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Title: THE WASTEWATER TREATMENT CHARACTERISTICS OF A ROTATING FLIGHTED CYLINDER

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The rotating flighted cylinder (RFC) was investigated as a potential wastewater treatment device. A RFC is a rigid tube with a helically-wound fin attached to the interior surface and operates by flowing wastewater through the tube as it rotates.

An 8-inch and 24-inch diameter RFC was tested for solids-liquid separation, oxygen transfer, and removal of organic matter.

The 8-inch RFC did not separate solids from liquid to any meaningful extent. The 24-inch RFC did show significant solids-liquid separation and appeared to prevent sloughed biomass from exiting with the cylinders lower effluent.

Total oxygen transferred to the liquid was enhanced by increasing rotational speed and flow through the cylinder. Oxygen appeared to be transferred by other mechanisms

not exhibited in the recreation tests. BOD removal exceeded the oxygen made available according to these tests.

The 8-inch RFC obtained 90% BOD_5 and 80% COD removal at equivalent flow rates of .01 liter per minute.

The 24-inch RFC was able to achieve over 90% BOD_5 removal within a four to eight hour retention time with a volume of 500 liters. Continuous flow treatment yielded soluble BOD_5 removals above 90% but high suspended solids kept total BOD_5 removal around 70%. On a loading per surface area basis the biological capabilities of the RFC appears similar to the rotating biological discs. Nitrification was not significant during treatment.

Operational and capital costs make the unit a feasible package plant alternative.

The Wastewater Treatment Characteristics of a Rotating Flighted Cylinder

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I. INTRODUCTION

Two common methods of wastewater disposal in rural and remote areas have traditionally been to depend on the natural capacity of receiving waters to treat waste or to utilize subterranean drainage. Environmental legislation in an effort to maintain the resiliency of natural systems has sought to avert pollution overloads on the environment by eliminating or regulating the amount of waste discharged. This objective has expedited the need for extended treatment of waste in many areas which previously practiced disposal of raw or primary treated effluents. Effluent quality standards are now mandatory for all point sources of discharge as a result of the Water Pollution Control Act of 1972 and in addition, land use planning and zoning practices often preclude the use of septic tanks and cesspools.

Urban areas have approached wastewater treatment by constructing sewate greatment plants requiring large capital outlays and high operating costs while employing a number of operators with sufficient technical skill to maintain the facilities. This practice has normally proven satisfactory and the area served has supplied the needed revenues without economic strain.

However, rural areas inaccessible to an existing treatment plant's collection system face the dilemma of either providing their own treatment with potentially high per capita costs or discharging, raw waste - an act which now carries heavy fines and possible criminal indictments.

To remedy this situation several private firms have developed and marketed "package sewage treatment plants" which have served subdivisions, motels, restaurants, trailer parks, schools, military establishments, institutions, and industrial plants. With few exceptions these plants utilize a modified activated sludge-extended aeration process (1). The major objectives of this type of system is to produce a satisfactory effluent while requiring little operational and maintenance attention and providing low initial and operating costs.

Perhaps a potential small scale wastewater treatment unit is the Rotating Flighted Cylinder (RFC) originally conceived as a solids separator for manure slurries by Miner and Verley (2). This unit is a tube with a helically-wound fin attached to the interior surface and operates by flowing wastewater through the tube as it rotates. In contrast to the suspended growth systems of the popular package plants the Rotating Flighted Cylinder employs a fixed growth for biological treatment, in addition to its solids separating capacity. (Figures 1,2 and 3)

The biological mechanism of treatment in the Rotating Flighted Cylinder is similar to that of the Rotating

Biological Disc, although oxygen transfer characteristics differ because of the manner in which the two systems make contact with the wastewater.

While no RFC systems are in actual operation this device meets the criteria of simplicity, low maintenance and construction costs. The successful development of this system offers a valuable contribution to wastewater treatment in remote areas where conventional methods are functionally and/or economically impractical.

PURPOSE AND SCOPE

This study was to determine the feasibility of developing a sewage treatment system for small communities or establishments with the Rotating Flighted Cylinder serving as the basic unit.

Evaluation of the Rotating Flighted Cylinder's performance was based on the following:

(1) Its ability to separate solids from liquid in municipal sewage.

(2) The efficacy of biological treatment obtained at varying hydraulic loadings of municipal sewage.

(3) Its ability to transfer oxygen to water at various hydraulic flow rates and rotational speeds.

Figure 1. Eight-inch Rotating Flighted Cylinder.

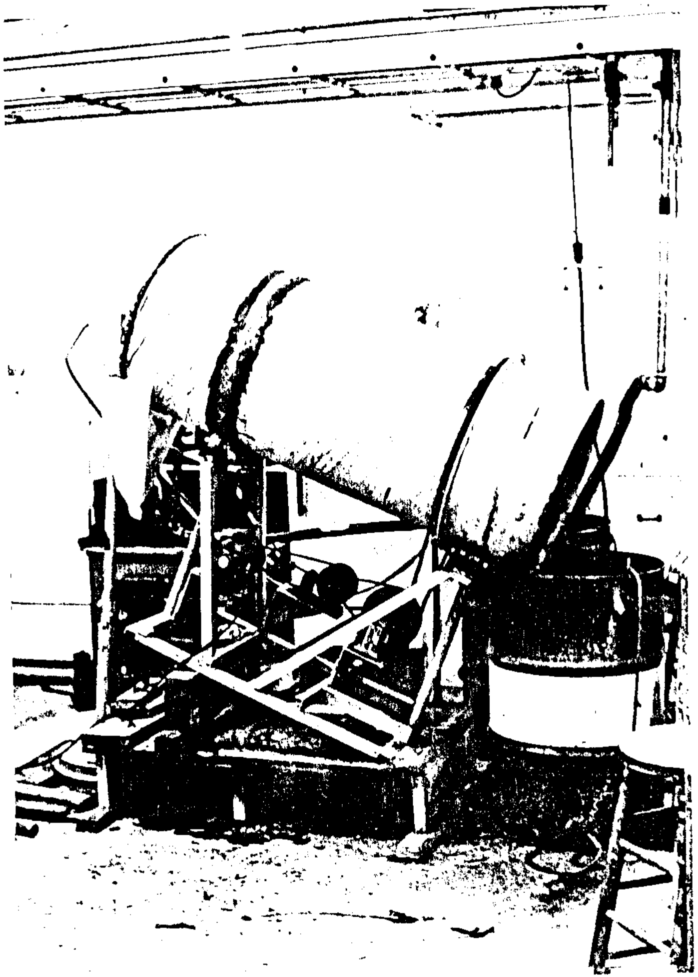
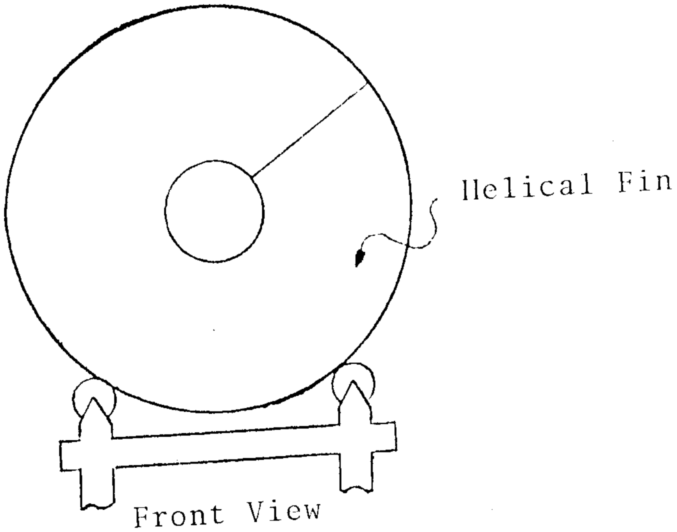
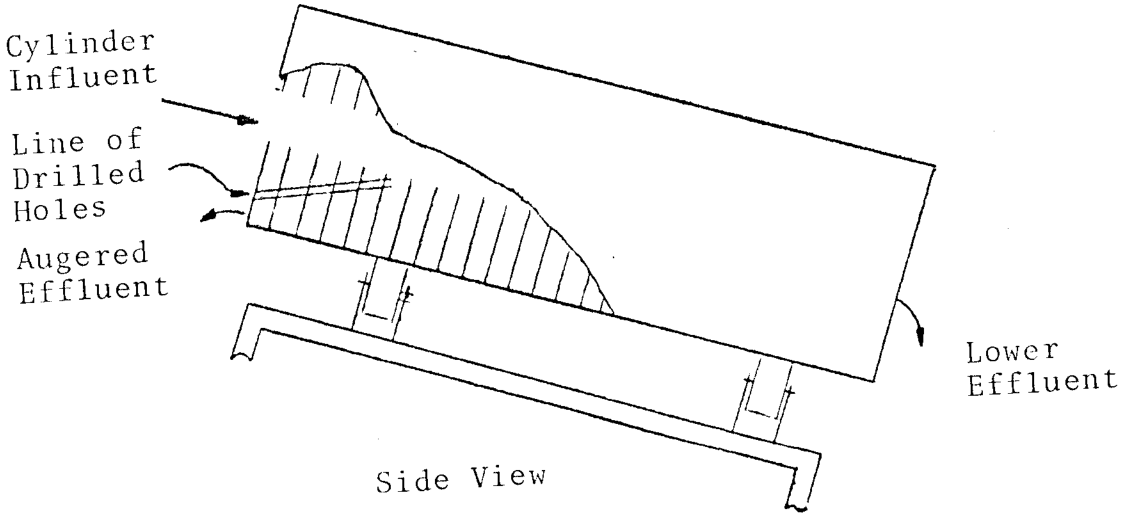


Figure 2. Twenty-four-inch Rotating Flighted Cylinder.



Front View



Side View

Figure 3 Schematic diagram of a rotating flighted cylinder

Table 1. Physical dimensions of 8-inch and 24-inch rotating-flighted cylinders.

	8-inch RFC	24-inch RFC
Length	4 ft.	5 ft.
Fin height	2½ in.	9 1/8 in.
Fin spacing	1 in.	1 in.
Angle to horizontal	13.3°	22°
Fin thickness	1/16 in.	3/16 in.
Volume of water	2.8 gal.	32 gal.
Rotational speed	0.79 rpm	0.71-2.61 rpm
Surface area*	35 ft.^{2}	320 ft.^{2}

* Effective area is approximately ten percent less than listed because of drilled holes at upper end of cylinder (see Figure 3).

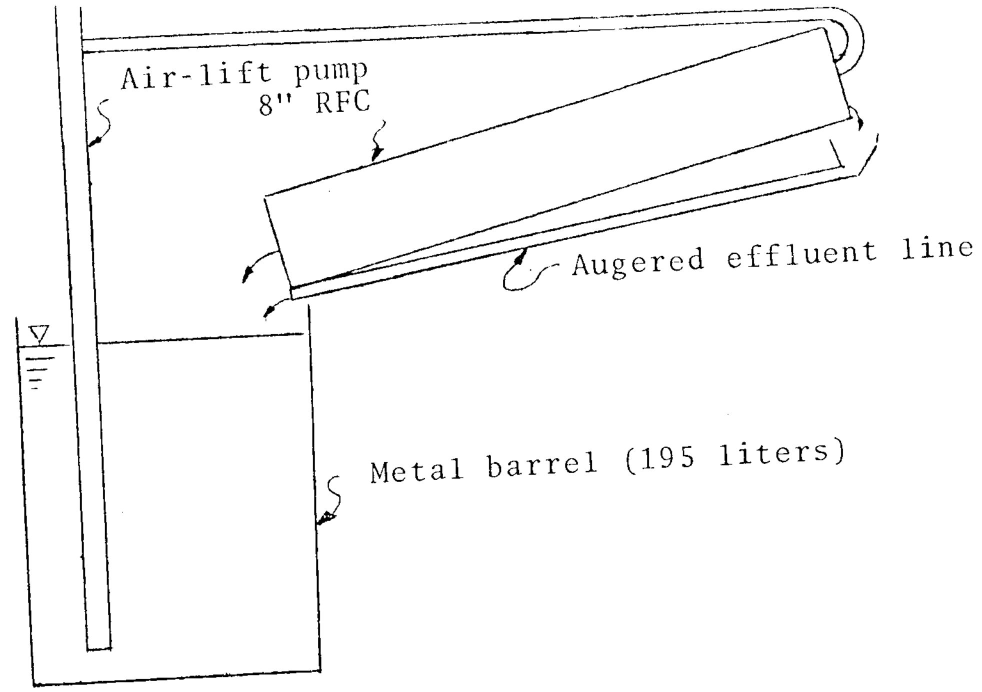


Figure 4 RFC system for slug load flow treatment

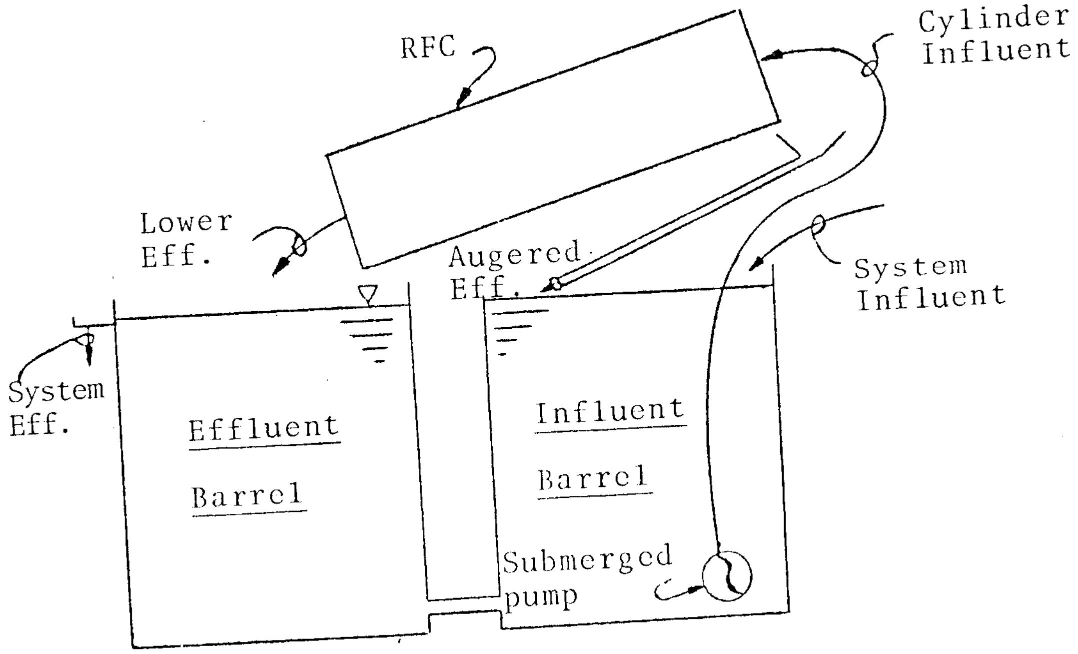


Figure 5 RFC system for batch and continuous flow treatment

THEORY AND BACKGROUND

Solid-liquid Separation

The Rotating Flighted Cylinder functions as a solid-liquid separator by causing waste to flow through a series of miniature settling basins partitioned by circular weirs acting as basin inlets and outlets. The settled solids are conveyed to the upper end of the cylinder by the interior fin, which in addition to forming weirs, also creates a helical channel which augers a portion of the flow upward as the cylinder rotates.

Miner and Verly (2) demonstrated that a 24-inch RFC was capable of significant solid-liquid separation when applied to swine and dairy waste slurries. A concentration factor defined as the ratio of retained solids[1] concentration of the augered effluent to the retained solids concentration of the cylinder influent was used to measure performance. For flows ranging from 4 to 50 lpm concentration factors for dairy manure slurries averaged about 12 without any increasing or decreasing trend. Swine manure slurries yielded a median concentration factor of 62 with a range of 20 to 112 for flows from 18 to 27 lpm.

An 8-inch RFC was found to remove 60% of the settleable solids in a beet pulp slurry at a flow of 2 lpm (3).

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[1] retained solids are defined as those not passing through a 1.19 mm screen mesh.

Sedimentation in the RFC can be theoretically described by considering each basin as an ideal settling tank and all solids as ideal discrete particles. All particles with a settling velocity, V_t, or greater will be completely removed when V_t enables the particle to fall a distance equal to the effective depth during the detention period in the basin.

$$V_t = y/T \qquad \text{(Equa. 1)}$$

y = depth

T = detention time

Figure 6 shows a velocity analysis curve for discrete particles (4).

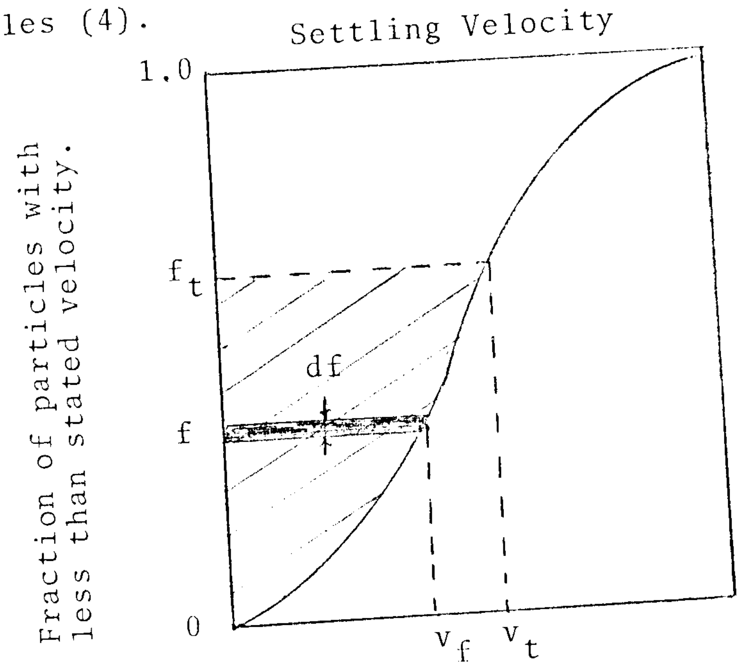

Figure 6. Settling-velocity analysis curve for discrete particles.

If n is the number of particles with $V \geq V_t$ which are completely removed then

$$n = (1-f_t)VC \qquad \text{(Equa. 2)}$$

f_t = fraction of particles with $V \leq V_t$

V = volume of basin

C = concentration of particles

The proportion of remaining particles removed by sedimentation will be v_f/v_t where $v_f < v_t$ and the total number removed, n_t, will be

$$n_t = n + VC \int_0^{f_t} v_f/v_t \, df \qquad \text{(Equa. 3)}$$

Since the depth of the RFC basin varies across its width, w, then v_t becomes a function of width. (Figure 7)

$$v_t = \frac{g(x)}{T} = v_t\ (x) \qquad \text{(Equa. 4)}$$

and f_t, in turn, also becomes a function of width.

$$f_t = f\ (x)$$

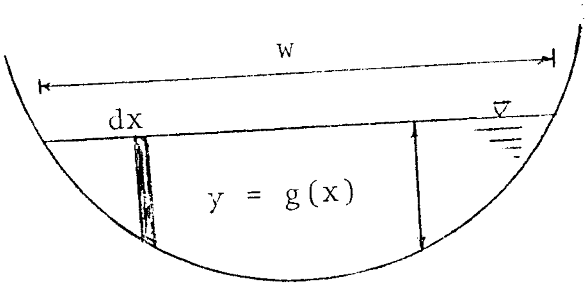

Figure 7. Cross-section of RFC settling basin.

The function f (x) can be separated into the fraction of particles with $v_t \geq y_{max}/T$ and the fraction with $v_t \geq g(x)/T$ but $\leq y_{max}/T$.

The number of particles, n, with $v \geq v_t(x)$ is now expressed

$$n = (1-f(w/s))\ VC + aC \int_0^w (1-f(x))g(x)dx \qquad \text{(Equa. 5)}$$

a = basin length

The proportion of remaining particles removed is now

$$aC \int_0^w \int_0^{f_t} v_f/v_t(x)\ df\ g(x)\ dx \qquad \text{(Equa. 6)}$$

and the total number removed, n_t, is

$$n_t = (a-f(w/s))VC + aC\int_0^w (1-f(x))g(x)dx + aC\int_0^w\int_0^{f_t} v_f/v_t(x)dfdx \qquad \text{(Equa. 7)}$$

Under the stated conditions all particles accounted for by the first two terms of Equation 7 would be removed in the first basin of the RFC and the remaining particles would be partially removed by each of the series of basins in the RFC as indicated by the final term of the equation. This model is of use to give a qualitative description of the sedimentation potential of the RFC rather than any quantitative application. The successive removal of particles described by Equation 6 is a key parameter to solid-liquid separation in spite of the non-ideal conditions that actually exist.

Deviation from ideal conditions will create factors both enhancing and inhibiting the sedimentation of solids. Since the ideal particles consist of discrete, non-floculating particles only the grit portion of municipal sewage can be considered as having truly ideal settling characteristics. The remaining solids can be classified under type-2 settling because they have a tendency to coalese, or flocculate, during sedimentation (5). As agglomeration among these particles occurs their settling velocity increases because the larger particles create a reduced surface-area-to-mass ratio and thus the drag forces opposing subsidence are reduced (4). This phenomena expedites solids removal more efficiently than the model predicts, however, type-2 particles are subject to other forces that oppose proper settling. Since these particles have specific gravities much lower than grit they are easily sheared and resuspended by turbulent forces.

Ideal conditions also presuppose that particles are initially equally distributed over the cross section of the tank. Although this is not true of particles entering the basin because entry is over a weir, the sloughing biomass particles are more uniformly distributed and a portion is already on the basin bottom.

Two other significant factors are short-circuiting and turbulence. The adverse effects of short-circuiting are reduced considerably by the numerous consecutive basins that must be passed through. It is apparent from observing the RFC in operation that a substantial portion of flow short-circuits across the top of each basin, however, there is a sufficient number of basins such that if a fraction of flow is dispersed in each basin then virtually all of the wastewater entering the cylinder will have spent non-short circuited time in several basins. In addition, that portion of flow dispersed in each basin will experience a much longer detention time than the average detention time. If one assumes that before leaving the cylinder all the flow has been dispersed in at least one basin then Figure 8 shows overflow rates for different degrees of short-circuiting. Since most of the flow spends time in a number of basins the chances of a particle experiencing an effective low overflow rate is increased.

Turbulent effects are capable of creating conditions both conducive and detrimental to sedimentation, although the latter dominates in most settling processes. Verley and Miner have related the Reynold's Number to flow through a RFC but no relationship has been developed between settling efficiencies and turbulence parameters (6).

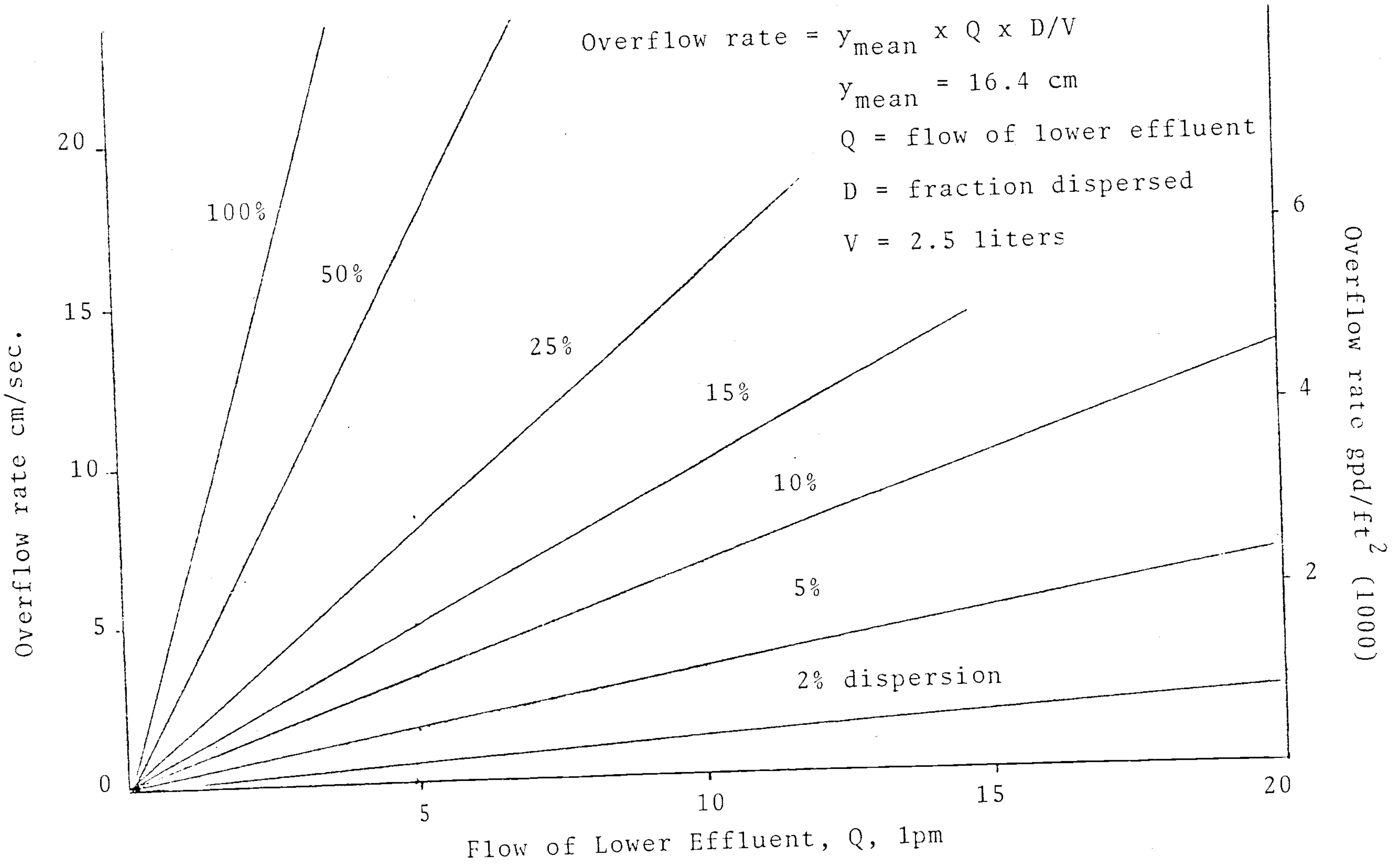

Figure 8 Effective overflow rates for 24-inch RFC

Oxygen Transfer

Aeration theory suggests that the magnitude of oxygen transfer in an RFC unit is a result of the degree of surface renewal, or turbulence. A rigorous quantitative model describing reaeration would be complex because of the hydraulic characteristics which include, in effect, a stream flowing down the cylinder running transverse to the augered stream. It would appear more productive to rely on empirical data in developing a relationship between measurable parameters and aeration rates.

Miner and Verly (2) measured oxygen transfer capabilities of an 8-inch RFC ranging from 20 grams O_2/day at one lpm to 800 grams O_2 and three lpm. It should be noted, however, than an air-lift pump was employed to recirculate water through the cylinder.

Power consumption for various wastewater aerators reported by Hervol and Pyle (7) is given in Table 2.

Table 2. Oxygen transferred per unit power consumed.

Aerator	kg O_2/kw-hr
Submerged Turbine with Sparger	1.6
Diffused Aeration	2.7
Slow Speed Turbines	3.7
High Shear Axial Flow	2,2

Biological Treatment

A biological growth medium exposing its microbial population to a liquid and gas phase intermittantly has been described as a two-phase contact (TPC) system (8). The predominant form of TPC treatment is the rotating biological disc (RBD) unit which has biological characteristics closely paralleling the RFC unit. This type of operation incorporates characteristics of the trickling filter and activated sludge processes into one unit by providing a media for fixed growth and a mechanism for continuous aeration.

Two-phase contact was first investigated in the United States by Buswell in 1929 on a unit he referred to as a biological wheel. Buswell's report concluded that the actual area occupied by the unit was about one-tenth of that required for a trickling filter, power cost was low and nitrification was accomplished (9). An experimental unit was later developed and A.T. Maltby secured a patent for it in 1931 (10). TPC systems have been used for wastewater treatment for over 15 years in Europe (11) and in 1969 more than 400 such operations existed there (12).

Perhaps one of the most important characteristics of the TPC system is its ability to maintain a very high microbial population during operation. Joost found food to microorganism ratios to be .02-.05 in a RBD system whereas activated sludge values are typically 0.3 (13). Equivalent MLVSS concentrations have been found at 17,000 mg/l (13) (14) and 50,000 mg/l (11) as compared to activated sludge values of around 3,000 mg/l (5). The large number of organisms expedites the stable treatment of concentrated waste and shock loadings. This attribute has made TPC systems attractive to industrial waste treatment as well as municipal (12).

The movement of the supporting media provides turbulence which enhances treatment efficiencies by increasing aeration of the wastewater and promoting biological activity. The latter phenomena was described by Hartman who showed that biological activity was increased by the transport of substrate and oxygen to a fixed biofilm by turbulence (15). Oxygen transfer is further expedited by exposure to the gas phase where the thin layer of waste covering the film is aerated under conditions providing a constand and excess supply of oxygen. While the rate-limiting step in trickling filter biofilms is most often oxygen transfer (16), two-phase contact provides a means for minimizing this effect.

In a rotating disc unit study, Pretorious (17) noted that the quantity of growth varied significantly throughout a series of discs with the growth being thicker nearest the influent entrance. In addition, he observed a distinct difference in the nature of the microbial population on the different discs, evidently due to the plug-flow regime in the unit.

The amount of biomass supported by the medium is limited by shearing forces, inability of biomass to support its own weight, possible anaerobic conditions at the surface of the medium, and concentration of substrate (14) (17). Pretorius obtained a maximum biomass of 43 gms/m^2 dry weight (17). Borchardt found biomass growth at approximately 200 gms/m^2 dry weight (9).

Several investigators have demonstrated that RBD processes are capable of achieving high degrees of nitrification (11) (18). Antonie has shown that when the wastewater BOD concentration approaches 30 mg/l the nitrifying organisms can compete with the more rapidly growing carbon oxidizing organism. Nitrification then proceeds rapidly and is virtually complete when the BOD concentration is approximately 10 mg/l (11).

Actual operation of two-phase contact systems has yielded treatment efficiencies of 80-90% when combined with primary and secondary clarification (11) (12) (19). The following observations have been made during operation of RBD systems and are presumed to have resulted from characteristics also possessed by the rotating flighted cylinder.

1. Concentrated wastes can be effectively treated (9) (11) (19).

2. Shock load capabilities are excellent (9) (19).
3. Bulking, foaming, or floating sludges are never a problem (9).
4. Washout potential is non-existent.
5. No clogging problem as in trickling filter.
6. Volume of sludge produced is low and dewaters more readily than waste activated sludge (9).
7. Nitrification at low organic loadings.
8. Effluent has slight brownish color, typical of biological filters (17).
9. Simple operation and low maintenance (9) (11).
10. Power requirements are low (9) (11)

Wastewater Treatment Costs[2]

Marginal costs for increased capacity in wastewater treatment are sufficiently small so as to create substantial decreases in cost per unit volume treated. Unfortunately treatment plants the size common to package plants present unit costs quite in excess of larger facilities. Nicoll found costs for extended aeration package plants in Great Britain to be as shown in Figure 9 (20). The Federal Water Pollution Control Administration reported the cost indicated by Figure 10 for similar plants in the United States (21). In a study of package treatment plant

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[2] All costs have been normalized to Oct. 1975 by the Engineering News-Record price-index.

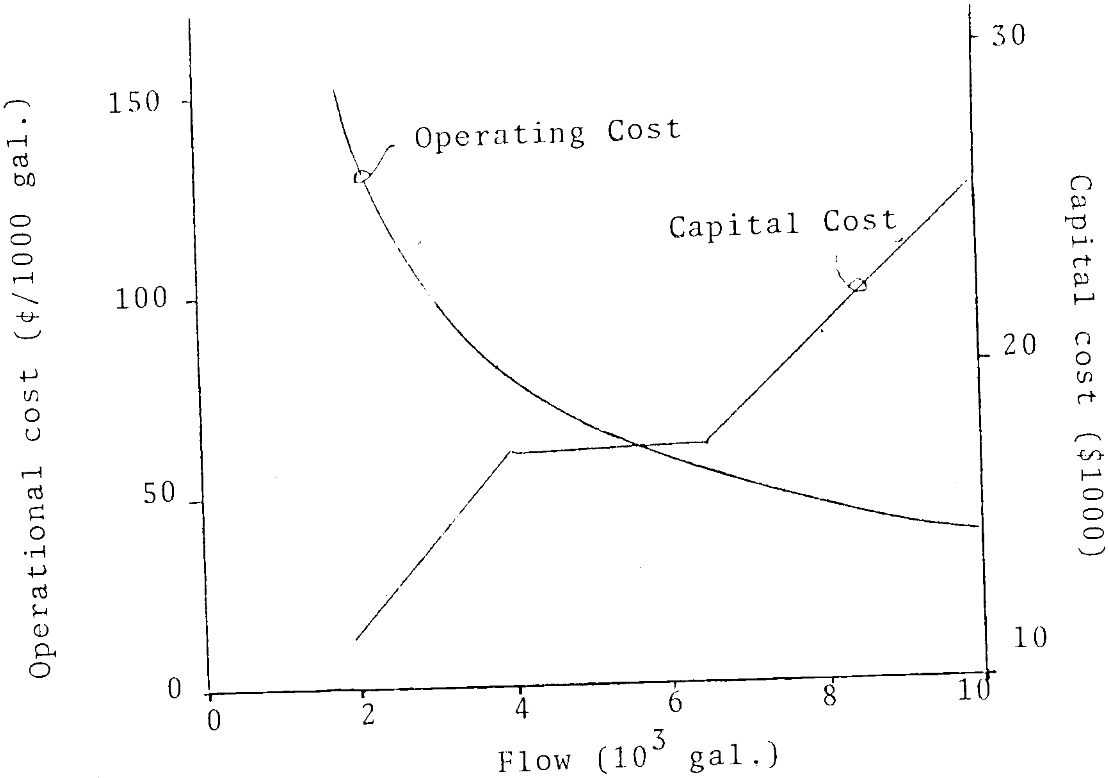

Figure 9 Operating and capital cost of package treatment plants according to Nicoll (20).

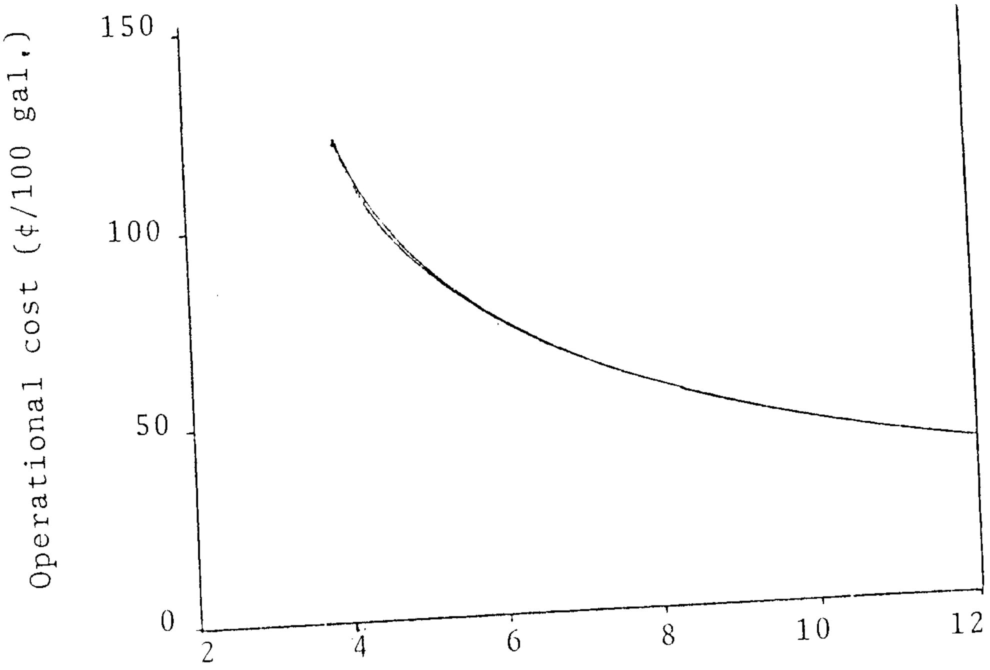

Figure 10 Operating and capital cost of package treatment plants according to FWPCA (21).

prices Lamp tabulated the prices found in Table (22).

Table 3. Mean list price of package plants by plant size.

Plant size (gpd)	No. of plants in sample	Mean list price ($)	Standard deviation
300	4	877	301
500	7	1593	765
600	6	1031	379
900	3	1358	221
1000	9	2572	2537
1500	9	2526	822
2000	7	5017	2182
2500	4	4530	1672
3000	5	6605	2384
4000	6	7088	2170
5000	11	8690	2133

METHODS AND MATERIALS

Apparatus and Procedure

The RFC unit and accompanying materials and equipment were set up and operated at the Water Research Demonstration Laboratory of Oregon State University adjacent to the Corvallis Wastewater Treatment Plant. Two RFC units of eight and 24 inch diameters were investigated. Table 1 gives information on the physical dimensions and Figure 3 shows illustrations of the units.

For sewage treatment, comminuted raw sewage was pumped from the treatment plant to the laboratory where it was made available for the RFC system. The 8-inch RFC was initially set up with a 55 gallon metal barrel into which the cylinder effluent emptied and from which the cylinder influent was pumped by an air lift pump. This system was fed by delivering a slug load of the desired volume of waste to the barrel (Figure 4). For the continuous flow regime of both RFC's and the batch treatment of the 24-inch RFC the system tested consisted of two 55 gallon metal barrels connected by a two-inch steel pipe located one inch from the bottom of each barrel (Figure 5). A submerged centrifugal pump at the bottom of the influent barrel pumped sewage through a ½-inch tygon tube to the upper end of the cylinder. Flow rate was controlled by pinching the tubing. The fluid flowed through the inclined cylinder as it rotated such that a portion of the flow exited through the lower end of the cylinder into the effluent barrel while the remaining flow was augered back to the upper end where it was returned to the influent barrel. Because of the low flow rates required for continuous flow treatment the influent sewage from the plant line was run into an overflow reservoir from which a low flow-rate pump delivered it to the RFC system. An air-lift pump was employed to accomplish this during operation of the 8-inch cylinder but due to difficulty in monitoring and regulating flow rates a variable speed Masterflex tubing pump was used during operation of the 24-inch cylinder. Effluent from the entire system left the effluent barrel at an opening cut four inches below the top of the barrel.

For oxygen transfer determinations a plug was inserted in the two inch pipe connecting barrels so that only the effluent barrel was used. The centrifugal pump was placed at the bottom of this barrel and delivered water to the cylinder's upper end. The augered effluent was returned to the effluent barrel. The sodium sulfite/colbaltous chloride method (23) was used to deoxygenate tap water. A Yellow Spring Instruments Dissolved Oxygen Meter-Model 54 was used to measure oxygen concentrations. For the 8-inch cylinder 14 grams of Na_2SO_3 and a pinch of CoCl were added to the barrel of tap water, stirred and allowed to sit several minutes. Flow and rotation were then started and dissolved oxygen in the barrel was recorded at five minute intervals until the DO concentration reached 7 mg/1.

The 24-inch cylinder was deoxygenated somewhat differently because the cylinder held a significant volume of water. After filling the barrel with tap water 14 grams of Na_2SO_3 and a pinch of CoCl were added. One hundred liters were then pumped into the cylinder without rotation and an equal amount of tap water was added to the barrel to fill it again. More Na_2SO_3 (7.5 gms) was added to the barrel, stirred, and allowed to sit a few minutes. Flow and rotation were then started and dissolved oxygen concentration was recorded at two minute intervals. All dissolved oxygen tests were run at temperatures between 15 and 20 degrees centigrade.

Sampling

Sampling during batch treatment was done in one-liter pyrex reagent bottles. Influent samples were collected from the line discharging raw sewage into the system. Treated samples were collected from the effluent barrel by submerging a sample bottle sufficiently to allow wastewater to flow gently into the bottle.

Composite samples over an eight or nine hour period were taken during continuous flow treatment, after the system had run approximately 16 hours. Influent was collected as it entered the influent barrel and effluent was collected as it left the effluent barrel. These samples were collected in a 250 graduated cylinder and immediately added to the composite sample in a one liter pyrex bottle at 3^{o}C. A typical composite sample schedule is shown below.

Time	Influent (ml)	Effluent (ml)
8:00 AM	200	50
9:30 AM	200	100
11:00 AM	200	200
12:30 PM	200	200
2:00 PM	100	200
3:30 PM	50	200
5:00 PM		200

Sampling for solids-liquid separation was accomplished by collecting samples every ten minutes for one hour from the influent to the upper cylinder end, the lower cylinder end effluent and the augered effluent. During operation of the 8-inch cylinder 50ml samples were taken and 150ml samples were used for the 24-inch cylinder. The samples collected over the sampling period were composited separately for each of the three collection points.

Dissolved oxygen samples during treatment were collected from the barrels in 300ml BOD bottles by submerging the bottle just enough to allow wastewater to flow gently into the bottle until completely full.

Analyses

Evaluation of the system was based primarily on the results of several standard wastewater analyses. Five-day

BOD and COD tests were run according to Standard Methods For The Examination of Water and Wastewater with the azide modification of the Winkler method used to determine dissolved oxygen in the BOD test. Both total and soluble samples were analyzed. Total samples were well-mixed aliquots of the sample as it was collected whereas soluble samples consisted of the filtrate of a total sample filtered through a GF/C 5.5cm Whatman glass fibre filter paper.

Kjeldahl nitrogen was determined according to Standard Methods (22) except 100ml. Micro-Kjeldahl flasks were used instead of 800 ml Kjeldahl flasks. Digestion was accomplished with 10ml of sample and 10 ml of digestion reagent boiled approximately 30 minutes beyond the cessation of visible white SO_3 fumes. The sample was then diluted by adding approximately 30ml of distilled water and 10ml of hydroxide=thiosulfate to raise the pH. The digested samples were steam distilled until approximately 20ml were collected in boric acid. The boric acid and distillate were then measured and analyzed for Ammonia concentration by nesslerazation and colorimetric determination with a Coleman Junior II spectrophotometer, Model 6-20.

Amonia nitrogen concentrations were measured by clarifying a 100ml sample with $ZnSO_4$, raising pH to ten with a NaOH and centrifuging at rpm for 15 minutes. The supernatent was then nesslerized and ammonia concentration determined with the Coleman spectrophotometer.

Suspended solids determinations were made by filtering a measured volume of sample through a previously dried and weighed GF/C 5.5cm Whatman glass fibre filter paper and drying for a minimum of four hours at 100°C.

Total Solids and Total Volitile solids were analyzed according to Standard Methods.

The azide-modification of the Winkler Method was used to find dissolved oxygen concentration on samples immediately after collection.

Analyses of BOD, COD, Kjeldahl and Ammonia nitrogen, were performed on samples that had been stored at 2°C for one to three days. All solids determinations were done within hours after collection of the sample.

BOD samples were run in triplicate, and COD and suspended solids samples in duplicate. For ammonia and Kjeldahl nitrogen one sample was prepared for colorimetry and three dilutions were then measured spectrophotometrically. Values were averaged, except any results of triplicate analyses deviating significantly (approx, 50%) from the accompanying samples were discarded.

DISCUSSION OF OPERATION AND RESULTS

In principle, operational and maintenance care of a RFC unit is minimal and simple. However, during this investigation engineering problems arose requiring special attention. Other than maintaining dependable flow rates with the air-lift pump, operation of the 8-inch RFC proceeded smoothly.

The 24-inch RFC presented unanticipated problems primarily because of its weight. Shortly after commencing operation, the belt from the drive shaft to the cylinder was unable to maintain sufficient friction and slipping became frequent. This situation was remedied by increasing tension on the belt. Although this solved the immediate problem, such a solution creates excessive wear on the shaft bearings and causes increased power consumption. More sophisticated engineering of the mechanical aspects of the system could no doubt alleviate this problem.

A second unexpected problem arose when the 24-inch RFC failed structurally. Abrasive wear and flexural stresses produced a crack where the lower rollers contacted with the cylinder. By doubling the number of lower rollers from two to four and thickening the contact area with a fiberglass band approximately ¼ inch thick and eight inches wide the load was sufficiently spread to relieve the problem. Shortly before termination of data collection the contact area of the upper rollers developed a similar failure which was temporarily repaired by a small epoxy-fiberglass band. Occassional pump clogging plagued the system but better adapted pumps could eradicate such occurences. No operational problems were encountered that appeared inherent in the RFC process and it is confidently envisioned that the entire system could be designed so as to require practically no operational or maintenance attention.

The time required to achieve a full microbial growth in the 8-inch RFC was one week. The 24-inch RFC was initially operated for three weeks before it attained a full growth, however, this appeared to be due to the smooth, slick surface which created problems of adherence. Once growth appeared, after the second week, it proceeded rapidly and later start-ups after growth had dried out completely required about a week to reach full density. Growth was considered "full" when the interior surface was completely covered with a thick bacterial slime.

Results of solids-liquid separation measurements in the 8-inch cylinder indicated that suspended solids are removed in the unit but that the mechanism appears to be by dissolution rather than sedimentation. For a range of flow rates both the lower effluent and the augered effluent most often had a lower suspended solids concentration than the cylinder influent. The degree of removal is more of academic interest rather than any pragmatic application as can be seen by Table 4.

Solids-liquid separation as well as liquefaction was accomplished by the 24-inch RFC as Table 5 illustrates. The augered effluent was seen visually to contain large amounts of sloughed biomass in every case whereas sloughed biomass was seen only at the highest cylinder flow rate in the lower effluent. The percent of solids removed[3], in the lower effluent increased with rotational speed. The percent of solids concentration[4] appeared to decrease with rotational speed, as expected.

The effect of rotational speed on the augered effluent concentration is influenced by two factors, turbulence and flow rate. As rotation increases, turbulence within the helical channel creates conditions less conducive to efficient settling and more expeditious to the dissolution of soluble particles by physically breaking them up, thus exposing more surface area, and proving a greater rate of liquid turnover at the solid-liquid interface of the particles. The flow of augered effluent increases proportionally with rational speed, therefore the rate of solids accumulation would have to increase with flow in

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[3] % solids removal $(SS_{inf}-SS_{lower\ eff})/SS_{inf}) \times 100$

[4] % solids concentration=$(SS_{aug\ eff}-SS_{inf})/SS_{inf}) \times 100$
SS=suspended solids

Table 4. Results of solids-liquid separation tests with municipal sewage by 8-inch RFC.

Cylinder Influent (1pm)	Suspended Solids				
	Cylinder Inf. (mg/1)	Lower Eff. (mg/1)	Percent Removal	Augered Eff. (mg/1)	Percent Conc.
2.3	161	167	-3.7%	162	+0.6%
2.8	184	186	-1.1%	153	-16.9%
4.1	195	186	+4.6%	181	-7.2%
4.6	94	85	+9.6%	73	-22.3%
6.9	211	164	+22.3%	174	-17.5%
10.4	102	---	----	87	-14.7%

Table 5. Results of solids-liquid separation tests with municipal sewage by 24-inch RFC.

Cyl. Inf. (1pm)	Augered Eff. (1pm)	RPM	Suspended Solids				
			Cyl. Inf. (mg/1)	Lower Eff. (mg/1)	Percent Removal	Augered Eff. (mg/1)	Percent Conc.
7.5	4.4	2.00	176	133	24.4%	204	+15.9%
6.8	3.0	1.36	201	161	19.9%	184	-8.5%
7.7	1.8	0.82	99	92	7.1%	98	-1.0%
21.1	2.9	1.36	193	194	-0.5%	168	-13.0%
7.8*	5.0	2.31	141	72	48.9%	157	+11.4%
8.8*	3.1	1.36	130	81	37.7%	152	+16.9%
7.6*	2.1	0.94	104	75	27.9%	179	+72.1%

*Raw sewage introduced with recirculated flow directly into cylinder.

order to maintain a constant solids removal on concentration But due to the turbulence factor solids accumulation is actually less and the dilution effect of the increased flow further limits solid-liquid separation. The sloughing of biomass might be increased by the higher shear of larger flows but the rate of sloughing is probably less than proportional to flow rate since the ability of the biomass to support itself is a function of other things in addition to shearing forces (13).

The effect of rotation on the lower effluent is attributed to the dissolution of solids as described above.

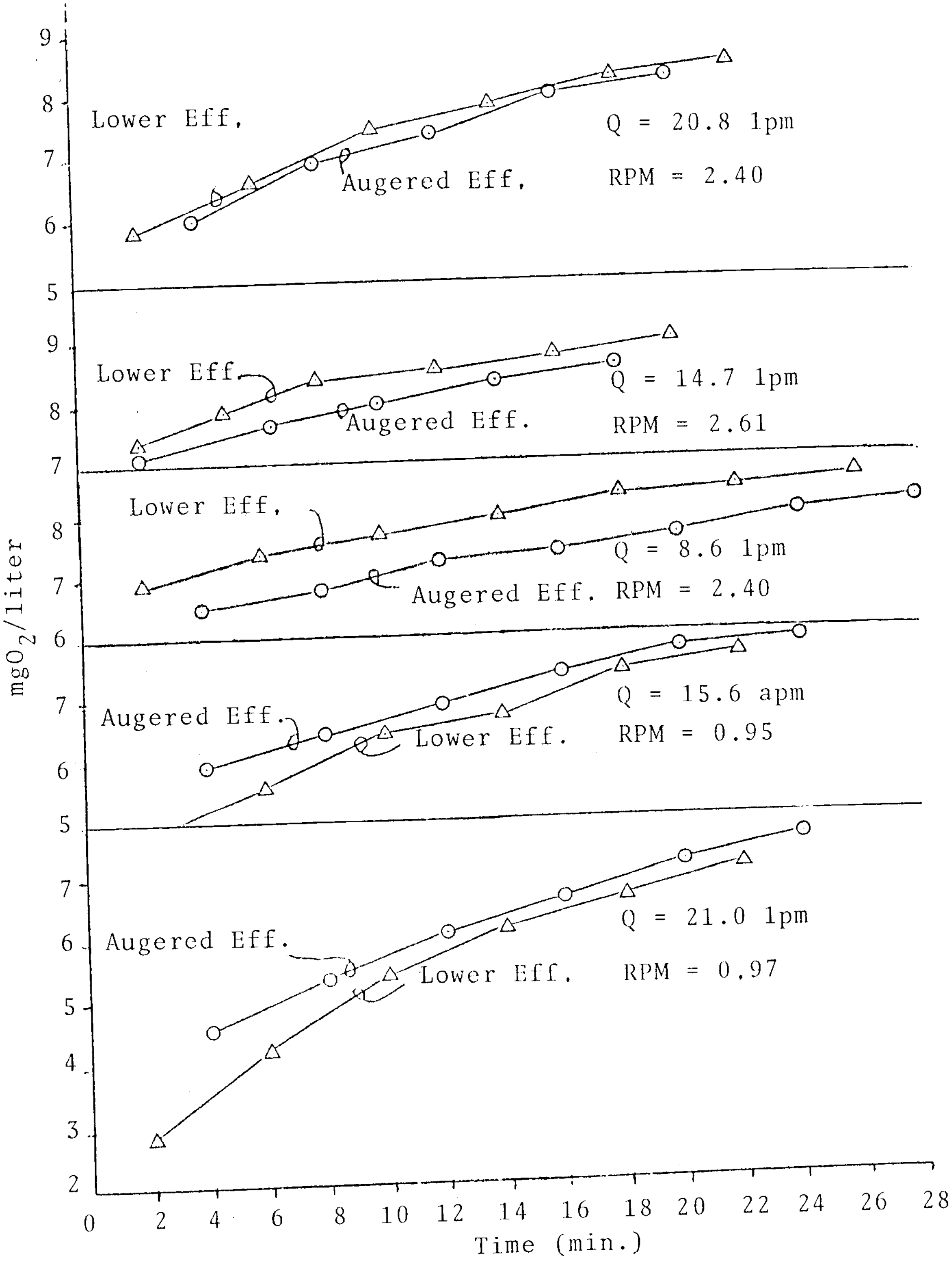
An important characteristic of the RFC, in contrast to trickling filter and RBD processes, is its ability to remove the solids it produces. While all three operations depend on the mechanism of converting substrate BOD to biomass for a significant portion of their BOD removal capacity, the RFC alone has the potential of eliminating secondary clarification.

Data obtained from the reaeration tests indicate that oxygen transfer is enhanced by increasing flow rate and rotational speed. It was also observed that the difference in oxygen concentration between the lower effluent and the augered effluent was a function of flow rate and rotational speed. At high rotational speeds (2.5 rpm) the lower effluent showed higher dissolved oxygen concentration than the augered effluent while at lower speeds (0.95 rpm) the reverse was true. As the flow rate increased the difference became less (Figure 11).

The reaeration rate of the augered stream is thought to be influenced by turbulence and the rate at which a thin liquid layer is exposed to the air phase although the relative contribution of each cannot be ascertained. Increasing rotational speed will cause both of these mechanisms to increase oxygen transfer. If the rate of total oxygen transferred is less than proportional to rotational speed then the augered effluent will have lower dissolved oxygen concentrations at higher rpm's since the augered flow is proportional to rotational speed. Also, the residence time in the cylinder contributes significantly to the rise in oxygen concentration. These effects probably account for the positions of the DO lines in Figure 11. The decreases in the difference between these lines is attributed to increased turbulence and corresponding mixing at higher flow rates. A Reynold's Number based on the flow over a circular weir is shown in Figure 12 (25).

Efforts to develop a definite correlation between reaeration data and a turbulence parameter proved futile. While it appears obvious that increased flow and rotation, both of which caused increased reaeration rates, contribute to greater agitation and mixing no adequate parameter based

Figure 11. Reaeration rates of augered and lower effluents in the 24-inch RFC



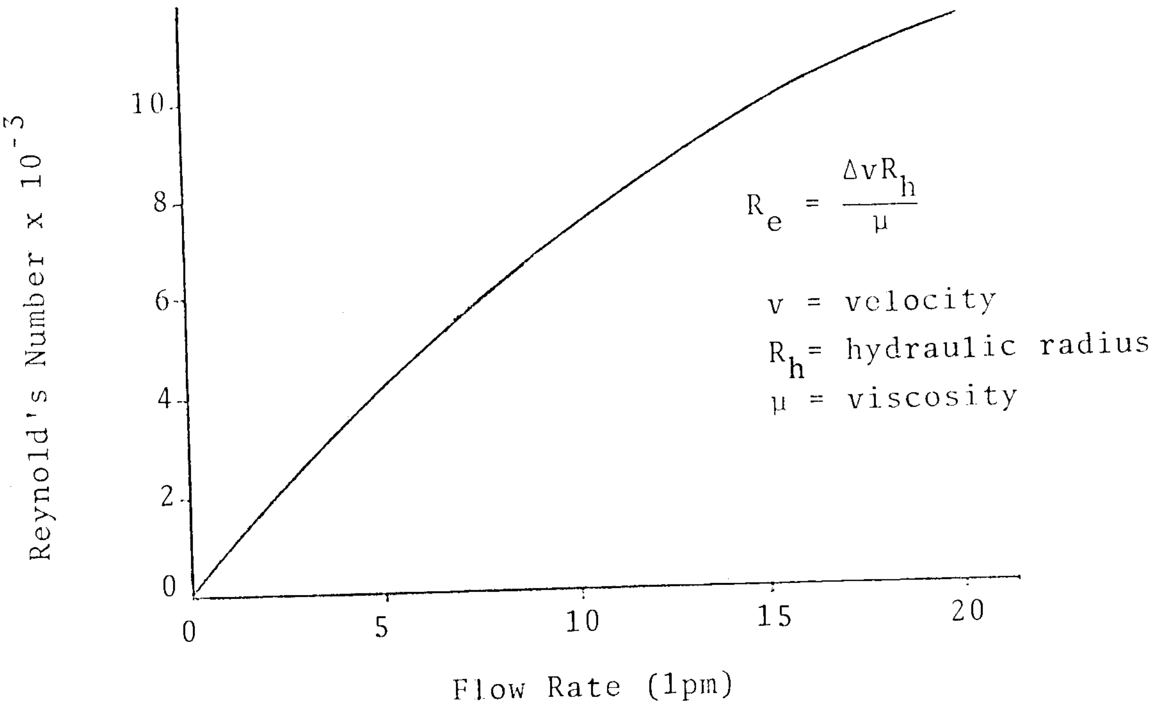


Figure 12. Reynold's Number for flow over a circular weir in the 24-inch RFC.

Day	Total BOD_5 (mg/l)				Total COD (mg/l)		
	Inf.	Eff.	%	k (hr^{-1})	Inf.	Eff.	%
1	200	15	93	.0648	415	74	82
2	200	18	91	.0602	404	80	80
3	280	28	90	.0576	559	116	79
4	220	24	89	.0554	466	86	82
5	210	15	93	.0660	300	100	67
6	210	14	93	.0677	310	76	75
7	180	20	89	.0549	314	55	82

Table 6. Results of slug load fed system with 8-inch RFC (Flow rate = 120 liters/day, System Volume = 200 l)

on flow, geometry and/or rotational speed was developed. Figures 13 and 14 show empirical relationships for the RFC units. Figure 13 indicates that there is a maximum flow corresponding with a given rotational speed where oxygen transfer is no longer enhanced by increasing the flow rate. This leveling off effect is probably due to increased depth in the stream flow, which, according to stream aeration theories (26), would actually lower the rate of reaeration within the stream itself. The increased flow would tend to cancel the decreased concentration rate thus creating a more or less constant overall rate coefficient.

A comparison of BOD removal and reaeration capacity indicates that the BOD is removed two to three times faster than oxygen is being supplied when $BOD_{ult} = 1.5 \times BOD_5$. Two reasons for the existence of this situation are listed below:

1. Removal of BOD through sedimentation.
2. Aeration of the thin layer of waste on the biofilm as it is exposed to the air phase contributes significantly to reaeration in a manner not fully reflected by the reaeration test.

Power consumption in the RFC system resulted from an influent pump, a recycle pump, and a motor rotating the cylinder.

Since the need for an influent pump will depend on whether or not the treatment site allows for gravity flow

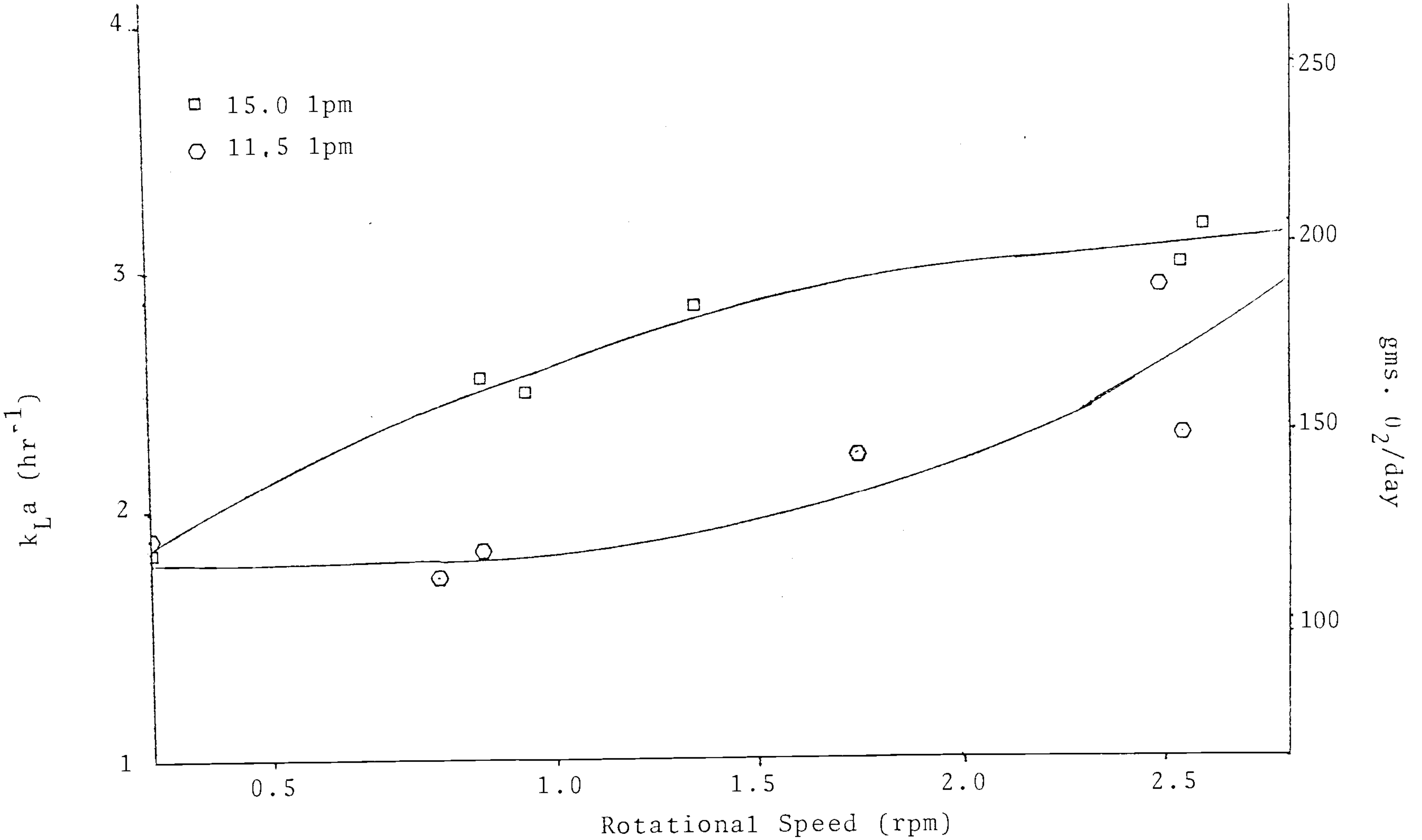


Figure 13. Oxygen transfer rate -vs- rotational speed in the 24-inch RFC.

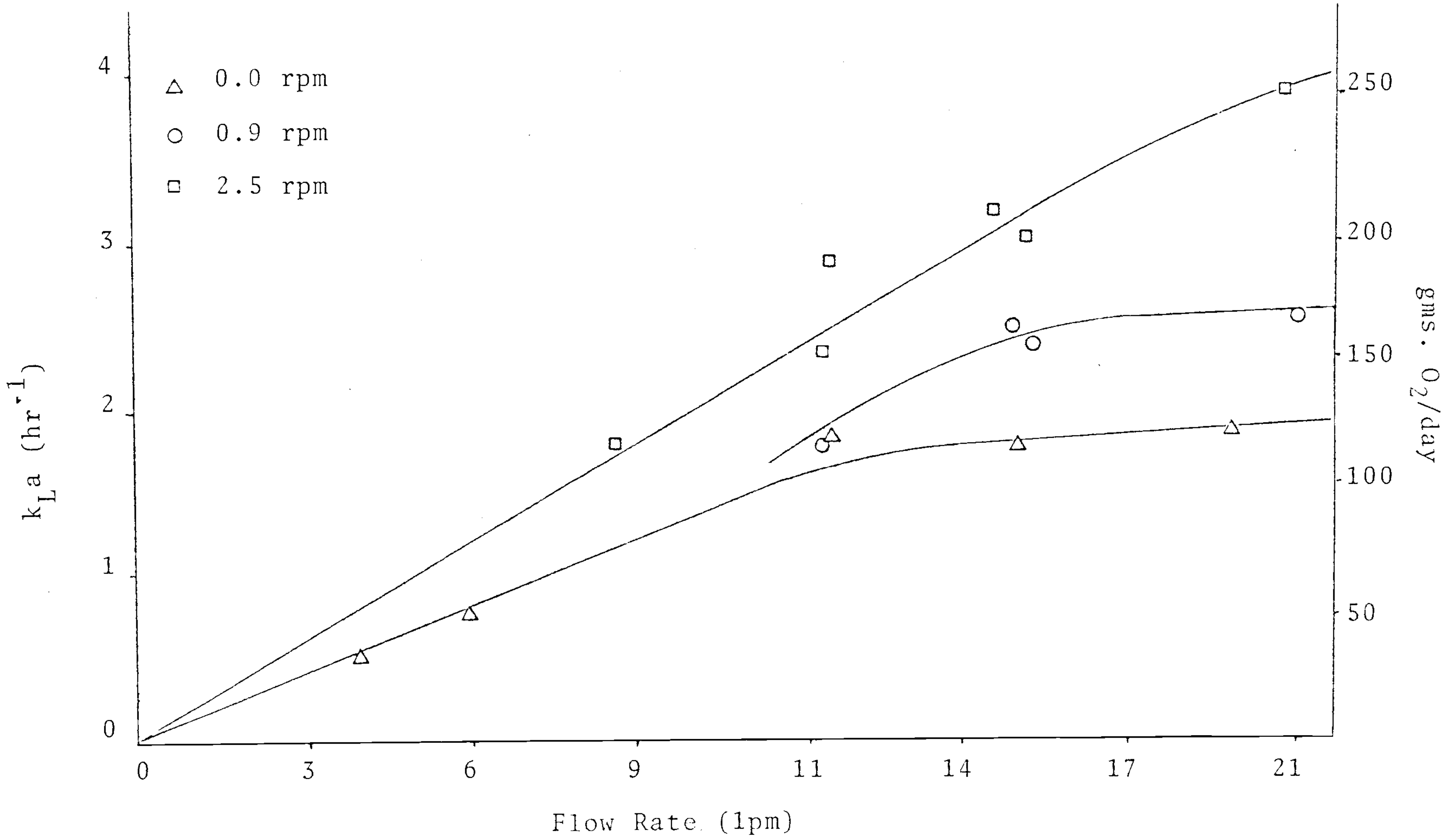


Figure 14. Oxygen transfer rate -vs- flow rate in the 24-inch RFC.

Table 7. Rearation coefficients and oxygen transfer capacity.

8-inch RFC			24-inch RFC			
Cyl. Inf. (1pm)	k_La (hr^{-1})	gmsO_2/day	Cyl. Inf. (1pm)	RPM	k_La (hr^{-1})	gmsO_2/day
2.1	0.483	20.9	4.3	0.00	0.47	30.3
2.6	0.566	24.5	6.0	0.00	0.74	47.9
2.8	0.508	21.9	8.6	2.40	1.89	122.5
3.0	0.565	24.4	11.7	0.00	1.89	122.5
3.0*	0.583	25.2	11.6	0.72	1.72	111.5
4.6	0.593	25.6	11.6	0.89	1.84	119.2
12.5	2.120	91.6	11.2	1.76	2.24	145.2
			11.3	2.55	2.32	150.3
			11.8	2.50	2.96	191.8
			11.8	2.66**	1.92	124.4
			15.0	0.00	1.93	118.6
			15.2	0.73	2.57	166.5
			15.2	0.94	2.50	162.0
			15.6	0.95	2.38	154.2
			14.8	1.36	2.88	186.6
			15.3	2.55	3.06	198.3
			14.7	2.61	3.17	205.4
			19.7	0.00	1.86	120.5
			21.0	0.97	2.54	164.6
			20.8	2.40	3.95	256.0

*no rotation

**opposite rotation

this source of power consumption is not included in the useage of the RFC system.

Figure 15 shows power consumption for the recycle pump based on flow through a ten foot, ½-inch steel pipe and an elevation head of 2.5 feet. Figure 16 shows power consumption for a ½ hp motor rotating the cylinder. The motor values were obtained from actual wattage readings during operation of the system and it is conceivable that more refined engineering could reduce the amount of energy required here.

As an aerator the RFC is far less efficient than conventional aeration units (Table 2). Using reaeration test data the 24-inch RFC has an oxygen transfer efficiency of about 40 grams 0_2/kw-hr. By calculating an efficiency based on the soluble BOD removed, the transfer becomes significantly larger. Batch test showed that as much as 150 mg/1 of soluble BOD could be removed in a two hour detention period. By projecting BOD_{ult} to be 1.5 x BOD_5 the oxygen transfer efficiency is approximately 200gms 0_2/kw-hr. This value is probably conservative because of the conservative inaccuracies inherent in the soluble BOD_5 measurements.

Evaluation of the biological treatment efficiency of the RFC was somewhat obscured by the accumulation of solids in the influent and effluent barrels. By arranging the recirculating flow so that the liquid was pumped from the

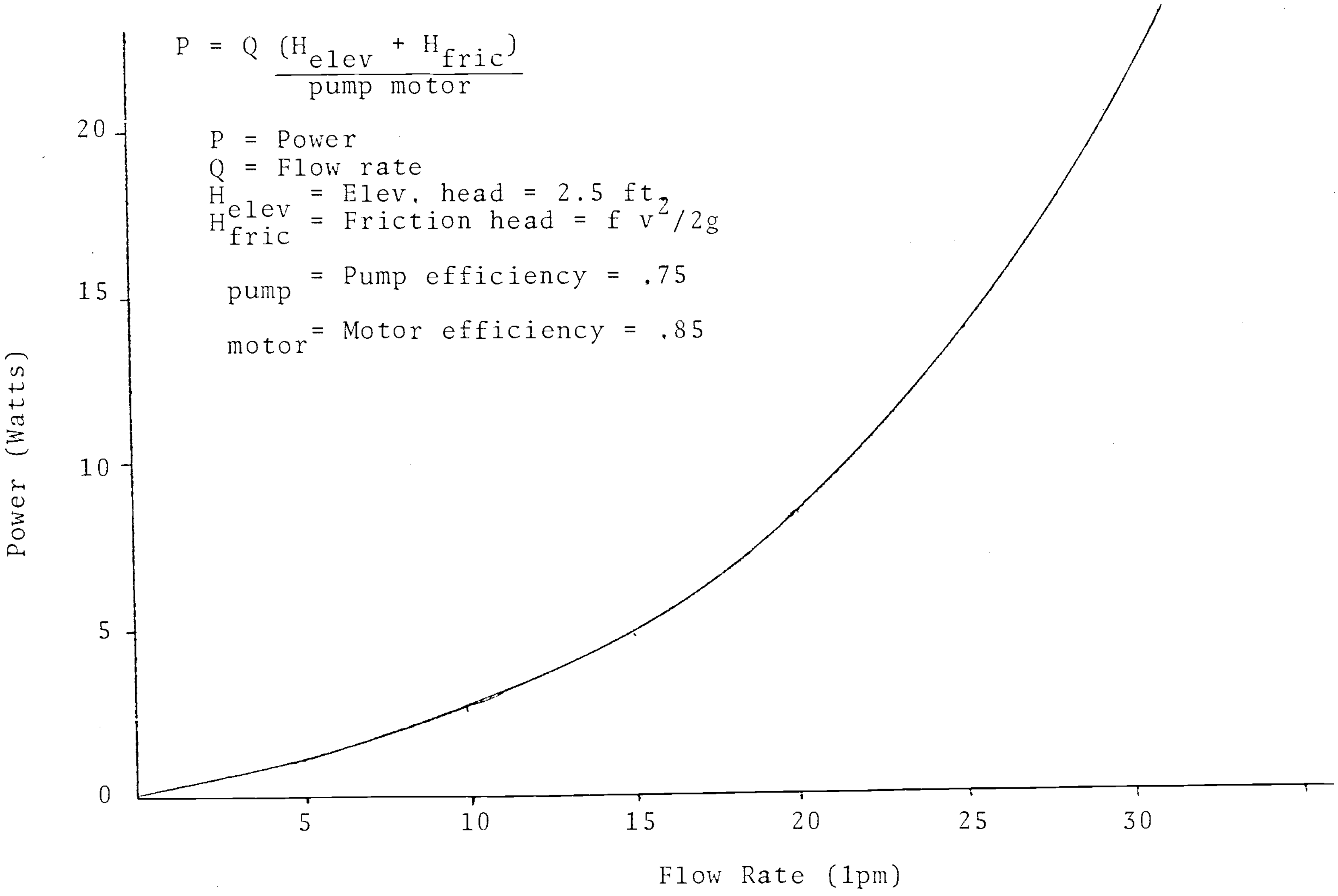


Figure 15. Pump power consumption in RFC system

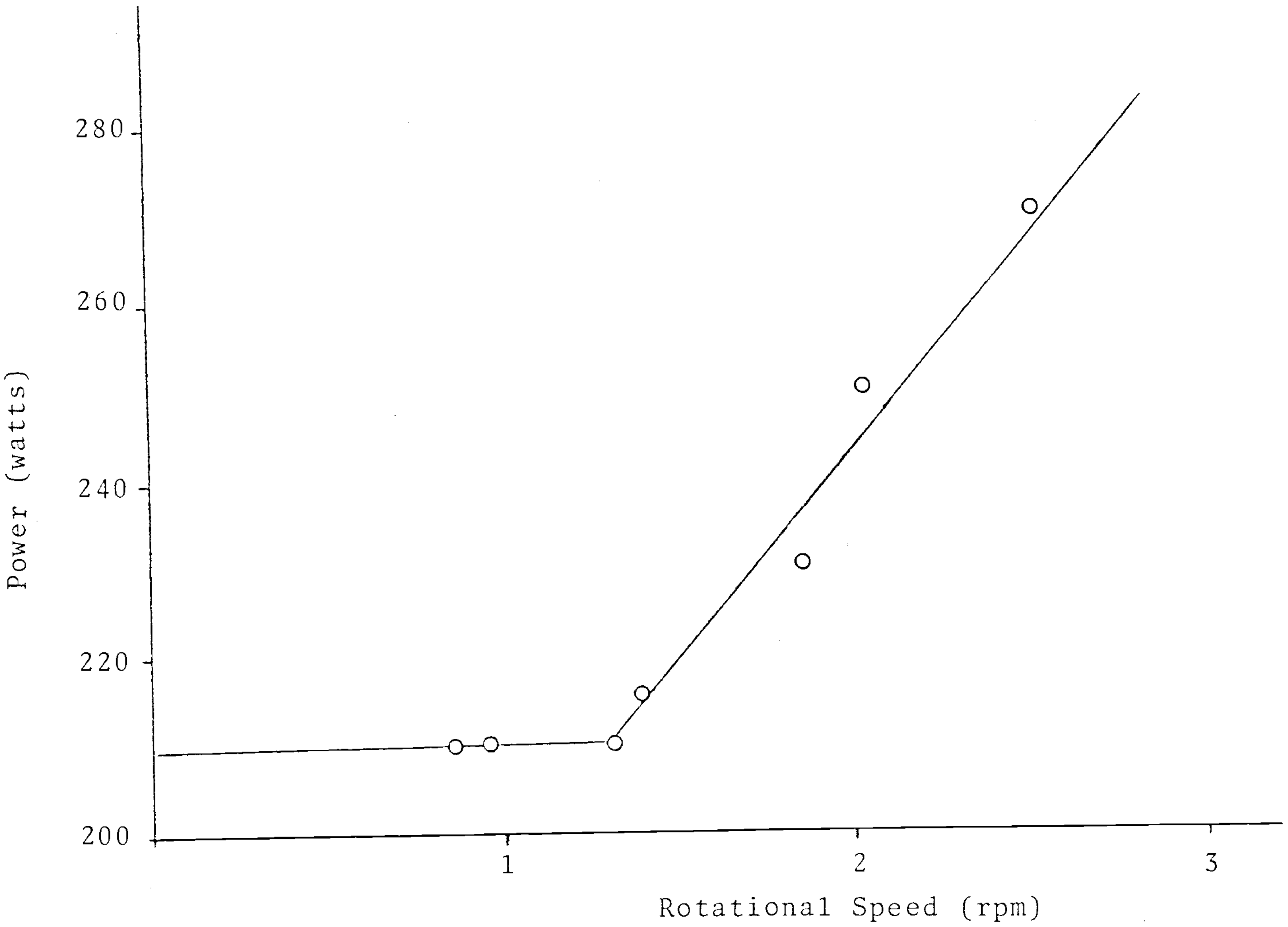


Figure 16. Power Consumption of ½-horsepower motor used to rotate 24" RFC.

bottom of the barrels it was hoped to keep solids sufficiently dispersed throughout the system so as to avoid their deposition (Figure 5). In spite of this, sedimentation in the barrels appeared to account for removal of a portion of the waste load.

Two different feed systems were used to test the treatment capabilities of the 8-inch RFC. A daily slug load of 120 liters of raw sewage was added to the system shown in Figure 4 and results are given in Table 6. The second system (Figure 5) was a continuous flow regime with results given in Tables 8 and 9.

By considering the rate of BOD_5 removal to approximate a first order reaction one can determine the rate constant for each system,

$$dL/dt = -kL$$

$$1/T \ln (L_{inf}/L_{eff}) = -k$$

where T is the average detention time in the system and L is BOD_5. For the seven runs of the slug load fed system an average k value of .0609/hr was obtained with a standard deviation of .00486.

The wide variation of influent concentrations presented difficulty in evaluating treatment efficiencies for the continuous flow system and the unreliability of the influent air-lift pump accounted for a degree of inconsistancy in the data. Nevertheless, average k values of .0674/hr for total

Table 8. BOD$_5$ results of municipal sewage continuous flow treatment with 8-inch RFC

Influent flow (lpm)	Cylinder Influent (lpm)	BOD$_5$ (total) mg/l				BOD$_5$ (soluble) mg/l			
		Inf.	Eff.	remov	k(hr-1)	Inf.	Eff.	remov	k(hr^{-1})
0.07	3.4	101	29	71.3%	.0131	23	10	56.5%	.0087
0.10	3.9	252	43	82.9%	.0265	93	23	75.3%	.0210
0.19	4.6	288	83	63.6%	.0355	78	21	73.1%	.0374
0.24	8.5	492	173	64.8%	.0376	235	80	66.0%	.0388
0.33	4.6	528	139	73.7%	.0661	199	24	87.9%	.1047
0.39	10.5	552	210	62.0%	.0565	237	109	54.2%	.0454
0.50	3.4	222	106	52.3%	.0554	90	35	61.1%	.0708
0.50	3.3	295	132	55.3%	.0603	118	52	55.9%	.0615
0.60	3.2	276	80	71.1%	.1115	66	21	68.2%	.1031
0.71	3.4	336	104	69.1%	.1249	116	39	66.4%	.1161
0.90	2.7	187	84	55.1%	.1080	76	38	50.0%	.0936
1.68	2.7	282	180	36.2%	.1131	114	92	19.3%	.0540

Table 9. COD results of municipal sewage continuous flow treatment with 8-inch RFC

Influent flow rate (lpm)	Cylinder flow rate (lpm)	COD (total) mg/l			COD (soluble) mg/l		
		Influent	Effluent	removal	Influent	Effluent	removal
0.07	3.4	380	121	68.2%	105	75	28.6%
0.10	3.9	454	133	70.1%	163	72	55.8%
0.19	4.6	451	172	61.9%	174	91	47.7%
0.24	8.5	900	327	63.7%	524	192	63.4%
0.33	4.6	896	267	70.2%	485	88	81.8%
0.39	10.5	834	400	52.0%	472	230	51.3%
0.50	3.4	473	200	57.5%	184	81	56.0%
0.50	3.3	522	212	59.4%	207	110	46.9%
0.60	3.2	-	-	-	-	-	-
0.71	3.4	661	169	74.4%	176	73	58.5%
0.90	2.7	514	167	67.5%	159	125	21.4%
1.68	2.7	502	318	36.7%	175	147	16.0%

BOD_5 and .0629/hr for soluble BOD_5 were calculated with standard deviations of .0379 and .0336, respectively.

Batch treatments with the 24-inch RFC indicated that the system was capable of high organic matter removal efficiencies but it was unclear as to what portion of treatment could be attributed to sedimentation and decomposition in the barrels. An attempt to ascertain the removal in the barrels was made by filling the barrels with raw sewage and allowing the sewage to remain without recirculation. Two separate non-circulating runs showed significantly different results but soluble BOD_5 and COD appeared to remain fairly constant. Since sedimentation in the barrels is minimized by the recirculation of the system it is estimated that the cylinder is responsible for as much as 80 to 90% of the system's treatment efficiencies. Tables 10 and 11 show how treatment efficiency progressed with time. In determining rate coefficients it was found that the k values decreased with the length of treatment. For total BOD_5 it is suspected that the agitation and turbulence of the system enabled a greater BOD demand by the dissolution of particulates than was attained in the BOD bottle. This suggests that the system is actually removing more BOD than is reflected by the initial measurements. Soluble BOD_5 is affected by this same phenomena but to an even greater extent. The difference between initial soluble BOD_5 and the total particulate BOD_5

Table 10. BOD_5 and DO results of municipal sewage batch treatment with 24-inch RFC

Detent. Time (hrs)	Cyl. Flow (lpm)	Rotat. Speed (rpm)	Total BOD_5 (mg/l) Inf.	Eff.	removal	$k(hr^{-1})$	Soluble BOD_5 (mg/l) Inf.	Eff.	removal	$k(hr^{-1})$	Dis. Oxygen (mg/l)
2.0	0.0	0.0	344	215	37.5%	.235	119	99	16.8%	.092	-
4.0	0.0	0.0	344	190	44 8%	.148	119	96	19.3%	.054	-
8.0	0.0	0.0	344	160	53.5%	.096	119	107	10.1%	.013	-
12.0	0.0	0.0	344	169	50.9%	.059	119	96	19.3%	.018	-
6.0	8.7	1.33	423	93	78.0%	.253	212	36	83.0%	.296	-
16.25	7.9	1.33	336	10	97.0%	.216	189	5	97.4%	.224	-
8.0	9.4	0.75	467	67	85.7%	.243	249	18	92.8%	.328	2.3
12.0	9.4	0.75	467	42	91.0%	.201	249	13	94.8%	.246	5.3
16.0	10.3	0.72	422	49	88.4%	.135	265	18	93.2%	.168	6.1
2.0	7.5	2.28	447	178	60.2%	.460	212	87	59.0%	.445	0.2
4.0	7.5	2.28	447	81	81.9%	.427	212	34	84.0%	.458	1.8
8.0	7.5	2.28	447	39	91.3%	.305	212	13	93.9%	.349	2.7
12.33	7.5	2.28	447	30	93.3%	.219	212	2	99.1%	.378	4.6

Table 10.(cont.) BOD_5 and DO results of municipal sewage batch treatment with 24-inch RFC

Detent. Time (hrs)	Cyl. Flow (lpm)	Rotat. Speed (rpm)	Total BOD_5 (mg/l)				Soluble BOD_5 (mg/l)				Dis. Oxygen (mg/l)
			Inf.	Eff.	removal	k(hr^{-1})	Inf.	Eff.	removal	k(hr^{-1})	
20.25	7.5	2,28	447	16	96.4%	.164	-	-	-	-	4.9
2.0	20.9	0.71	426	227	46.7%	.315	134	47	64.9%	.524	0.9
4.0	20.9	0.71	426	134	68.5%	.289	134	7	94.8%	.738	1.3
8.17	20.9	0,71	426	73	82.9%	,216	134	7	94.8%	.361	5.5
12.0	20.9	0.71	426	-	-	-	134	9	93.3%	.225	6.7
2,0	21.4	2.22	498	246	50.6%	.353	251	88	64.9%	.524	-
4.0	21.4	2.22	498	120	75,9%	.356	251	21	91.6%	.620	2.5
7,83	21.4	2,22	498	41	91.8%	.312	251	5	98.0%	.490	5.8
12.0	21.4	2.22	498	18	96.4%	.277	251	5	98.0%	.326	8.0
2.0	17.5	2.22	504	224	55,6%	.401	230	72	68.7%	.581	-
4,08	17.5	2.22	504	115	77.2%	,362	230	26	88.7%	.545	2.0
8.0	17.5	2.22	504	40	92.1%	.317	230	9	96.1%	.405	5.7
12.0	17.5	2.22	504	18	96,4%	.278	230	6	97.4%	.304	6.5

Table 11. COD results of municipal sewage batch treatment with 24-inch RFC

Detention Time (hrs)	Cyl. Inf. (lpm)	RPM	COD (total) mg/l			COD (soluble) mg/l		
			Inf.	Eff.	removal	Inf.	Eff.	removal
2.0	0.0	0.00	919	433	52.9%	-	-	-
4.0	0.0	0.00	919	393	57.2%	251	200	20.3%
8.0	0.0	0.00	919	374	39.3%	251	220	12.4%
12.0	0.0	0.00	919	359	60.9%	251	209	16.7%
2.0	0.0	0.00	1175	878	25.2%	-	-	-
10.0	0.0	0.00	1175	732	37.7%	-	-	-
6.0	8.7	1.33	856	166	80.6%	391	104	73.4%
16.3	7.9	1.33	675	64	90.5%	300	56	81.3%
8.0	9.4	0.75	877	153	82.6%	389	73	81.2%
12.0	9.4	0.75	877	130	85.2%	389	79	79.7%
16.0	10.3	0.72	935	147	84.3%	410	84	79.5%
2.0	7.5	2.28	872	327	62.5%	312	169	45.8%
4.0	7.5	2.28	872	193	77.9%	312	113	63.8%
8.0	7.5	2.28	862	118	86.5%	312	73	76.6%

Table 11 (cont.). COD results of municipal sewage batch treatment with 24" RFC

Detention Time (hrs)	Cyl. Inf. (lpm)	RPM	COD (total) mg/l Inf.	Eff.	removal	COD (soluble) mg/l Inf.	Eff.	removal
12.3	7.5	2,28	872	82	90,6%	312	62	80.1%
20.3	7.5	2.28	872	81	90.7%	-	-	-
2.0	20.9	0.71	743	397	46.6%	267	132	50.6%
4.0	20.9	0.71	743	252	66.1%	267	73	72.7%
8.2	20.9	0.71	743	145	80.5%	267	53	80.2%
12.0	20.9	0.71	743	105	85.9%	267	56	79.0%
2.0	21.4	2.22	920	423	49.7%	512	186	63.7%
4.0	21,4	2.22	920	264	65.6%	512	90	82.4%
7.8	21.4	2.22	920	132	85.7%	512	50	90.2%
12.0	21.4	2,22	920	81	91.2%	512	50	90.2%
2.0	17.5	2.22	1131	422	62.7%	430	152	64.7%
4.1	17.5	2.22	1131	247	78.2%	430	94	78.1%
8.0	17.5	2.22	1131	132	88.3%	430	65	84.9%
12.0	17.5	2.22	1131	87	92.3%	430	55	87.2%

that is eventually solubilized in the system is greater than the difference between the particulate BOD_5 solubilized in the BOD bottle and that solubilized in the system. Since these relative amounts were unknown the rate coefficients were calculated as an average of the measurements over a twelve hour period (Table 12).

The rate constants increased with increasing flow rates through the cylinder probably due to greater reaeration capacity at higher flow rates. Rate also appeared to be more rapid at high rpm's probably again due to reaeration and increased exposure to the air-phase on the rotating biofilm.

The continuous flow run with the 24-inch RFC yielded lower treatment efficiencies than equivalent batch treatments except for removal of soluble BOD_5 (Table 13). When the average continuous flow detention time is compared to a similar batch treatment detention time it is seen that total COD removal is about 12% lower, soluble COD is about 6% lower, total BOD_5 is 15% lower, and soluble BOD_5 is approximately the same. The higher suspended solids concentration in the effluent appeared responsible for the lower efficiencies of the "total" measurements. This was also reflected in the rate constant for total BOD_5 removal. The soluble BOD_5 rate constant is about the same as the batch treatments when the variation with cylinder flow is considered.

The ratio of the soluble BOD_5 rate coefficient for the 8-inch and 24-inch RFC continuous flow systems is 5.4 and

Table 12. Average BOD_5 rate coefficients for batch treatment with 24-inch RFC.

Cylinder Flow Rate (lpm)	Rotational Speed (rpm)	Total BOD_5 $k(hr^{-1})$	Soluble BOD_5 $k(hr^{-1})$
8.0	1.33	.235	.260
9.4	0.75	.222	.287
7.5	2.28	.353	.408
20.8	0.71	.273	.462
21.4	2.22	.325	.490
17.5	2.22	.340	.459

Table 13. Results from continuous flow treatment with 24-inch RFC.

Cylinder flow rate = 12.7 lpm, Rotational speed = 2.07 rpm

Flow (lpm)	Total COD (mg/l)			Soluble COD (mg/l)			Suspended Solids (mg/l)		
	Inf.	Eff.	removal	Inf.	Eff.	%	Inf.	Eff.	removal
0.88	824	195	76.3%	363	73	79.9%	352	94	73.3%
1.00	854	232	72.8%	359	80	77.7%	398	110	72.5%
1.00	954	295	69.1%	393	107	72.8%	448	153	65.8%

Flow (lpm)	Total BOD$_5$ (mg.l)				Soluble BOD$_5$ (mg/l)				DO (mg/l)
	Inf.	Eff.	removal	k,hr^{-1}	Inf.	Eff.	removal	k,hr^{-1}	
0.88	398	90	77.4%	.157	250	8	96.8%	.364	1.5
1.00	442	110	75.1%	.167	239	15	93.7%	.332	0.5
1.00	430	119	69.4%	.154	222	15	93.2%	.323	0.3

the ratio of their areas is 9.1. This comparison is not completely valid because of the error in the 8-inch RFC coefficient.

By expressing the RFC's organic loading and removal capacity in terms of organic load per area per time the RFC system can be compared with RBD systems (see Table 1 for RBD surface areas). Figure 17 through 21 show removal efficiency as a function of daily loading per square meter of surface area. A relationship developed by Popel (27) for RBD systems is included in the figures illustrating BOD_5 removal efficiency. Popel's curve resulted from data collected at numerous RBD systems in Europe which included secondary clarification. The soluble BOD_5 data (Figure 18) appears to correlate very well with Popel's RBD observations. Soluble BOD_5 offers the best comparison because secondary clarification has little effect on its removal. The total BOD_5 data (Figure 17) shows higher efficiency for the RFC than the RBD systems. Since the amount of BOD removal by sedimentation in the RFC system is surely less than secondary clarification Figure 17 indicates that biological treatment in the RFC is slightly more efficient than the RBD. Figure 19 compares data of RBD and RFC continuous flow systems. None except Popel's include secondary clarification.

These comparisons show that the RFC is very similar to the RBD in its ability to biologically treat waste.

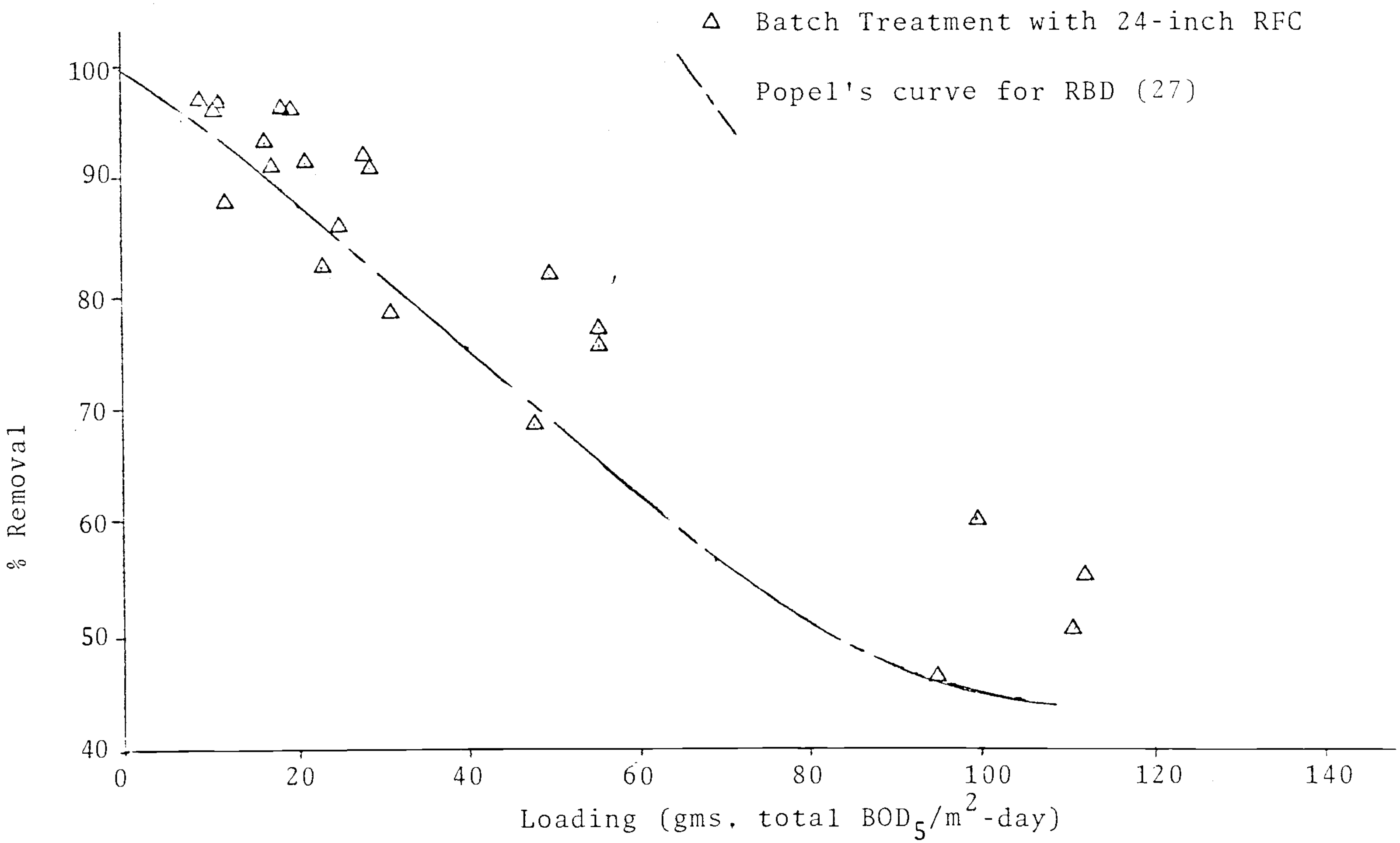


Figure 17. Efficiency of BOD_5 removal -vs- BOD_5 loading for 24-inch RFC.

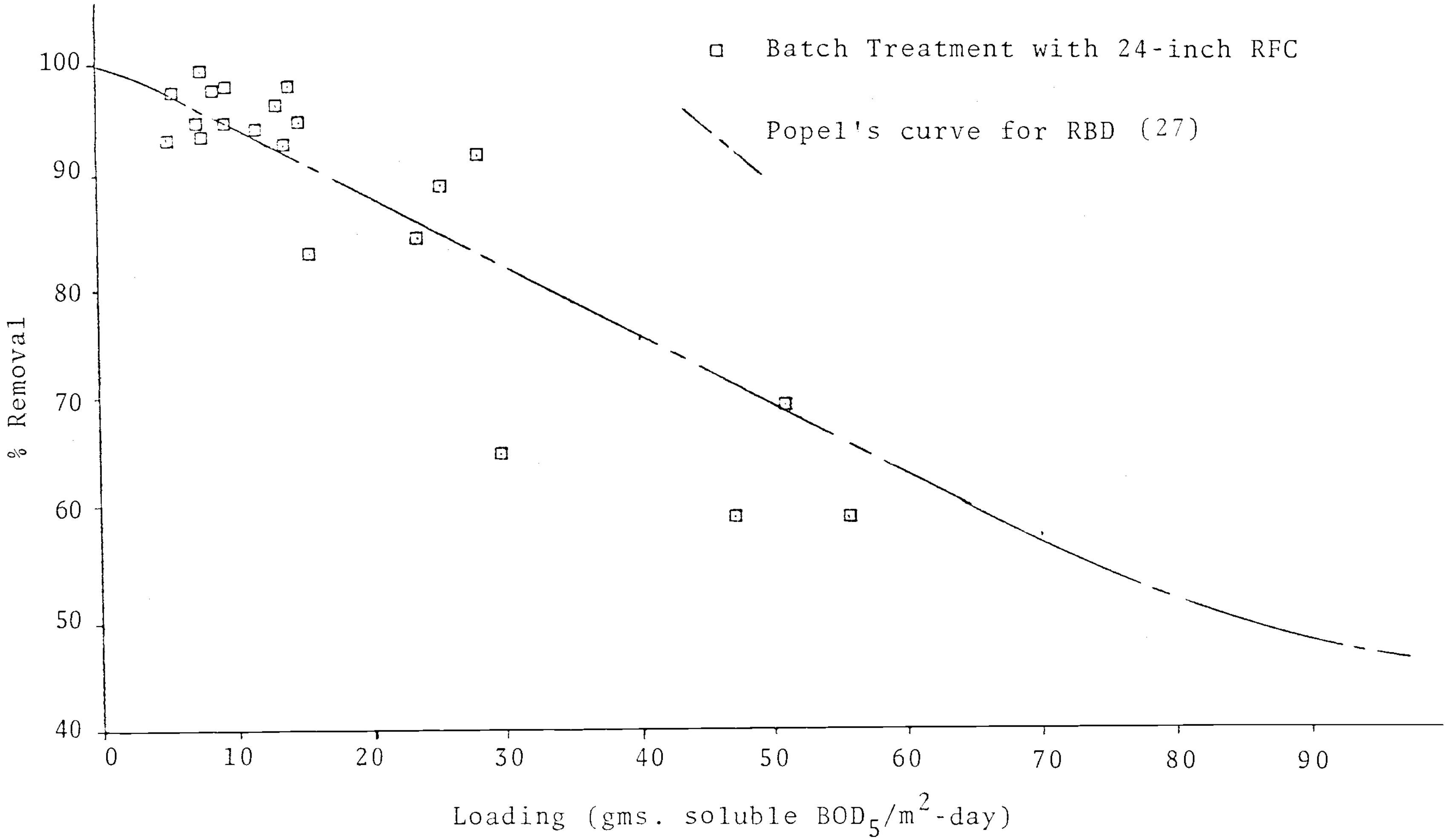


Figure 18. Efficiency of BOD_5 removal -vs- BOD_5 loading for 24-inch RFC.

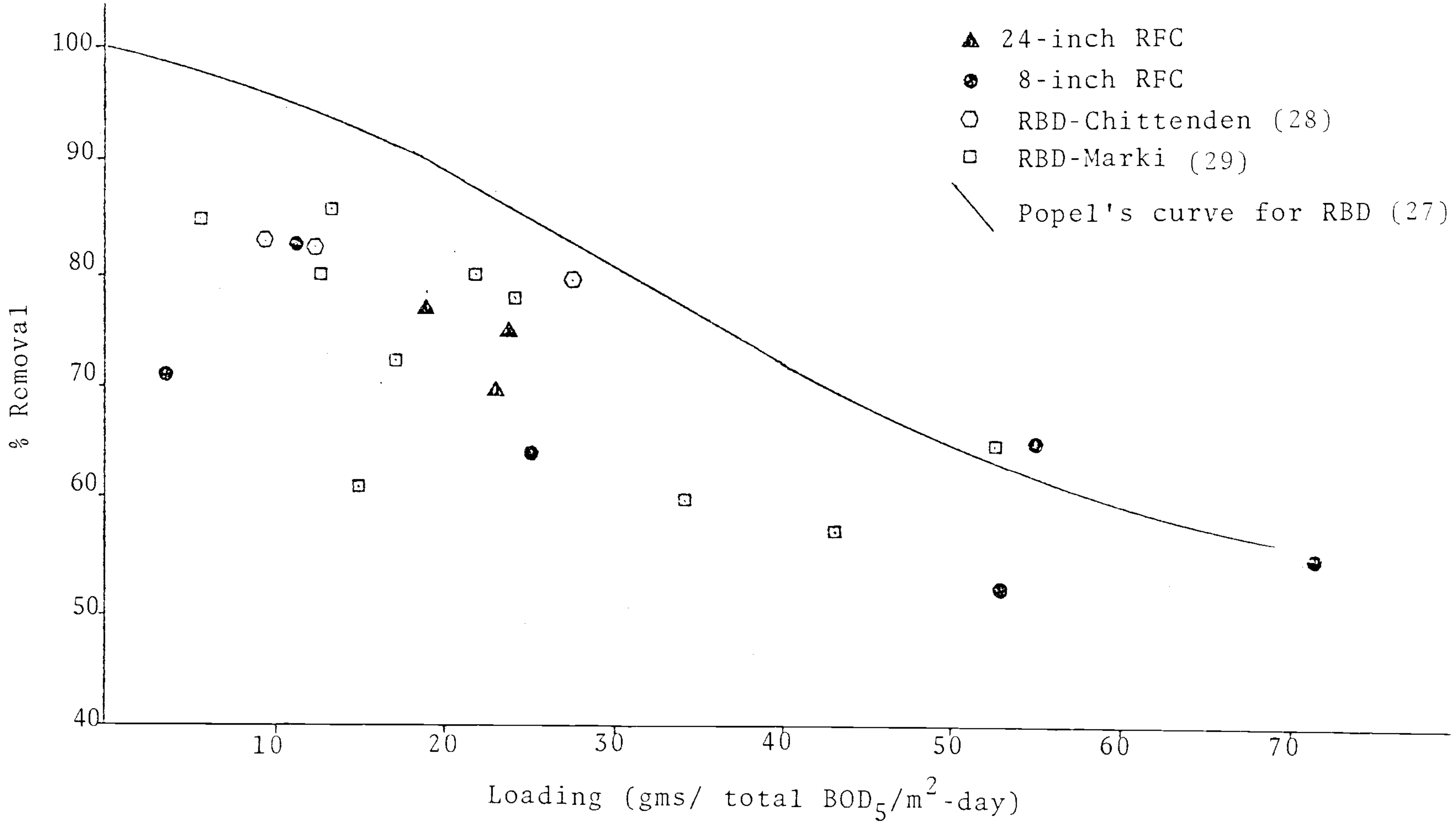


Figure 19. Efficiency of BOD_5 removal -vs- BOD_5 loading for continuous flow with RFC and RBD systems.

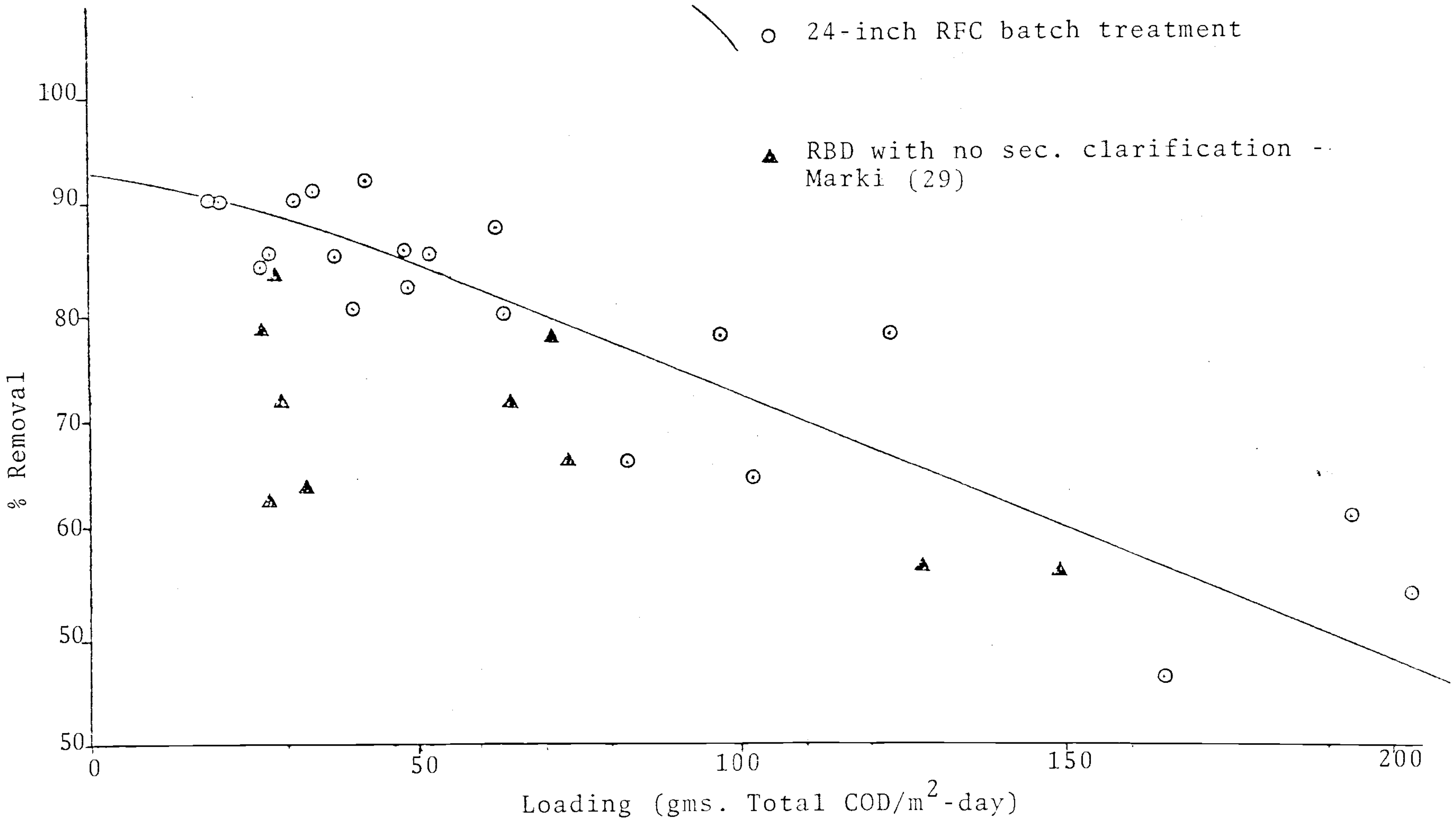


Figure 20. Efficiency of COD removal -vs- COD loading for 24-inch RFC and RBD.

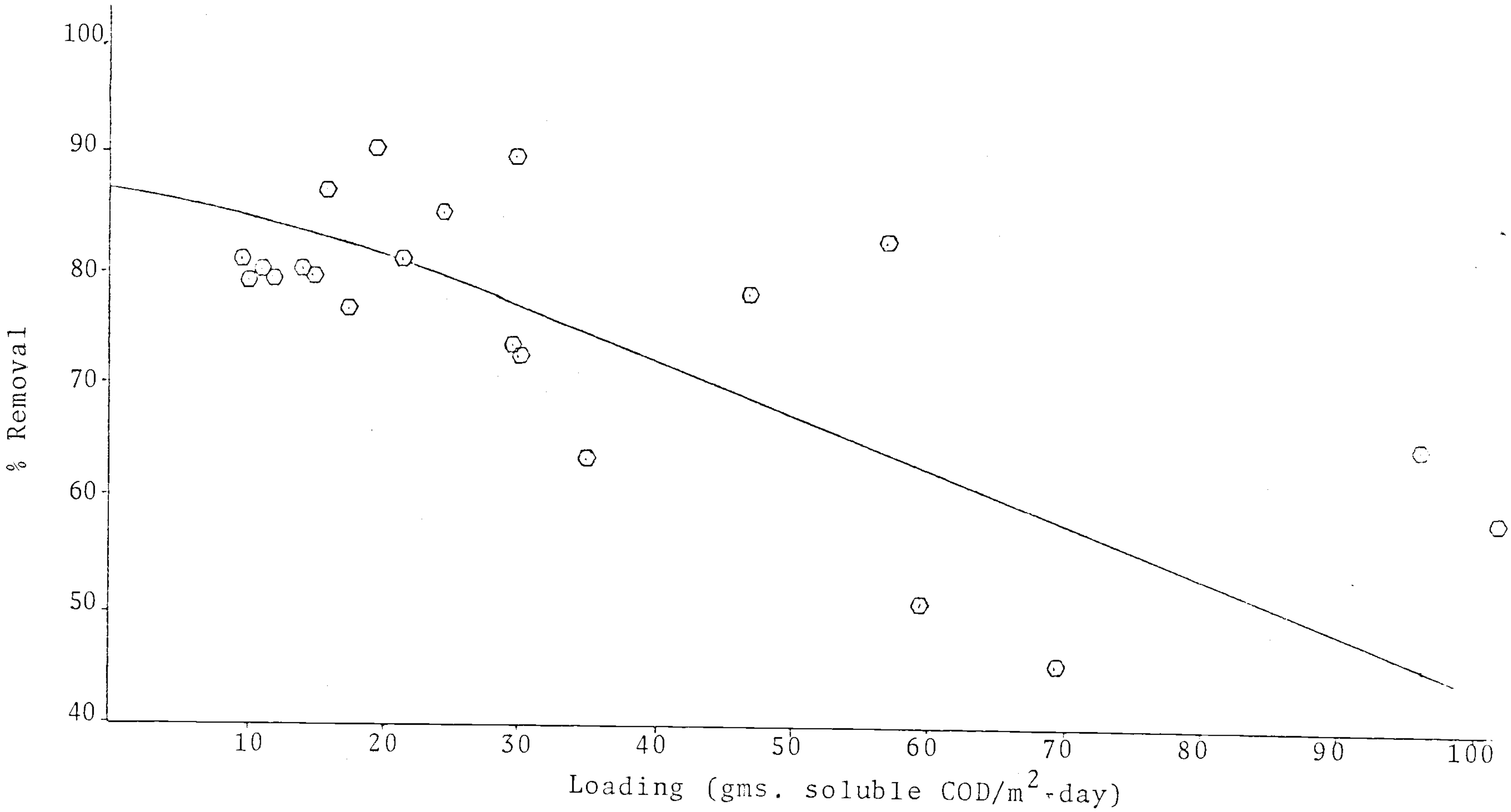


Figure 21. Efficiency of COD removal -vs- COD laoding for 24-inch RFC.

Table 14 gives removal capacities for the 24-inch RFC.

Table 15 shows data for nitrogen removal. There are instances where total and ammonia nitrogen removal exceed 50 percent, but it is nevertheless apparent that the RFC did not produce effective nitrification. In contrast to the rotating biological disc which is operated essentially in a plug flow regime thus achieving nitrification in the latter stages, the entire RFC biomass is exposed to approximately the same loading concentration at any one time. Visual observations revealed a uniform growth throughout the system.

At long detention times when BOD concentration becomes dilute, favorable circumstances for nitrifyers exist. The absence of nitrification during these times is perhaps due to insufficient time to establish a viable population. There was some indication of nitrification, although by no means conclusive, during operation of the 8-inch RFC. Because of storm water dilution the raw sewage BOD concentration was in the range of 20 mg/l. A continuous flow result showed the effluent BOD to exceed the influent BOD by a few mg/l, a situation simultaneously experienced by the trickling filter plant next door and attributed to nitrification.

Cost considerations for an RFC unit are only speculative but appear to compare favorably to other package plant operations.

Table 14. Efficiency and removal capacities for 24-inch RFC batch treatment.

Parameter	Efficiency Removal	Loading gm/m^2-day	Total Removal gms/day
Total BOD_5	95%	12	308
"	90%	23	559
"	80%	41	886
"	70%	60	1134
Soluble BOD_5	95%	9	231
"	90%	16	389
"	80%	33	713
"	70%	48	907
Total COD	90%	20	486
"	80%	70	1512
"	70%	110	2079
Soluble COD	85%	9	207
"	80%	21	454
"	70%	42	794

Table 15 Organic and ammonia nitrogen results for municipal sewage batch treatment with 24-inch RFC.

Detention Time (hrs)	Cylinder Flow Rate (lpm)	Rotational Speed (rpm)	Organic Nitrogen (mg/l)			Ammonia Nitrogen (mg/l)		
			Influent	Effluent	Removal	Influent	Effluent	Removal
16	10.32	.72	66.5	58.8	11.6%	19.9	14.9	25.0%
8	7.54	2.28	67.0	32.5	51.5%	26.0	17.7	31.9%
12	7.54	2.28	67.0	35.7	46.7%	26.0	17.6	32.3%
20	7.54	2.28	67.0	30.8	54.0%	26.0	19.5	25.0%
2	20.86	.71	69.2	52.0	24.9%	34.1	28.4	16.7%
4	20.86	.71	69.2	51.5	25.7%	34.1	24.8	27.3%
8	20.86	.71	69.2	41.8	39.6%	34.1	21.6	36.6%
12	20.86	.71	69.2	37.0	46.5%	34.1	21.6	36.6%
2	21.44	2.22	57.9	43.4	25.0%	42.3	33.1	21.8%
4	21.44	2.22	57.9	37.4	35.4%	42.3	30.4	28.1%
8	21.44	2.22	-	42.4	26.8%	42.3	25.1	40.7%
12	21.44	2.22	-	-	-	42.3	20.2	52.3%

By estimating unit power cost at $.01/kw-hr and power consumption at .27 kilowatts a total annual power cost of $36 is computed. Because of the low care required any maintenance could be easily integrated into the existing establishment being served. Capital costs are estimated to be below $2500 based on experience with the 24 inch model. From examination of the costs given on page 22 and 23 an RFC unit offers a competitive alternative, economically, to existing treatment plants.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions of wastewater treatment studies are often more indicative than definitive because of the inherent lack of control and the gross parameters involved. In many respects the evaluation of the RFC is no exception with results only suggesting certain conditions and relationships. It is apparent from the results obtained that an RFC is a potential wastewater treatment device and that the feasibility of further development is warranted. Listed below are conclusions arrived at through this study.

1. Operationally, the RFC is a simple method of wastewater treatment for small scale systems.
2. It is economically feasible.
3. It is capable of producing an effluent with little sloughed biomass solids.
4. It is capable of removing over 90% of soluble BOD_5 in a batch treatment at a four hour detention period. (Equivalent flow equals two lpm).
5. Over ninety per cent soluble BOD_5 removal is obtained at one lpm continuous flow treatment.
6. It's BOD and COD loading and removal capacities based on surface area are the same and possibly greater than rotating biological discs units.
7. Ammonia and organic nitrogen removal efficiencies are poor.

From the experience of this research it is appropriate to offer certain recommendations that might enhance the further development of a rotating flighted cylinder system.

1. Treatment of a synthetic wastewater would yield more reliable kinetic and capacity relationships. This data for the 8-inch and 24-inch RFC would provide a means of scaling up or down different size models.
2. The effect of simple, preliminary sedimentation tank to which the augered effluent is returned should be investigated.
3. By utilizing the 8-inch RFC to treat the effluent of the 24-inch RFC system a nitrifying population could be established. Such a duel system should be investigated for nitrification abilities.

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