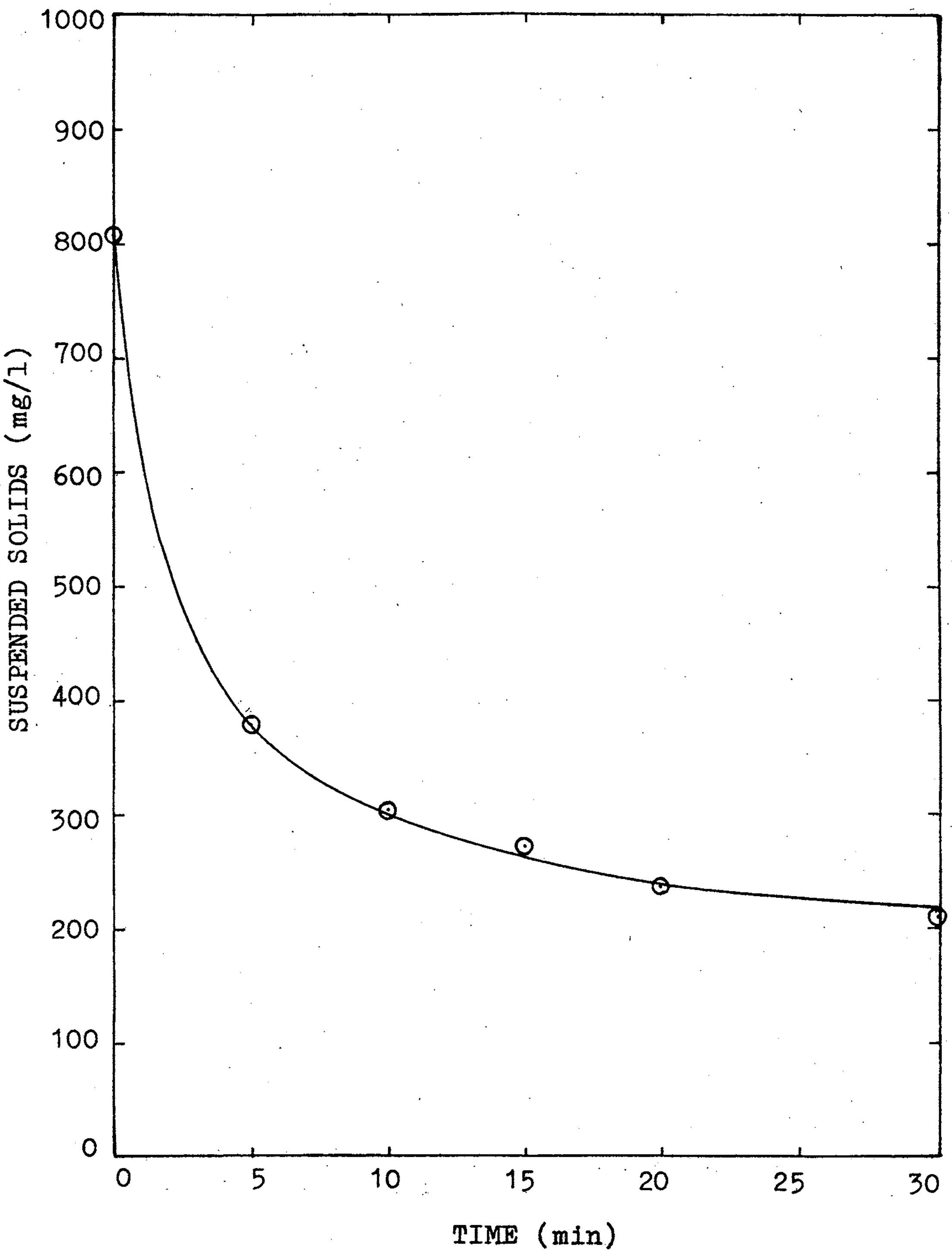

Figure 10. Unit #10, Continuous Recycle Results, Suspended Solids Removal, with Diatomite Filter Trap, Q_u = 7.5% Q

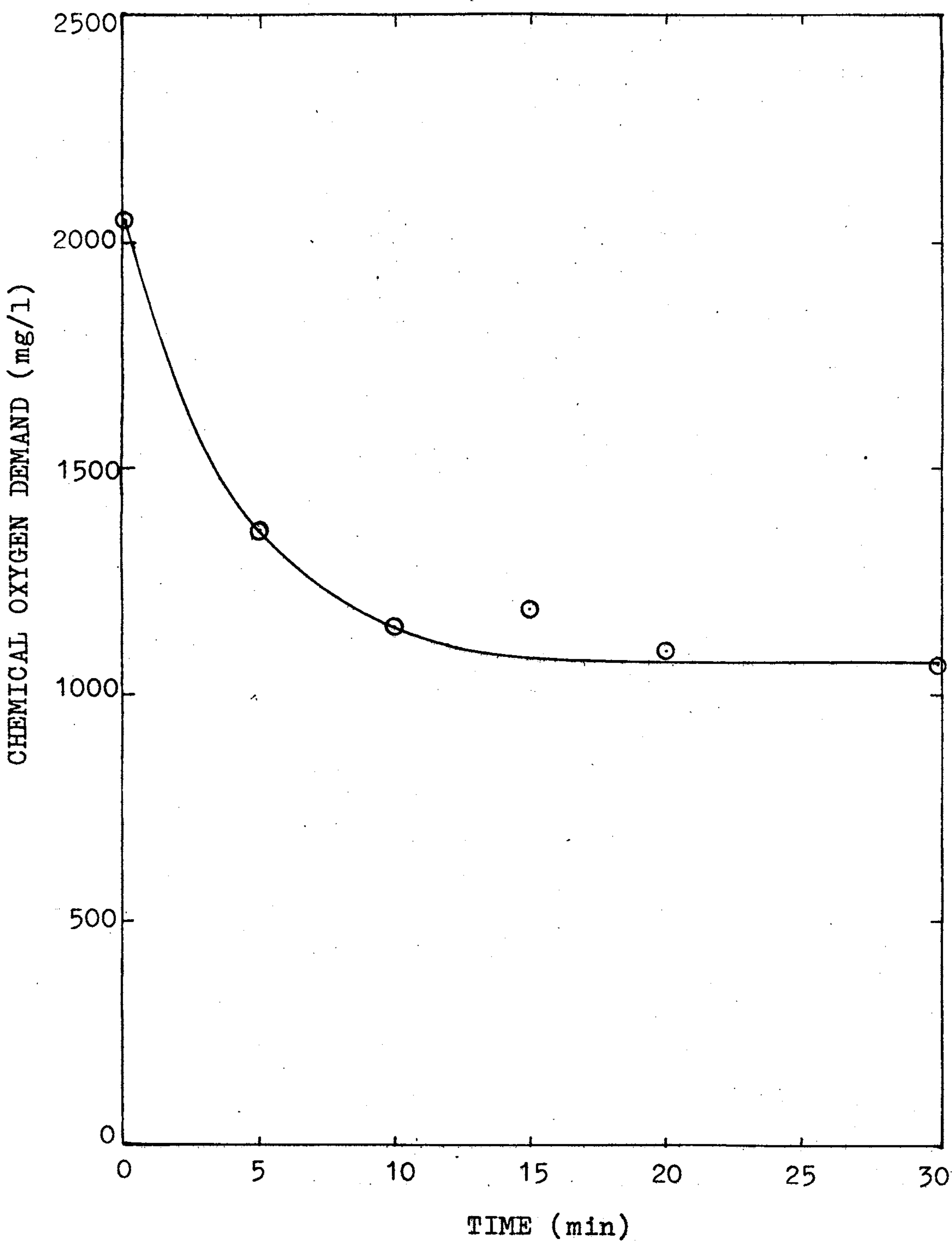

Figure 11. Unit #10, Continuous Recycle Results, COD Removal, with Diatomite Filter Trap, Q_u = 7.5% Q

of 66% was accomplished at the end of 20 minutes. Figure 11 shows that the original COD concentration of 2053 mg/l was reduced to 1359 mg/l, ie, a removal of 31% was observed after 5 minutes. A continually decreasing rate of removal of COD is observed from 5 to 20 minutes. After 20 minutes there is essentially no removal at all. A cumulative COD removal of 46% was accomplished by the end of 20 minutes.

(b) Sand Filter Contamination Trap

i. 2.5% Underflow

Figure 12 shows that the suspended solids was decreased from an original suspended solids of 712 mg/l to 488 mg/l after 5 minutes. A removal efficiency of 31% was achieved. There was a constantly decreasing rate of removal from 5 minutes to the end of the operation. For the last 10 minutes of the operation there was essentially no solids removal though. From Figure 13 it is seen that the COD was reduced from 1594 mg/l to 1386 mg/l after 5 minutes. After 5 minutes there is no further removal. A total removal of solids of 48% and COD of 14% was achieved at the end of 20 minutes.

ii. 5% Underflow

The results of unit #10 using the sand filter contamination trap and an underflow rate of 5% is shown in Figure 14 and Figure 15. It can be seen again that most of the solids and COD removal occurs in the first 5 minutes of operation. A solids removal of 37% and COD

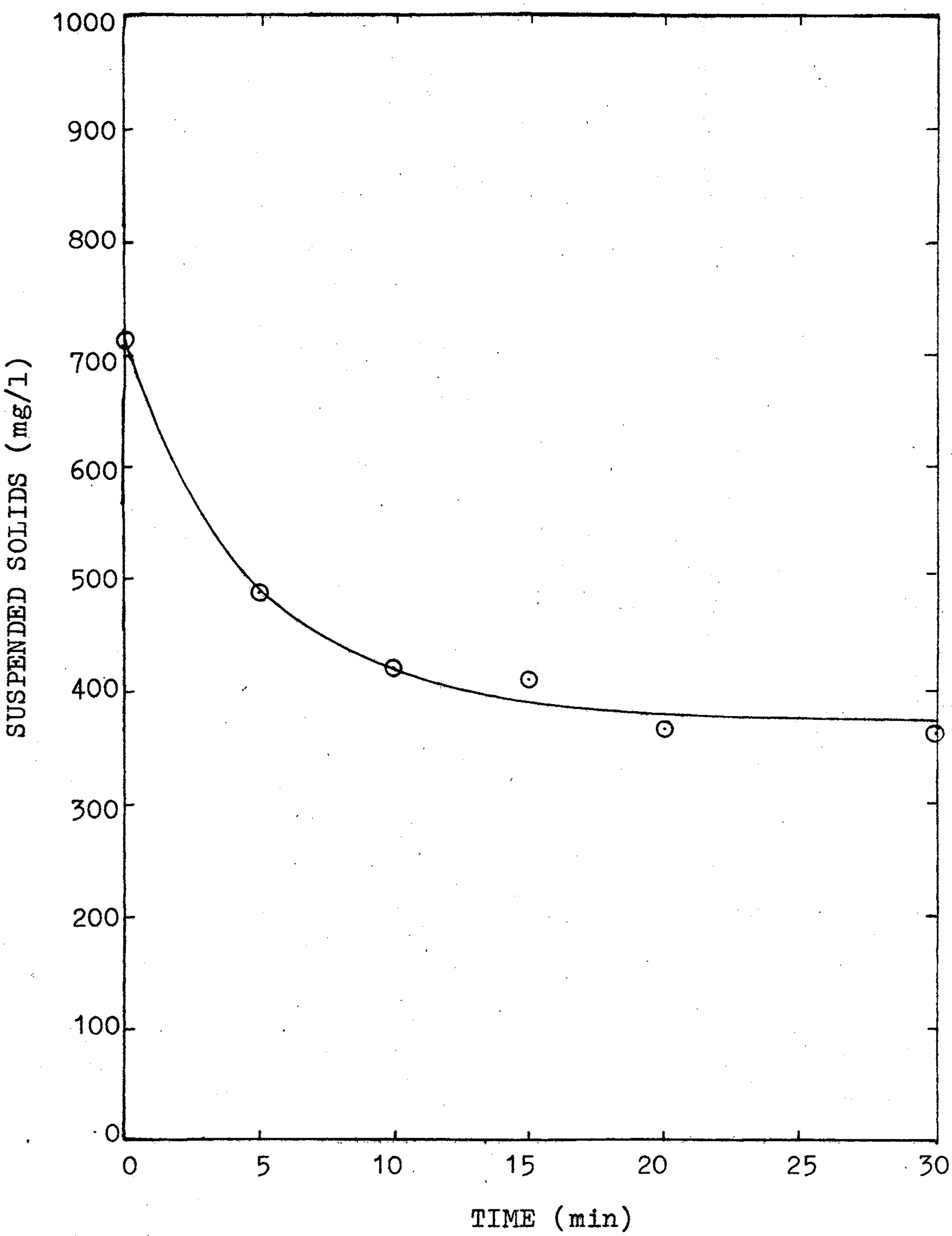

Figure 12. Unit #10, Continuous Recycle Results, with Sand Filter Trap, Q_u = 2.5% Q

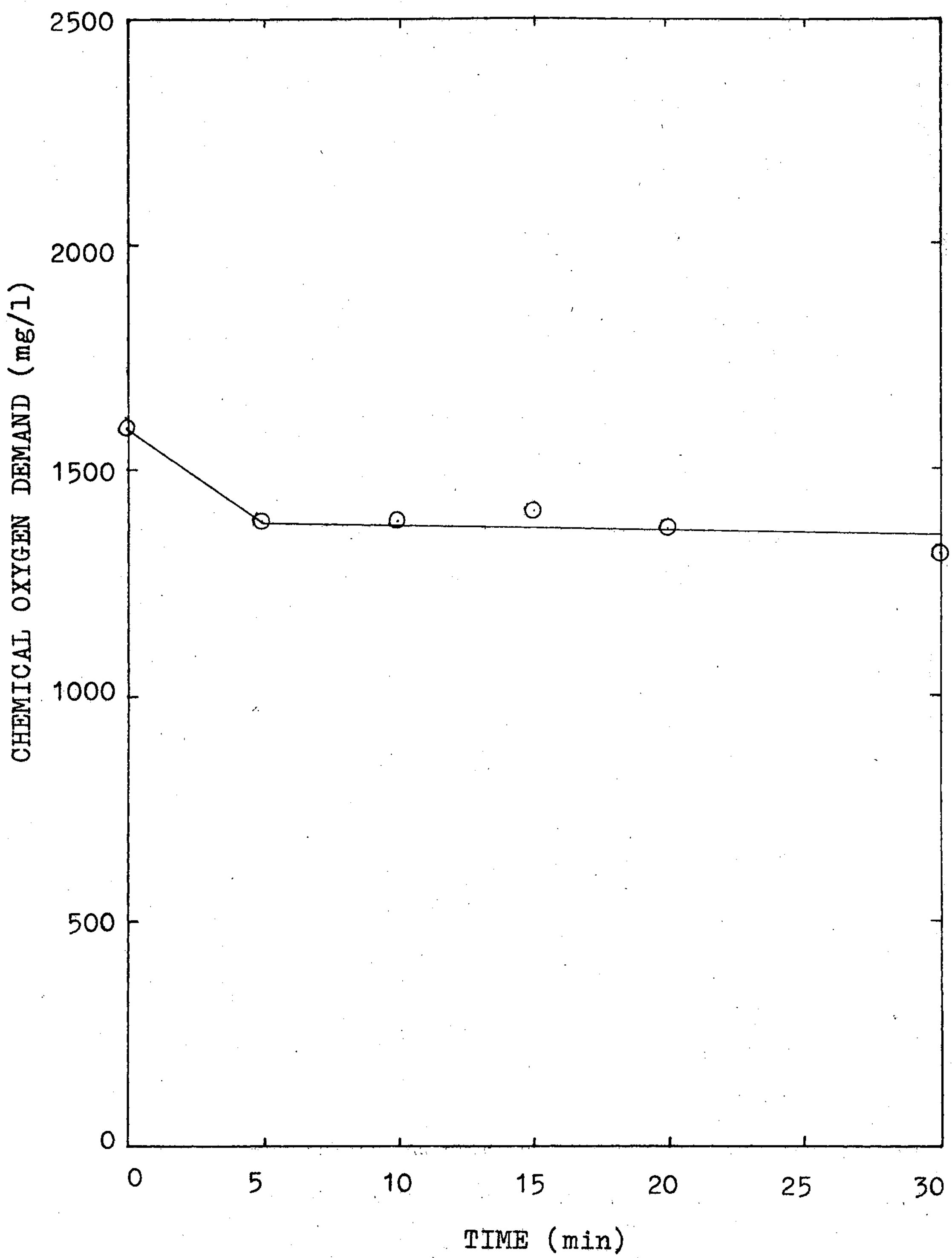

Figure 13. Unit #10, Continuous Recycle Results, with Sand Filter Trap, Q_u = 2.5% Q

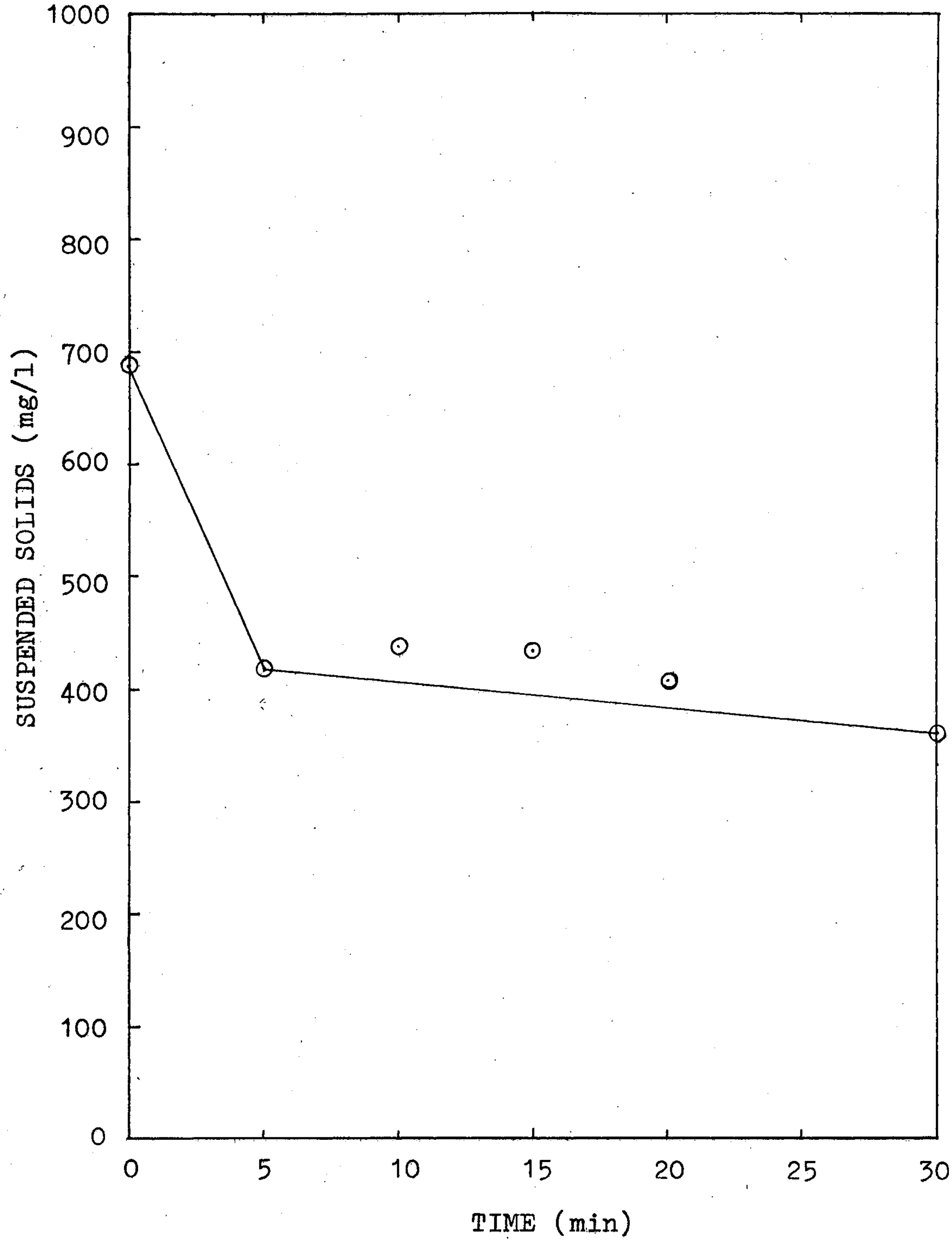

Figure 14. Unit #10, Continuous Recycle Results, Solids Removal, with Sand Filter Trap, Q_u = 5% Q

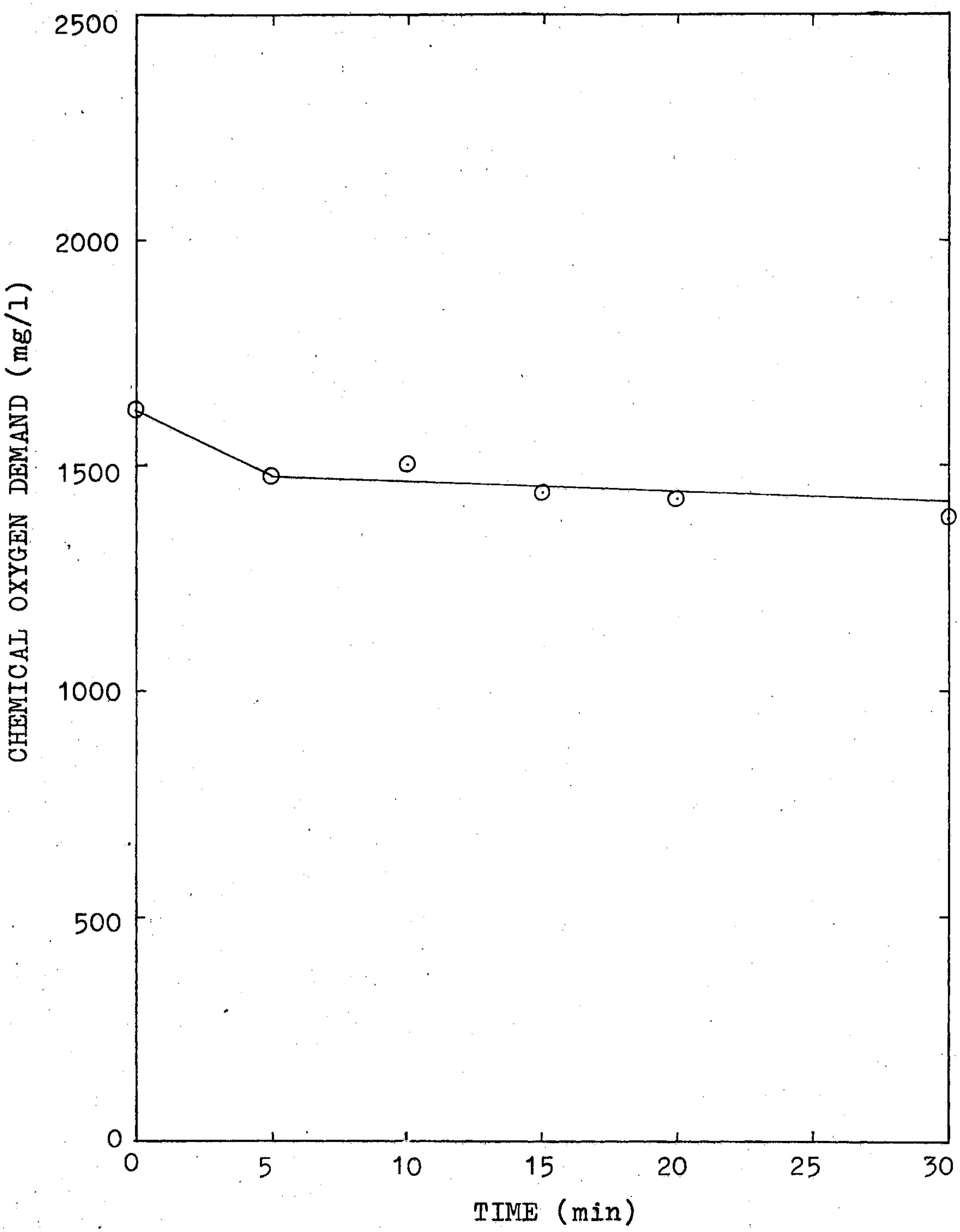

Figure 15. Unit #10, Continuous Recycle Results, COD Removal, with Sand Filter Trap, Q_u = 5% Q

removal of 9% was obtained during the first 5 minutes. Very little removal occurs after the first 5 minutes. Forty percent of the suspended solids and 14% of the COD were removed at the end of 20 minutes.

iii. 7.5% Underflow

Figure 16 gives the results of solids removal of hydrocyclone unit #10 with the sand filter contamination trap and an underflow rate of 7.5%. The original solids of 529 mg/l was decreased to 331 mg/l during the first 5 minutes. A removal of 35% was observed. After 5 minutes there was essentially no solids removal. Figure 17 gives the results of COD removal of unit #10 with sand filter contamination trap. A increment of 6% removal of COD was observed every 5 minutes till 10 minutes after operation. After 10 minutes there was almost no removal till the end of the operation. A total removal of 15% was achieved in 20 minutes.

F. Comparison of Unit #9 and #10

A table of results are given in Table III for easier comparison of the performance of hydrocyclone #9 and #10. Figure 18 also shows that the cumulative suspended solids removal efficiency of unit 9 and unit 10 with diatomaceous earth contamination trap at 5% underflow rate. The curves are of the same pattern for 3 passes. After 3 passes unit 10 still has a reasonable degree of solids removal while the solids removal has almost ceased in unit 9. It is believed that the lower pressure drop of unit 10 is not

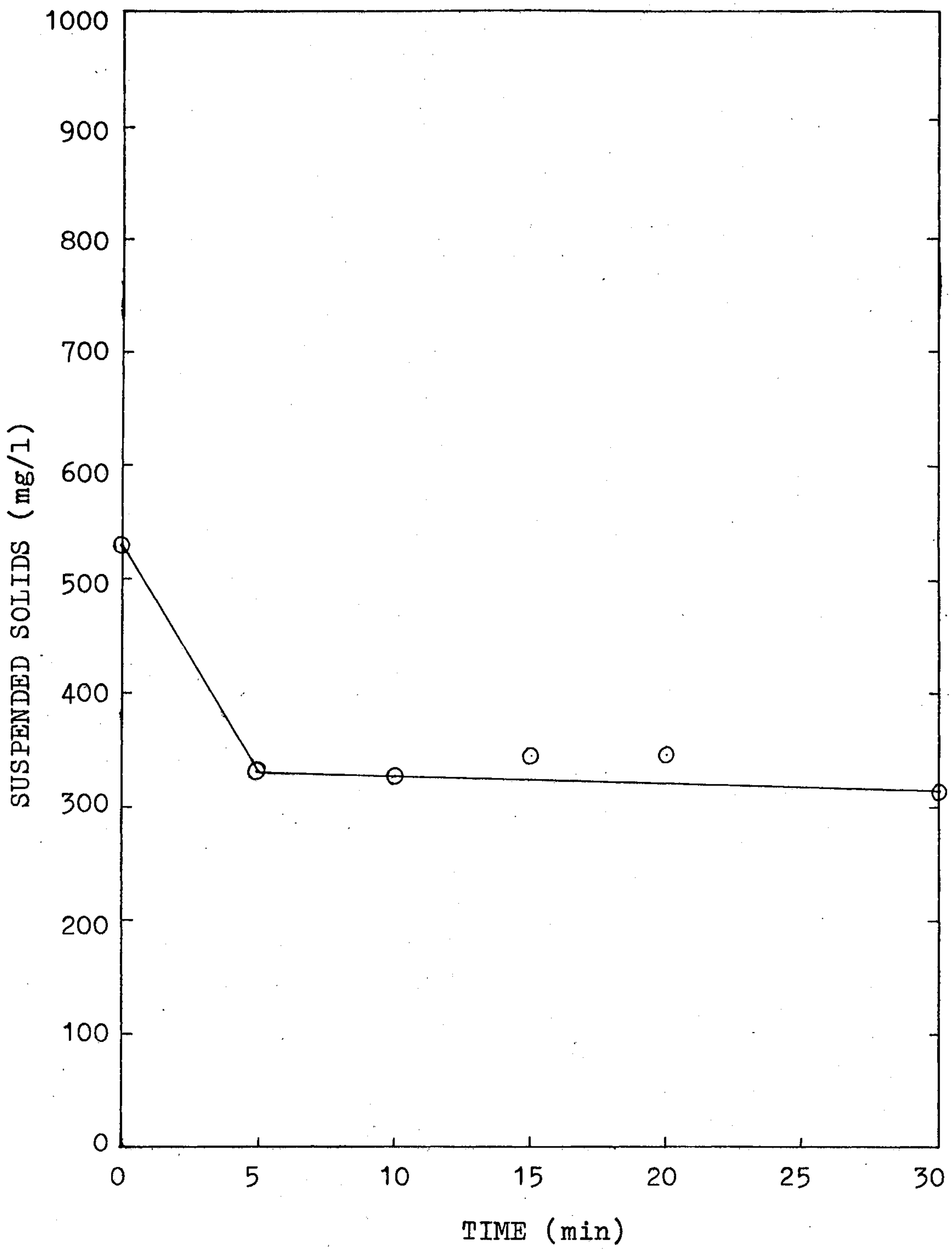

Figure 16. Unit #10, Continuous Recycle Results, Solids Removal, with Sand Filter Trap, Q_u = 7.5% Q

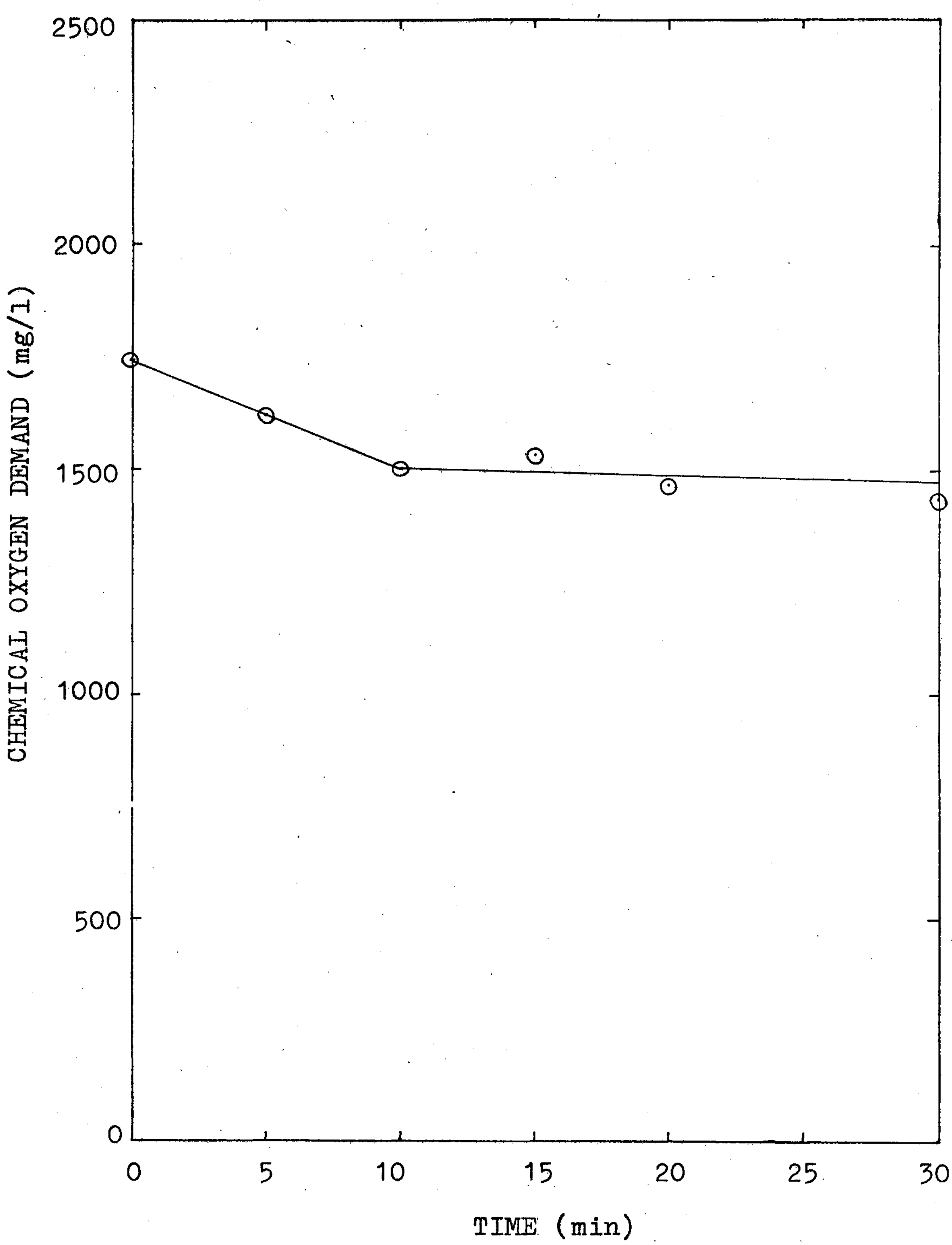

Figure 17. Unit #10, Continuous Recycle Results, COD Removal, with Sand Filter Trap, Q_u = 7.5% Q

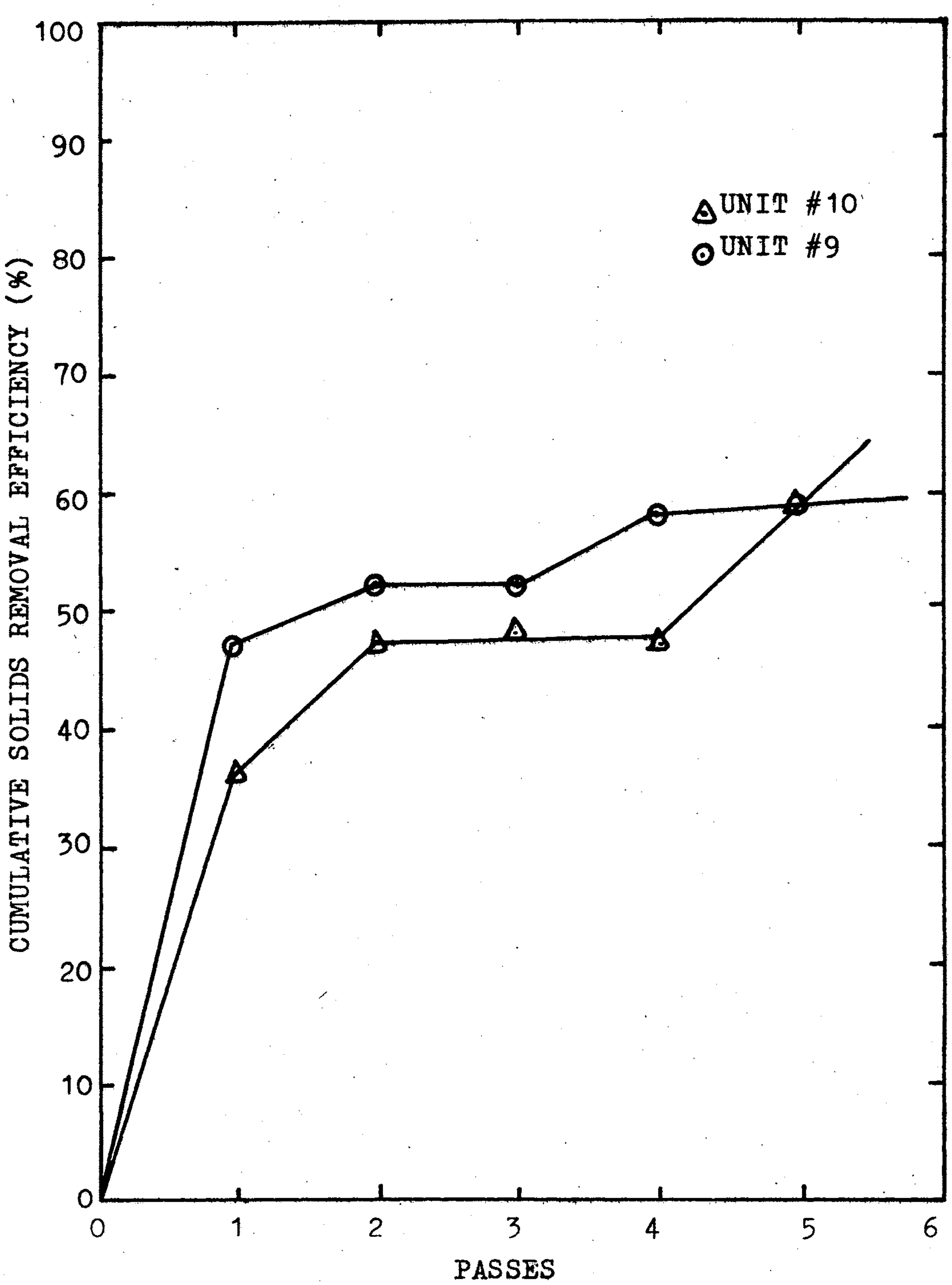

Figure 18. Cumulative Solids Removal Efficiencies, Unit #10 and #9

as destructive to agglomeration of solids as unit 9. consequently after 3 passes the size distribution of solids in the unit 10 test is such that further hydrocyclone separation is possible.

TABLE III

REMOVAL EFFICIENCIES OF UNIT #9 AND #10

Q_u	Time (min)	Unit #9 Diatomite Trap		Unit #10 Diatomite Trap		Unit #10 Sand Trap	
		S. S.	COD	S. S.	COD	S. S.	COD
2.5%	5			23%	17%	31%	14%
2.5%	20			41%	31%	48%	14%
5.0%	5	41%		44%	30%	37%	9%
5.0%	20	50%		58%	42%	40%	14%
7.5%	5			49%	31%	35%	6%
7.5%	20			66%	46%	35%	15%

G. Effect of Underflow Rate

1. Diatomaceous Earth Contamination Trap

Figure 19 shows the results of cumulative solids removal efficiency of continuous recycle system with diatomaceous earth contamination trap and with underflow recycled at three different rates. It can be seen that the cumulative solids removal efficiency is the highest when the underflow rate was recycled at 7.5%.

2. Sand Filter Contamination Trap

Figure 20 shows that the underflow rate had no effect on the suspended solids removal efficiency. It can be seen that all three underflow rates provide essentially the same accumulated removal efficiencies.

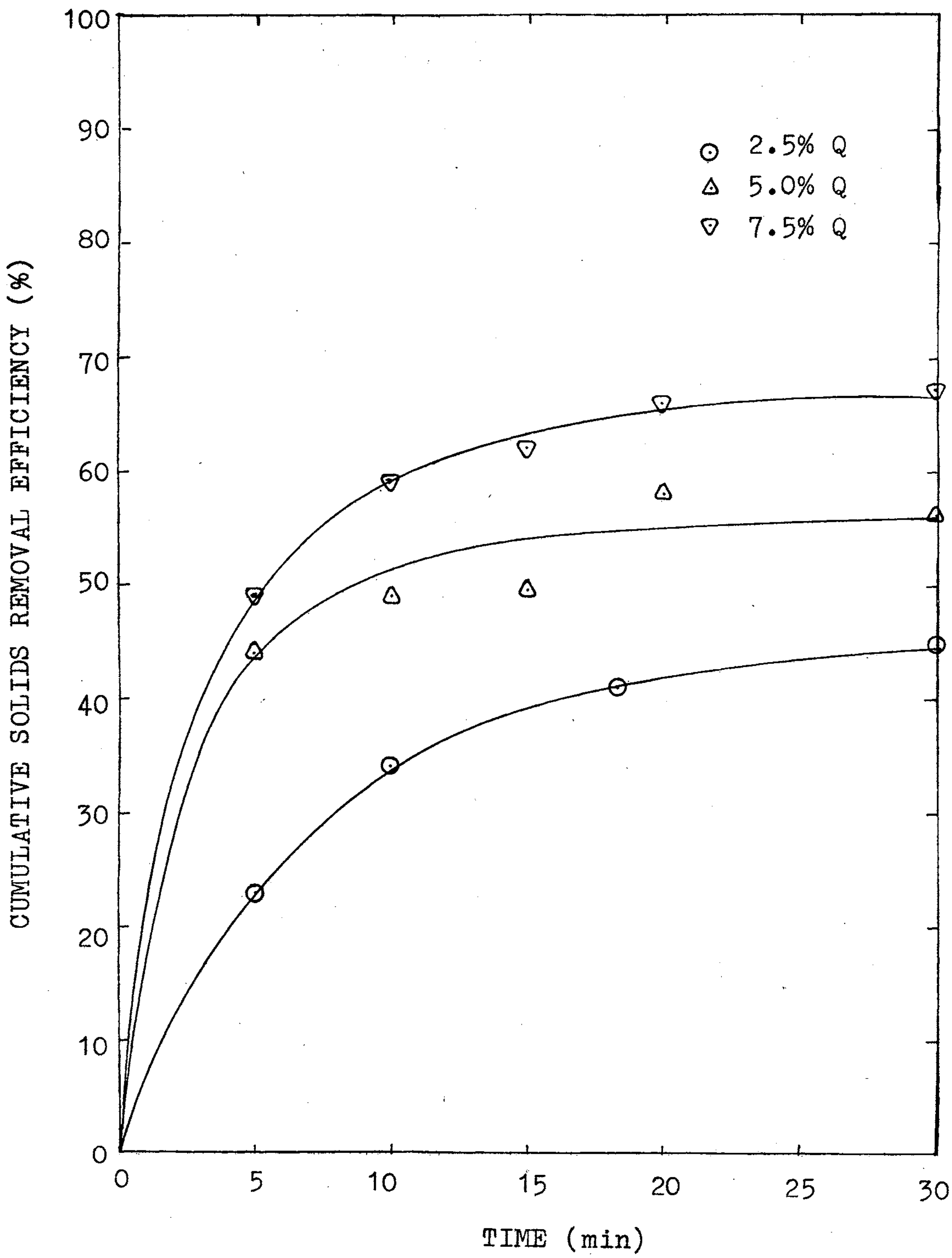

Figure 19. Unit #10, Continuous Recycle Results, with Diatomite Filter Trap, Q_u = 2.5% Q, 5% Q, 7.5% Q

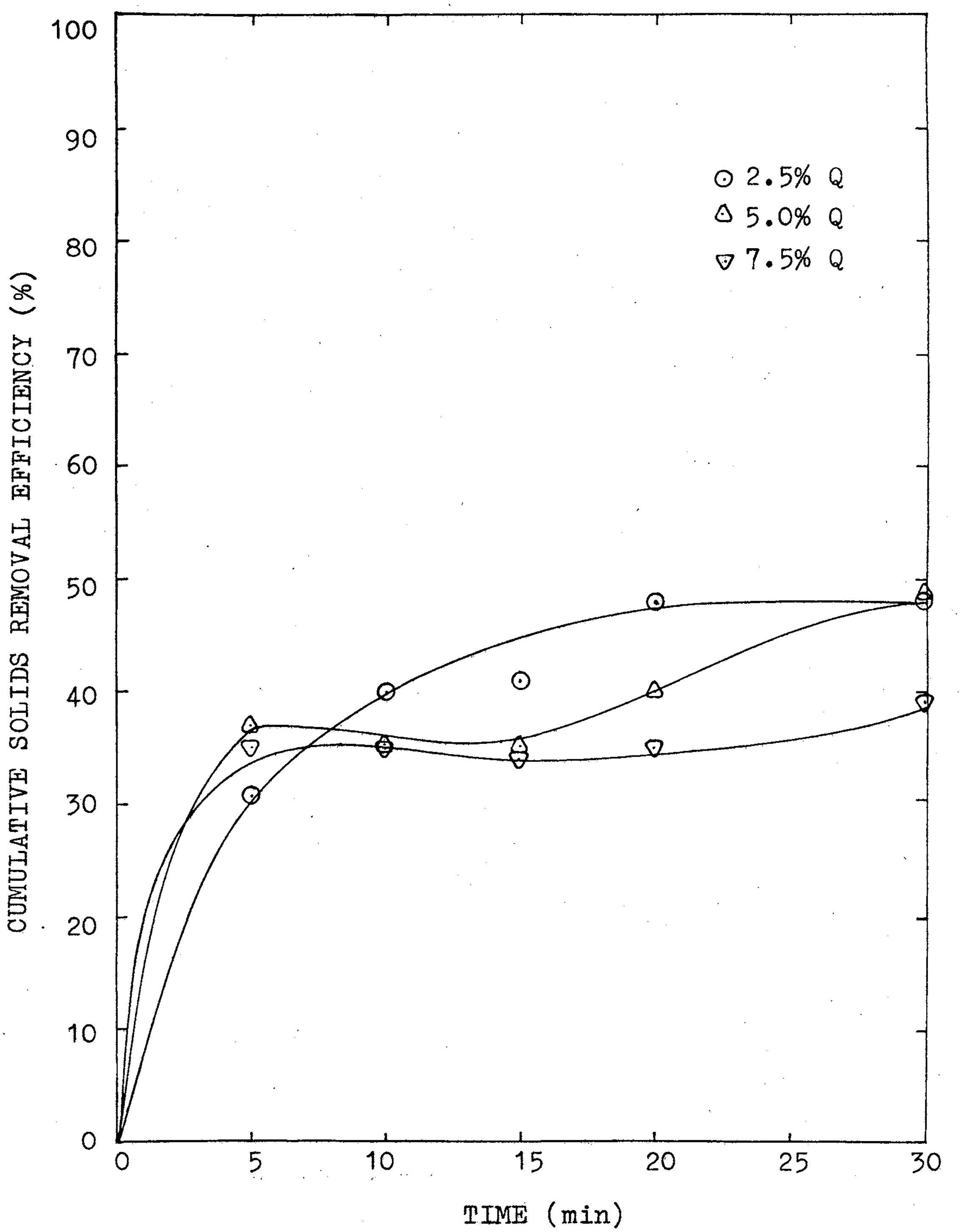

Figure 20. Unit #10, Continuous Recycle Results, with Sand Filter Trap, Q_u = 2.5% Q, 5% Q, 7.5% Q

H. Gravity Separation Studies

Figure 21 and Figure 22 give the results of gravity separation studies. For the first 5 minutes a solids and COD removal efficiency of 54% and 19% respectively was accomplished. While at 20 minutes a solids and total COD removal efficiency of 67% and 58% was accomplished.

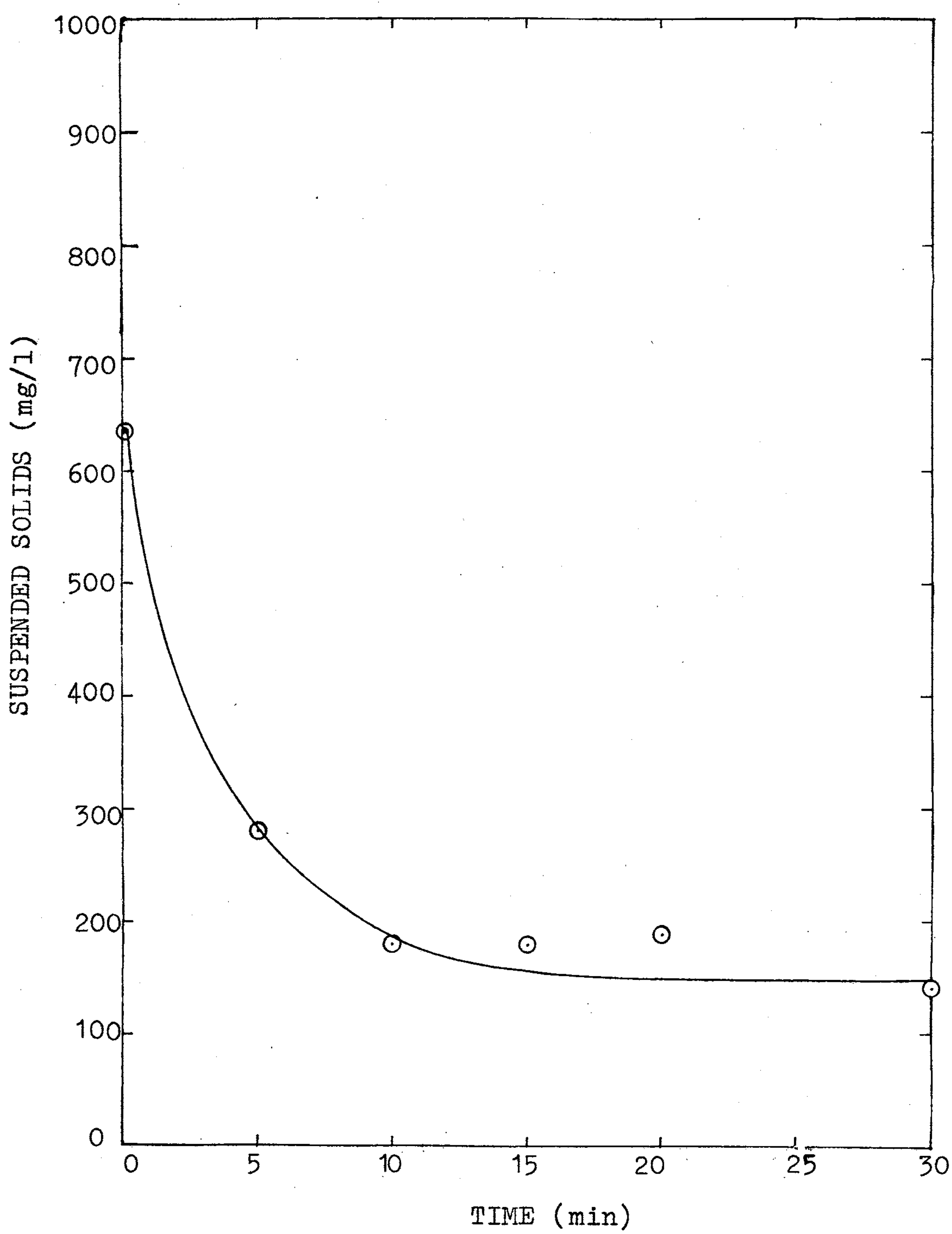

Figure 21. Gravity Separation Results, Solids Removal

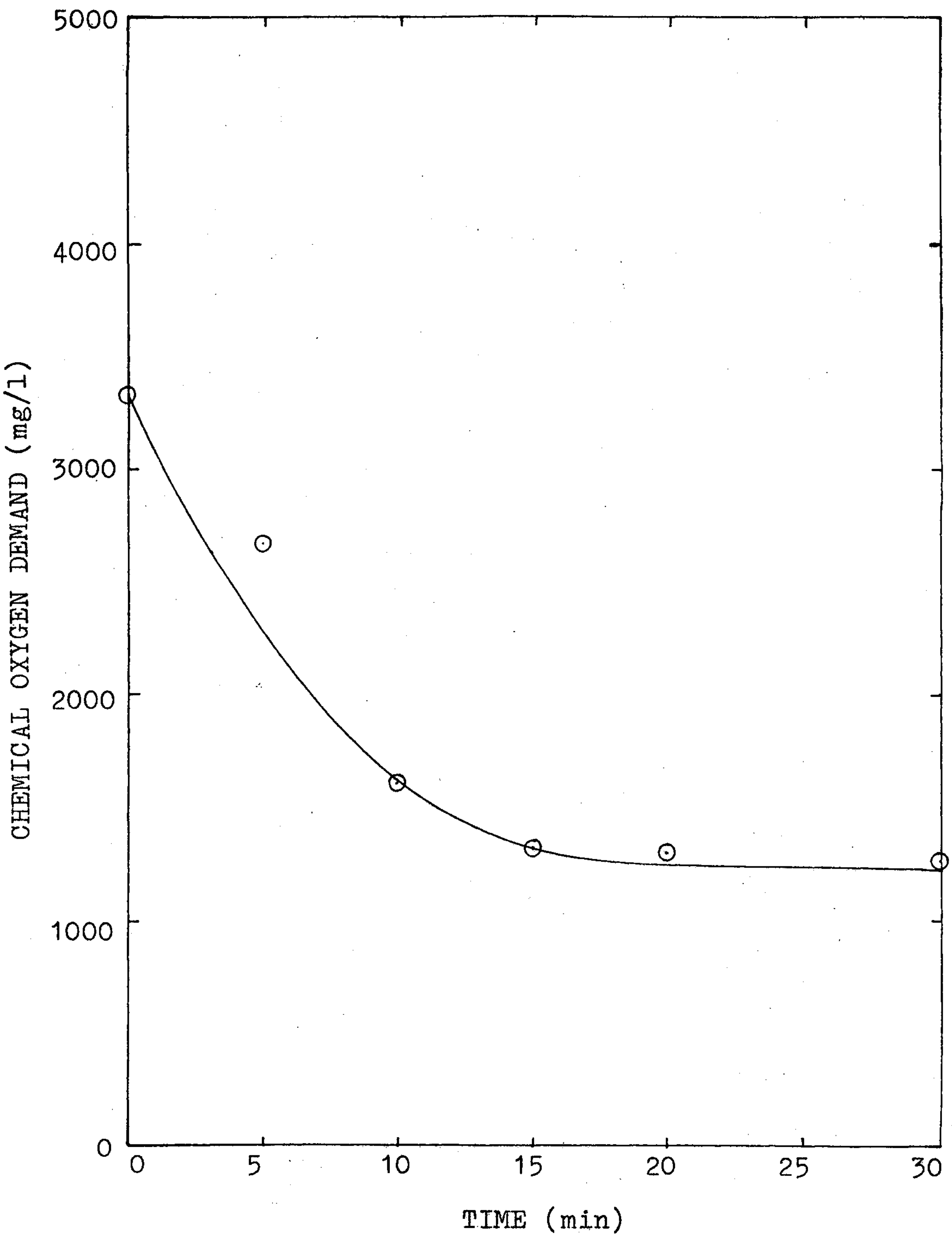

Figure 22. Gravity Separation Results, COD Removal

CHAPTER V

DISCUSSION

This study was conducted to investigate the feasibility of using 4 gallon per minute hydrocyclones for the solids-liquid separation of a synthetic kitchen waste.

Single pass studies were conducted on eight designs of 4 gallon per minute hydrocyclones without contamination traps. After testing the eight configurations of the first generation, the results indicated that pressure drops of 28 psi and 74 psi units gave better efficiency. The second generation design, unit #10, with a pressure drop of 20 psi was developed and tested. Results show that this configuration performs more effectively than all the first generation designs except unit #9 which had a pressure drop of 74 psi.

Studies were then directed to multiple pass studies in order to determine the efficiency of the hydrocyclones for various passes through the unit. It was found for both units that there was very little removal after the first pass (Figure 3 and 5). It was also found that the overall separation efficiency of the two hydrocyclones are very similar, even though unit 9 requires a pressure drop of 74 psi and unit 10 requires only a pressure drop of 20 psi. It was also found that the residual suspended solids in the waste after multiple passes through unit 9 was approximately 375 mg/l, whereas, the residual suspended solids from unit 10 was approximately 410 mg/l. These values are important in that they represent the lowest level that the hydrocyclone would be able to lower the suspended solids for this particular waste. Therefore, the efficiency of the hydrocyclones are very dependent upon the initial solids. It is felt that these approximately 400 mg/l suspended solids are held tightly in suspension by the detergents in the waste water.

Continuous recycle studies were also conducted using both unit 9 and unit 10. It was found that there was very little solids-liquid separation after the first 5 minutes of operation. This supports the results of the single pass studies in which very little separation occurred after the first pass. These studies also showed that organic solids were being removed by the hydrocyclone. This was shown by the COD removed.

Two types of contamination traps were used in these studies. They consisted of a diatomaceous earth filter and a rapid sand filter. A diatomaceous earth filter will provide better clarification than a rapid sand filter. This was also evident in this study, however,in regards to the overall operation of the system no significant difference was observed in the performance of the two contamination traps. The loadings on the traps were high and both would require frequent backwashing.

The continuous recycle studies were conducted at three different underflow rates 2.5%, 5.0%, and 7.5% of the inflow. Overall very little significant difference was observed in the performance of the hydrocyclone when operated at the underflow rate above 2.5%. After 5 minutes of operation the 7.5% underflow rate produced a higher separation efficiency, however, it is questionable whether or not this is really significant. This is true especially when the 7.5% underflow rate is compared with the 5.0% underflow. There may be some improvement over the 2.5% underflow rate. However, this could have been due to operational problems. The diatomaceous earth filter was very difficult to operate at this low flow rate.

The synthetic kitchen waste was found to be very difficult to flocculate. Flocculation was achieved by lowering the PH and using very high concentrations of coagulating chemicals. Due to these difficulties it was determined that it would not be feasible to try to flocculate the waste before being passed through a hydrocyclone.

CHAPTER VI

CONCLUSIONS

The results of this study support the following conclusions:

(1) The hydrocyclone is a feasible means of solids-liquid separation of a kitchen waste water.

(2) Underflow rates above 2.5% had very little effect on the separation efficiency of the hydrocyclone.

(3) The diatomaceous earth filter and the rapid sand filter proved to be acceptable contamination traps.

(4) It is not feasible to flocculate the kitchen waste water before passing through a hydrocyclone.

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