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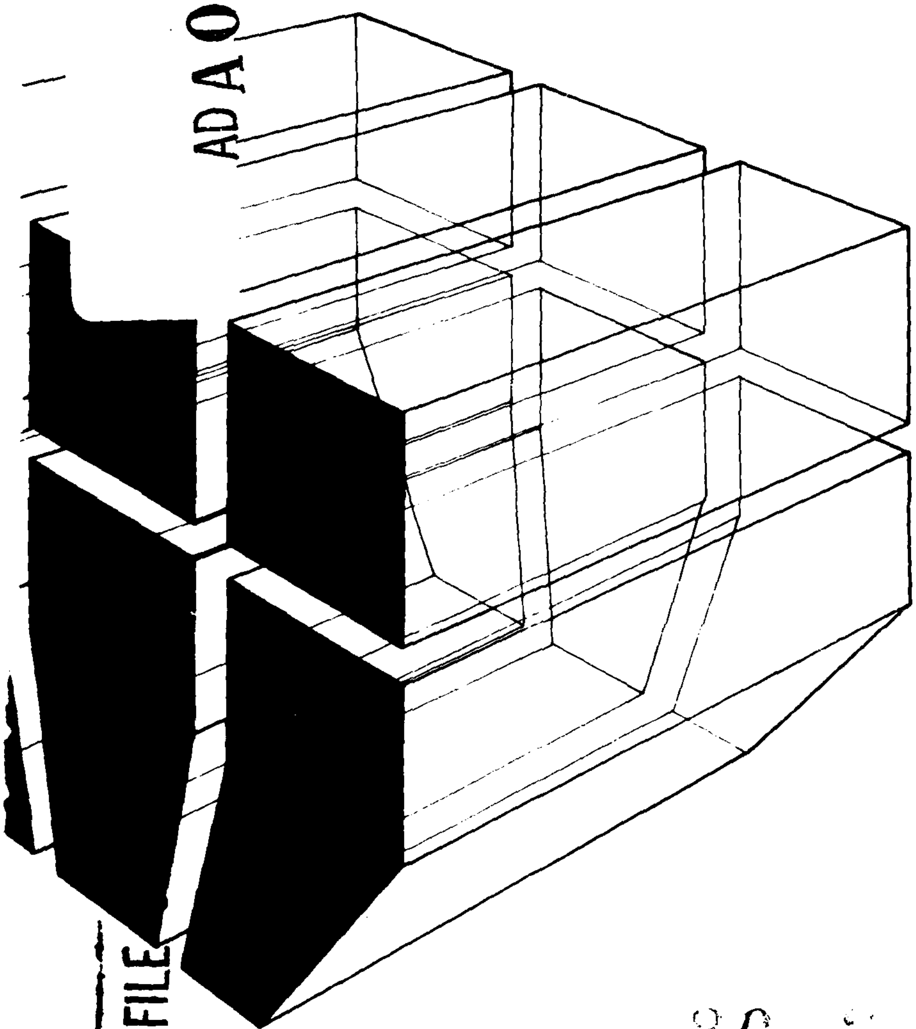
TERTIARY TREATMENT OF WASTEWATER USING A ROTATING BIOLOGICAL CONTACTOR SYSTEM



by
E. D. Smith
C.P.C. Poon
W. Mikucki
J. T. Bandy

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The use of rotating biological contactors (RBCs) to upgrade sewage treatment plants is relatively new in the United States, and only a few full-scale RBC secondary plants have been in operation for more than 1 year. RBCs appear to be simple to operate and maintain, cost competitive, reliable, economical, and compatible for retrofitting existing Department of Army (DA) sewage treatment plants without extensive renovation. However, data are scarce regarding RBC retrofitting strategies for upgrading existing secondary trickling-filter sewage treatment plants for additional

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biochemical oxygen demand (BOD) and nitrogen removal to meet current and anticipated National Pollution Discharge Elimination System (NPDES) requirements. In addition, because of differences in manufacturers' inherent design philosophies, no well-defined theory of design and operation is accepted by all manufacturers.

The overall objective of this investigation was to evaluate the performance of an RBC wastewater treatment process as an upgrading-retrofit unit process for BOD reduction and nitrification. Using a 0.5-m RBC plant at an existing full-scale trickling-filter plant, the flexibility, feasibility, and characteristics for BOD reduction and nitrification potential were determined under a variety of hydraulic, organic, and ammonia-loading regimes. The skill level and manpower requirements for system operation, and the effect of extremely low temperatures and sludge characteristics were also evaluated. The data obtained were used to estimate costs (capital and operational) of the retrofit system handling 1.0, 5.0, and 7.5 mgd (3800, 19 000, and 29 000 m^3/day).

Results showed that the biofilm developed in the RBC unit throughout this study was thin because of the low loading characteristics of this application. The removal of carbonaceous BOD was very steady. Ammonia nitrogen removal and nitrification, however, were not as steady. In addition, performance was affected by hydraulic shock loadings and low temperatures, but high organic loadings had little or no adverse effect. The pilot plant was easy to start up, maintain, and operate, with no nuisances associated with its operations. The RBC units can be installed in tankage followed by a clarifier, or installed in an existing secondary clarifier which has been modified for this purpose. This may eliminate the requirement of an RBC clarifier. Both options can be used to achieve the current standards of secondary treatment, but for tertiary treatment a filter is needed to achieve the effluent quality specified.

The design procedure is presented, along with design calculations for 1.0, 5.0, and 7.5 mgd plants. Capital costs and energy requirements for these plants at various options were listed for comparison. These results indicate that DA sewage treatment plants can be effectively upgraded.

FOREWORD

This investigation was performed for the Directorate of Military Programs, Office of the Chief of Engineers (OCE), under project 4A762720A896, "Environmental Quality Technology"; Task B, "Source Reduction Control and Treatment"; work unit 017, "Tertiary Treatment Using a Rotating Biological Disk System." The applicable QCR is 3.01.004.

The OCE Technical Monitor was Mr. Walt Medding, DAEN-MPO-U.

This investigation was performed by the Environmental Division (EN) of the U.S. Army Construction Engineering Research Laboratory (CERL).

Dr. R. K. Jain is Chief of the Environmental Division. COL L. J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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1 INTRODUCTION

Background

In 1972, Congress initiated a comprehensive program to restore and maintain the quality of the nation's rivers and lakes by passing amendments to the Federal Water Pollution Control Act (P.L. 92-500). The 1977 Clean Water Act (P.L. 95-217) reaffirmed this commitment through additional amendments which strengthened a number of the provisions of P.L. 92-500. These two laws require that Department of Defense (DOD) sewage treatment plant facilities and industrial and municipal waste treatment operations constrain their point source wastewater effluents within prescribed limits of quality. In fact, certain mandatory penalties are stipulated and enforced by the Environmental Protection Agency (EPA). Recently, several Department of Army (DA) sewage treatment plants (STP) have been upgraded to meet secondary and/or tertiary treatment requirements, and others are being considered for upgrading. As effluent requirements become more stringent, it is anticipated that fewer DA sewage treatment plants will be able to meet the National Pollution Discharge Elimination System (NPDES) permit stipulations, and therefore will require upgrading.

Several technologies are available as candidate upgrading mechanisms for meeting stringent NPDES permit stipulations. After evaluating these processes, researchers believe that the rotating biological contactor (RBC) process exhibits a significant potential for upgrading trickling filter-type secondary sewage treatment plants. The majority (approximately 95 percent) of DA sewage treatment plants are of the trickling filter type.

In comparison to many other sewage treatment technologies, very little is known about RBCs as a mechanism for upgrading (retrofitting) trickling filter sewage treatment plants to meet stringent NPDES requirements. In fact, the RBC process is relatively new in the United States and is usually used for secondary sewage treatment, not for upgrading existing sewage treatment plants. Only a few RBC plants have been operational for more than a year. This lack of experience is complicated by the fact that there is no well-defined, uniform theory of design and operation accepted by all RBC manufacturers. There is an even more conspicuous lack of empirical data and design criteria for use of RBC technology as a retrofit upgrading mechanism for trickling filter sewage treatment plants.

Objective

The objectives of this study were (1) to evaluate through a pilot-plant study the technical attributes of RBC technology to provide installation-specific information, and (2) to develop a design procedure for upgrading U.S. Army trickling-filter secondary sewage treatment plants by retrofitting a rotating disk unit to bring these plants into compliance with existing and anticipated NPDES permit stipulations.

Approach

A pilot-scale research investigation was performed at a full-scale, trickling-filter sewage treatment plant. The data from this study were evaluated and analyzed to provide design procedures for upgrading trickling-filter sewage treatment plants using RBC technology. The system's reliability, energy efficiency requirements, advantages/disadvantages, operational characteristics, and other pertinent information necessary for effective system assessment were evaluated.

Scope of Work

This study was not intended to investigate the mechanism of interaction between the heterogeneous cultures on the biological contactor and the various pollutants in the clarified trickling-filter effluent. No attempt was made to study the kinetics of pollutant removal.

Outline of Report

Chapter 2 discusses the Army's unique limitations, restraints, requirements, and capabilities in the area of sewage treatment.

Chapter 3 discusses the type of questions that DA personnel involved with sewage treatment plant pollution abatement are asking regarding RBC application to their problems.

Chapter 4 documents the history of, describes, and reviews the literature regarding RBC technology.

including the system's advantages and disadvantages.

Chapter 5 discusses ammonia removal for STP effluents in terms of reasons for regulations, history, theory, and empirical relationships. This chapter also lists publications containing information about RBC technology.

Chapter 6 provides design procedure and design calculations for 1.0, 5.0, 7.5 mgd (44, 219, 329 L/sec) plants, and Chapter 7 compares capital costs and energy requirements of various options. Special emphasis was placed on evaluating the RBC unit's performance capabilities, as well as its operational stability.

Mode of Technology Transfer

The information in this report will be issued in an Engineering Technical Letter.

2 ARMY SEWAGE TREATMENT LIMITATIONS AND CAPABILITIES

The Army Situation

In the area of wastewater treatment, the Army has many unique limitations, constraints, requirements, and capabilities, which include the following:

1. Most (approximately 95 percent) DA STPs are the trickling filter type; the remainder are activated sludge systems and extended aeration package plants.

2. Most of the STP facilities were designed and constructed between 1935 and 1945.

3. The STPs are relatively small. The design and operation of facilities for the treatment of low flows require some significantly different considerations than for larger plants. The overall facility design concept of simplicity is much more important in smaller plants. The factors which generally must be considered in the design of small plants include:

a. Available operator time will be minimal because of restrictive budgets.

b. Available operator skills will be restrictive, since the skills reside with only a few individuals rather than a large staff.

c. The plant may not be manned during night or weekend shifts.

d. Variations in hydraulic and organic loads will be greater.

e. Some process alternatives may be more applicable to smaller plants than larger ones.

4. Hydraulic and organic load fluctuations are common in DA STPs because:

a. The facilities are often underloaded because of decreases in the Army population during peacetime.

b. The civilian work force which contributes waste during normal working hours but not at other times creates significant diurnal loading changes.

c. Consolidation of training activities from several posts to only one installation, summer training, and reserve and national guard groups can create significant seasonal loading changes.

d. The sewage collection system may receive large quantities of infiltration during wet periods.

Upgrading DA STPs

As previously mentioned, most DA STPs are of the trickling filter type. Trickling filters have low energy needs and are relatively easy to operate. When properly designed, constructed, and operated, trickling filters can meet the discharge requirements of the law. Since discontinuing the use of trickling filter STPs would be uneconomical, these existing facilities should be used whenever possible. However, there has been a recent tendency among Architect/Engineer (A/E) firms to recommend abandoning existing DA trickling filter units and to replace them with capital- and energy-intensive, and more complex, newer technology. Certainly such complex technology should be used when it is applicable to specific wastewater problems. However, it is more sensible to continue using existing, proven trickling filters and other simple, reliable technologies for operations when it is economical to do so. An EPA report states, in part:

> The basic thrust of the report is that trickling filters often in combination with other treatment technologies should be considered for new facilities . . . as well as for continued uses in plants where they presently exist. . . . We are confident that trickling filters can continue to provide an

important contribution to our nation's water pollution control efforts.[1]

3 RBC TECHNOLOGY UPGRADING POTENTIAL FOR DA SEWAGE TREATMENT PLANTS

RBC technology has the potential to upgrade existing trickling filter and activated sludge plants economically and effectively, thus retaining and using DA's expensive secondary STP capital equipment.

Although RBCs have demonstrated their effectiveness, reliability, and economy, very little is known about RBC technology, in comparison to trickling filters and activated sludge processes. In fact, scrutiny of several publications reveals the conspicuous lack of information regarding RBC technology. For example, an excellent EPA report on upgrading trickling filters does not mention RBC technology as an alternative.[2] Another EPA report provides an on-the-job reference for activated sludge and trickling filter wastewater treatment plants.[3] The report is intended to optimize the performance of these two aerobic biological treatment systems and help establish process control techniques; other aerobic biological systems such as aerated lagoons, RBCs, and oxidation ponds are not discussed. There is no comparable manual for RBC technology.

The lack of data and guidelines regarding RBC technology emphasizes the need for more RBC research and analysis of operating RBC facilities. In an effort to compare and contrast RBC technology with other processes, DA personnel faced with sewage treatment problems are asking questions such as the following:

1. How can I insure that RBC technology is right for my particular situation?

2. How much does it cost?

3. Are the RBC units easy to install and start up? What about site preparation?

4. Can we obtain the process and install it into a tight compliance schedule?

5. What are the RBC's operational and maintenance problems?

6. How does RBC technology compare with other technologies?

7. Is the process reliable and effective under a variety of climatic conditions and under hydraulic, organic, and ammonia loadings?

8. What are the appropriate design criteria?

9. What are the system's land requirements?

10. What are its skill and manpower requirements?

11. Will this process require extensive modification to existing DA STPs?

12. Will the system require process limitations, applicability, and restraints?

13. Can the process be retrofit to existing secondary equipment to meet biochemical oxygen demand (BOD), suspended solids (SS), and ammonia requirements?

This report addresses many of these and other considerations.

4 THE ROTATING BIOLOGICAL CONTACTOR

History of the Rotating Biological Contactor

According to a recent EPA report:

> The RBC concept of treating waste streams biologically has been known for many years, but it was not until strong, lightweight plastics became available that significant interest in the technique began to develop. The treatment technique is to grow biologically active masses on a series of discs that slowly rotate, alternately exposing the biomass to the wastewater stream and the air above it. In early models, the discs were made of metal and were heavy, cumbersome, and subject to corrosion. Recent models have discs fabricated of polyethylene or polystyrene. Many investigators have found advantages for the RBC over activated sludge or other conventional treatment systems based on specialized circumstances. . . .[4]

[1] *Upgrading Trickling Filters*, 430/9-78-04 (EPA, Office of Water Program Operations [WH-547], June 1978).

[2] *Upgrading Trickling Filters*, 430/9-78-04 (EPA, Office of Water Program Operations [WH-547], June 1978).

[3] *Process Control Manual for Aerobic Waste Water Treatment Facilities*, EPA-430-9-77-006, PB-279474 (EPA, March 1977).

[4] F. T. Lense, S. E. Mileski, and C. W. Ellis, *Effects of Liquid Detergent Plant Effluent on the Rotating Biological Contactor*, EPA-600/2-78-129 (Industrial Environmental Research Laboratory, Office of R and D, USEPA, June 1978).

The following also provides historical information:

> The rotating biological contactor goes back to the 1920s. Investigators in both the U.S. and Germany experimented with using rotating wood surfaces. But wood surfaces were impractical to manufacture and deteriorated, and in those days, few communities were putting in secondary treatment.
>
> Not much more happened until the 1950s. In that decade, investigators at Stuttgart University, West Germany, attempting to improve the secondary treatment process, experimented with wooden and plastic flat disks rotating in wastewater.
>
> In 1959, J. Conrad Stengelin began to manufacture 2 and 3 m diam. expanded polystyrene disks in West Germany. The first commercial installation went on stream there in 1960. But the rotating disk process was not cost competitive with the activated sludge process; initial capital costs were considerably more than for activated sludge plants. Nonetheless, many small plants were installed in Germany in the 1960s—most serving less than 1000 people. These small municipalities were willing to pay more in initial cost to get a plant requiring little maintenance and low energy consumption.
>
> After 1960, further development of the rotating biological contactor stopped in Europe. But between 1960 and 1965 in the U.S., Allis-Chalmers did much development of rotating disks.
>
> In 1970, Allis-Chalmers sold its rotating biological contactor technology to the Autotrol Corp. (Milwaukee, Wisc). At that time, the polystyrene disks were still not competitive with the activated sludge process. Even as late as 1972, Autotrol had sold only a few RBC installations for sewage treatment. The capital cost of the polystyrene disks was simply too high.
>
> **Breakthrough sparks growth of RBCs**
>
> Then, in 1972, came an important breakthrough: the development of a more compact disk, one with much more surface area for a given volume. Till then, the RBC unit consisted of a series of parallel, flat 0.5 in. thick expanded polystyrene sheets, each separated by a 0.75 in. space. Now, Autotrol came out with an arrangement of 1/16 in. thick polyethylene sheets with a 1.2 in. space separating them filled with a honeycombed polyethylene configuration. Whereas the standard polystyrene RBC unit was 10 ft in diam. and 17 ft long with 21,000 ft² of surface area, the new polyethylene RBC unit was 12 ft in diam., 25 ft long, with 100,000 ft² of surface area. In recent years, Autotrol has developed a still more compact arrangement for nitrification applications—the distance between adjacent polyethylene sheets being only 0.6 in., with total surface area of a standard RBC being 150,000 ft².[5]

The authors of this report emphasize that Autotrol is not the only manufacturer or proprietor of RBC equipment.*

There are currently more than 600 commercial RBC installations, mostly in West Germany, France, and Switzerland, primarily serving populations ranging from 12,000 to 100,000, and treating a variety of domestic and industrial wastes.

Since 1972, the number of wastewater treatment plants in the United States using rotating biological contactors has increased more than 300, with another 300 now in the planning stages.[6]

RBC Process Description

An EPA Technology Transfer Publication describes the RBC process as follows:

> *Rotating Biological Contactors.* This process (also sometimes referred to as biodiscs or rotating biological surfaces) consists of a series of closely spaced discs (10–12 feet in diameter) mounted on a horizontal shaft and rotated while about one half their surface area is immersed in wastewater. The process has been used in Europe for several years. The discs are typically constructed of lightweight plastic. When the process is placed in operaton, the microbes in the wastewater begin to adhere to the rotating surfaces and grow there until the entire surface area of the discs is covered with a 1/16–1/8-inch layer of biological slimes. As the discs rotate, they carry a film of wastewater into the air, where it trickles down the surface of the discs, absorbing oxygen. As the discs complete their rotation, this film mixes with the reservoir of wastewater, adding to the oxygen in the reservoir and mixing the treated and partially treated wastewater. As the attached microbes pass through the reservoir, they absorb other organics for breakdown. The excess growth of microbes is sheared from the discs as they move through the reservoir. These dislodged organisms are kept in suspension by the moving discs. Thus, the discs serve several purposes. They provide media for the buildup of attached microbial growth, bring the growth into contact with the wastewater, and aerate the wastewater and suspended microbial growth in the wastewater reservoir. The speed of rotation is adjustable. The attached growths are similar in concept to a trickling filter, except that the microbes are passed through the wastewater rather than the wastewater being passed over the microbes. Some of the advantages of both the trickling-filter and activated-sludge processes are realized. As the treated wastewater

---

[5]Gene Dallaire, "Behind the Rapid Rise of the Rotating Biological Contactor," *Civil Engineering*, Series on Water Pollution Control, No. 11 (American Society of Civil Engineers, January 1979).

*Rotating biological contactors are also manufactured by Envirodisc Corp., Environmental Dynamics Corp., George Hormell, Inc., NEPTUNE CPC Eng. Corp., and perhaps other firms.

[6]Dallaire, "Behind the Rapid Rise of the Rotating Biological Contactor."

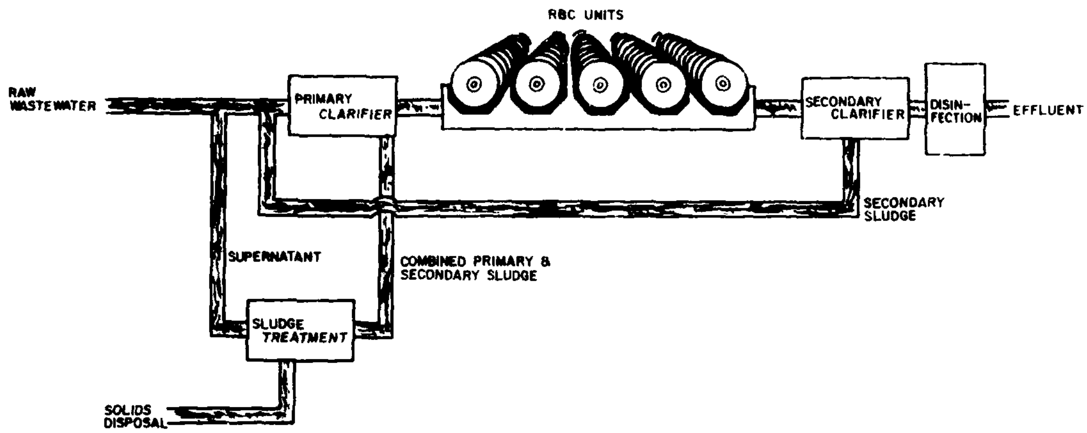

Figure 1. Typical secondary RBC plant.

flows from the reservoir below the discs, it carries the suspended growths out to a downstream settling basin for removal. The process can achieve secondary effluent quality or better. By placing several sets *of discs in series*, it is possible to achieve even higher degrees of treatment—including biological conversion of ammonia to nitrates if desired. . . .[7]

Figure 1 represents a typical secondary RBC plant.[8] An EPA Waste Pollution Control Series Report compares the operating characteristics of the process with activated sludge and trickling filter unit processes, and includes the following observations:

> The rotating disc process is similar to the trickling filter process in that they are both fixed film biological reactors. There are some key differences, however, which give the disc process some important benefits. In the disc system, the biomass is passed through the wastewater rather than the wastewater over the biomass. This provides intimate contact of all of the organisms with the wastewater and prevents problems with clogging of the media by excess biomass. Shearing forces created by rotation at peripheral disc velocities of 30 to 60 ft / min continuously and uniformly strip excess biomass from the discs. Continuous wetting of the entire biomass also prevents development of the flies often associated with trickling filter operation.
>
> Aeration with rotating discs is a very positive means of supplying sufficient dissolved oxygen to the attached biomass and prevents development of anaerobic conditions. Both the intensity of contact between the biomass and the wastewater and the aeration rate can be controlled simply by adjusting the rotational speed of the discs. This can be done to suit a particular wastewater and its treatment requirements.
>
> Wastewater retention time can also be controlled by selecting an appropriate disc spacing and tank size. This allows much higher degrees of treatment to be obtained than in the trickling filter process where relatively short retention times are unavoidable. It is unnecessary to recycle effluent to achieve minimum wetting rates or aid in sloughing as in the trickling filter. This allows the disc process to take advantage of the benefits of staged operation, which would otherwise be destroyed by effluent recycle.
>
> The rotating disc process is somewhat similar to the activated sludge process in that it has a suspended culture in its mixed liquor. However, the suspended culture is estimated to represent less than 5% of the total amount of biological solids on the discs and would therefore contribute only marginally to the treatment. Because of this, the disc process is not upset by variations in hydraulic or organic loading . . . as is the activated sludge process. Like the activated sludge process, the disc process does produce a sparkling clear effluent when operated at appropriate hydraulic loadings.

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[7] *Environmental Pollution Control Alternatives—Municipal Wastewater*, EPA 625/5-76-012, Environmental Pollution Control EPA Technology Transfer Publication (USEPA), pp 21-24.

[8] *Environmental Pollution Control Alternatives—Municipal Wastewater*, pp 21-24.

> Two problems encountered in the operation of activated sludge treatment plants are start-up at flows much lower than design flow and operation during periods of very low flow. Operating a rotating disc plant at low initial flows or during periods of very low flow will yield effluents of higher quality than at design flow. During periods of no flow, effluent can be recycled at a nominal rate to maintain biological activity. . . .
>
> Minimal operator attention and low power consumption are attractive features of the rotating disc process when compared to the activated sludge process, especially for package plant applications and for wastewater treatment needs in remote locations. Unlike the activated sludge process, the rotating disc process can be designed for any degree of treatment and the secondary sludge will settle well.
>
> The rotating disc process lends itself well to upgrading existing treatment facilities. Because of its modular construction, low head loss and shallow excavation, it can be installed to follow existing primary treatment plants, including Imhoff tanks and septic tanks.
>
> Many state regulatory agencies are requiring treatment plants to be designed to achieve various degrees of nitrification as well as BOD and suspended solids removal. To achieve this with the activated sludge process requires that the plant be constructed in at least two stages of aeration, settling and sludge recycle. The rotating disc process has demonstrated in this investigation that it can achieve any desired degree of nitrification with one settling tank and no sludge recycle.
>
> A disadvantage to the disc process is the need for covering the discs to protect the biological growth from freezing temperatures and precipitation and protect the discs from wind damage and vandalism. For installations as large as 100,000 population equivalent in Europe, heating and forced ventilation of the enclosure have not been found necessary. . . .
>
> . . . Although an enclosure is an additional expense for the disc process, aesthetic requirements for wastewater treatment facilities may dictate providing enclosures for all treatment processes in the near future.
>
> In winter, a covered treatment plant will experience fog and condensation from water evaporating from the relatively warm wastewater. This will accelerate corrosion and create slippery footing within the enclosure. To avoid this problem with rotating disc plants, a semicircular shaped, insulated cover has been developed to be supplied, as an integral part of a disc assembly. It covers only the discs and drive components. Fog and condensation are restricted to the atmosphere surrounding the discs, and less treatment plant area needs to be covered.[9]

The following literature review provides information concerning various aspects of theory, design, and operating experience associated with RBC systems.

Historically, rotating biological contactors have been used to remove organic carbon from wastewater. This process was later expanded to include nitrification and denitrification of wastewater. One of the earliest reports of RBC application in the United States is by Welch, who successfully treated highly concentrated wastes using an RBC system installed at Allis-Chalmers, West Allis, WI. In terms of chemical oxygen demand (COD), as much as 800 lb/1000 cu ft/day (1.28 kg/m^3/day) removal was recorded.[10] Torpey, et al., reported a 10-stage RBC with aluminum disks which decreased BOD from 124 mg/ℓ in the influent to 9 mg/ℓ in the effluent in 5 months. Nitrification also occurred, which reduced the ammonia nitrogen content of the effluent (NH_3-N) from 14.2 mg/ℓ to 5.7 mg/ℓ and correspondingly increased the nitrate from zero to 10.4 mg/ℓ in the effluent.[11] Antonie, in his study of the RBC process response to fluctuating flow, reported significant COD removal when the hydraulic residence time of wastewater was approximately 60 minutes. Hydraulic surge, which reduced the residence time to 30 minutes or less, resulted in low COD reductions.[12] In a later report, Antonie noted successful applications of the RBC process for treating various food and nonfood processing wastes.[13] In an EPA demonstration project using the RBC system as a full-scale secondary treatment plant, Antonie reported good BOD removal and some nitrification. In the winter, the system was placed in an enclosure to protect the biomass from freezing temperatures.[14] In a pilot study conducted by LaBella, et al., it was reported

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[9] *Application of Rotating Disc Process to Municipal Wastewater Treatment*, 17050 DAM 11 71, USEPA Water Pollution Control Research Series (USEPA, November 1971), pp 59-60.

[10] F. M. Welch, "Preliminary Results of a New Approach in the Aerobic Biological Treatment of Highly Concentrated Waste," *Proceedings*, 23rd Purdue Industrial Waste Conference (May 1968).

[11] W. N. Torpey, H. Heukelekian, A. J. Kaplovsky, and R. Epstein, "Rotating Disks with Biological Growths Prepare Wastewater for Disposal or Reuse," *Journal of the Water Pollution Control Federation*, Vol 43 (November 1971).

[12] R. J. Antonie, "Response of the Bio-Disc Process to Fluctuating Wastewater Flows," paper presented at the 25th Purdue Industrial Waste Conference (May 1970).

[13] R. J. Antonie and R. J. Hynek, "Operating Experience with Bio-Surf Process Treatment of Food-Processing Wastes," paper presented at the 28th Purdue Industrial Waste Conference (May 1973).

[14] R. J. Antonie, D. L. Kluge, and J. H. Mielke, "Evaluation of a Rotating Disk Wastewater Treatment Plant," *Journal of the Water Pollution Control Federation*, Vol 46 (March 1974), Part 1.

that the RBC process at a hydraulic loading of 1 gal/sq ft/day (0.04 m^3/m^2/day) could remove BOD from winery wastes at an efficiency comparable to that of an activated sludge process or an aerated lagoon. Capital costs of the activated sludge process and the RBC process were found to be approximately equal. However, the yearly operating cost of the RBC process was found to be $6000 per year less than the activated sludge process for a flow of 0.34 to 0.44 mgd (1290 to 1665 m^3/day).[15] Chittenden, et al., also used the RBC system to treat anaerobic lagoon effluents. At an hydraulic loading of 4.0 gpd/sq ft (0.16 m^3/m^2/day), increasing the rotating speed of the first stage to 6 rpm produced a 79.5 percent BOD reduction and an overall BOD reduction of 83.2 percent from an influent having an average of 225 mg/ℓ BOD. Higher hydraulic loading and lower rotating speeds resulted in poor efficiency of BOD removal and very little or no dissolved oxygen in the system.[16] In using a synthetic wastewater for the RBC process study, Stover, et al., reported that more than 90 percent COD removal was possible as long as the organic loading was kept below approximately 400 lb/1000 cu ft/day (0.64 kg/m^3/day). Using the same RBC system for slaughterhouse waste treatment, only 70 percent COD removal was achieved, even though the organic loading was low at 100 lb/1000 cu ft/day (0.64 kg/m^3/day). Increasing the loading to 400 lb/1000 cu ft/day (0.64 kg/m^3/day) significantly reduced removal efficiency to 15 percent. Expressed in lb COD/day/1000 sq ft of disk surface area, the maximum COD removal for slaughterhouse waste was approximately 4.0 lb COD/day/1000 sq ft (19.5 g/m^2/day).[17]

Applications of the RBC process for nitrification of wastewater or sludge supernatant have been reported. Weng and Molof evaluated various parameters affecting the process performance and showed that among influent loading (mg/ℓ), flow rate (ℓ/day), rotational disk speed (rpm), detention time (min), effective disk surface area (sq ft), and submerged disk depth (in.), only influent loading, flow rate, and effective disk surface area were important in determining nitrification efficiency (temperature steady at 20°C and disk rotating speed at 10.5 or more rpm). In effect, NH_3-N loading in lb NH_3-N/day/1000 sq ft was the only controlling factor.[18]

Antonie reported that at various treatment plants using the Bio-Surf RBC process, as much as 0.8 lb NH_3-N/day/1000 sq ft (3.9 g/m^2/day) could be removed. Generally, 90 to 95 percent nitrification was obtainable.[19] A pilot plant study conducted by Hao and Hendricks showed excellent NH_3-N removal from the Columbus, IN, sewage treatment plant. In January and February, when cold temperatures prevailed, 50 to 60 percent NH_3-N removal was obtained at an hydraulic loading of 2.5 gpd/sq ft (0.103 m^3/m^2/day) and 90 to 95 percent NH_3-N removal at 1.5 gpd/sq ft (0.06 m^3/m^2/day).[20] When high-strength ammonia wastewater (780 mg/ℓ NH_3-N on the average) was applied to a four-stage RBC system, Lue-Hing, et al., found that at an overall NH_3-N loading of 15.6 lb of NH_3-N/day/1000 cu ft (25 g/m^3/day) and a wastewater temperature of 10°C, 99.4 percent of the NH_3-N was removed; at an overall loading of 43.5 lb of NH_3-N/day/1000 cu ft (70 g/m^3/day) and a wastewater temperature of 20°C, 99.8 percent of the NH_3-N was removed. The maximum removal rates in the first stage ranged from 95 lb of NH_3-N/day/1000 cu ft (152 g/m^3/day) at 9°C to 170 lb of NH_3-N/day/1000 cu ft (272 g/m^3/day). Recirculation of effluent in the RBC process showed insignificant improvement of nitrification.[21]

Temperature sensitivities of the RBC system have been evaluated by Murphy, et al., over a range from 5 to 25°C. For both nitrification and denitrification, RBC temperature sensitivities were reported to be similar to those of suspended growth systems having long sludge retention times.[22]

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[15]S. A. LaBella, I. H. Thaker, and J. E. Tehan, "Treatment of Winery Wastes by Aerated Lagoon, Activated Sludge, and Rotating Biological Contactor," paper presented at the 27th Purdue Industrial Waste Conference (May 1972).

[16]J. A. Chittenden and W. J. Wells, "Rotating Biological Contactors Following Anaerobic Lagoons," *Journal of the Water Pollution Control Federation*, Vol 43 (May 1971).

[17]E. L. Stover and D. F. Kincannon, "Evaluating Rotating Biological Contactor Performance," *Water and Sewage Works*, Vol 123 (March 1976).

[18]C. N. Weng and A. H. Molof, "Nitrification in the Biological Fixed-Film Rotating Disk System," *Journal of the Water Pollution Control Federation*, Vol 46 (July 1974).

[19]R. L. Antonie, "Nitrification of Activated Sludge Effluent: Bio-Surf Process," Parts I and II, *Water and Sewage Works*, Vol 121 (November-December 1974).

[20]O. Hao and G. F. Hendricks, "Rotating Biological Reactors Remove Nutrients," Parts I and II, *Water and Sewage Works*, Vol 122 (October-November 1975).

[21]C. Lue-Hing, et al., "Biological Nitrification of Sludge Supernatant by Rotating Disks," *Journal of the Water Pollution Control Federation*, Vol 48 (January 1976).

[22]K. L. Murphy, et al., "Nitrogen Control: Design Considerations for Supported Growth Systems," paper presented at the 48th Annual Conference, Water Pollution Control Federation, Miami Beach, FL (October 1975).

With more than 4 months of RBC nitrification study at the Belmont Wastewater Treatment Plant at Indianapolis, IN, Reid, Quebe, Allison, Wilcox and Associates, Inc., reported that although the RBC process appeared as a feasible alternative nitrification process for waste containing relatively consistent NH_3-N loadings, the process was unable to consistently maintain low (less than 1.0 mg/ℓ) NH_3-N levels in the effluent when the *influent* NH_3-N *load varied.*[23] In the same study, it was found that the RBC system could reduce the total BOD_5 (carbonaceous portion only) in the clarified activated sludge effluent from 8 to 18 mg/ℓ to 6 to 13 mg/ℓ. The percentage of BOD_5 removal was low (0 to 57 percent) compared to the secondary treatment process. However, soluble carbonaceous BOD_5 removal was more successful (1 to 10 mg/ℓ to 1 to 3 mg/ℓ, or 0 to 80 percent removal). By removing a portion of the treated effluent total suspended solids (TSS), an effluent quality to meet a BOD_5 of less than 10 mg/ℓ can be obtained with no difficulty.

Other studies also indicate the inability of the RBC system to remove total BOD_5. Reh, et al.,[24] Lagnese,[25] and Sullivan, et al.,[26] collected and analyzed operational data from various *full-scale* RBC *plants and* concluded that design of RBC systems should be based on soluble BOD_5 loading, rather than on total BOD_5 loading. In using the RBC system for upgrading existing secondary treatment plants and for tertiary treatment, it is important to recognize the inability to remove particulate BOD_5, particularly when the particulate portion of the total BOD_5 is high. When the RBC unit is operated in series and following secondary treatment, a less efficient performance can be expected, since the wastewater contains a higher fraction of refractory organics. Finally, nitrified effluent from the RBC unit contains nitrogenous oxygen demand (NOD), which can be a significant portion of the effluent BOD_5. Lagnese suggested that a nitrification inhibitor be used in the BOD_5 analysis to eliminate NOD from the analysis.[27] However, this approach may require some revision or clarification of the NPDES permit. Important RBC design considerations include the characteristics of wastewater to be treated and the degree of treatment desired. These considerations dictate such treatment system parameters as number of stages, speed of RBC rotation, reaction tank volume, media density, and pretreatment, according to a literature search performed by Griffith, et al.[28]

Systems treating municipal wastewater usually provide for two to four stages for secondary treatment and up to 10 stages if further treatment is required. Disk rotation velocities of 1 fps (peripheral velocity) are common for initial stages, with lower velocities (0.5 fps) used in later stages as the oxygen demand in the wastewater is reduced. Disk reaction tank volumes which provide 0.12 gal/sq ft (4.89 ℓ/m^2) of disk (including disk volume), or 1-hour detention time, at an hydraulic loading rate of 1.5 gpd/sq ft (0.06 m^3/day/m^2) of disk area, are common. A wide range of hydraulic and organic loading rates has been reported for systems treating domestic wastewater. Hydraulic loading rates ranging from 0.09 to 44.1 gpd/sq ft (0.004 to 0.17 m^3/day/m^2) of disk surface area and organic loading rates of 0.20 to 6.0 lb BOD per day/1000 sq ft (0.98 to 2.93 g/m^2) of disk surface area are documented. Systems having disks aligned parallel to the direction of flow and perpendicular to the direction of flow are both documented. The disk reaction tank is generally contoured to the shape of the disks, which improves mixing of the wastewater within each stage. Documented disk materials include aluminum, polystyrene, polyethylene, and Plexiglas. Desirable basic properties in a disk material are low density and a rigid shape. Disk diameters range from 6 in. to 12 ft (152 mm to 3.6 m), with spacing between disks ranging from ⅜ to ¾ in. (9.6 to 19.2 mm). The disk generally has between 40 to 50 percent of its diameter covered in wastewater, with the only criterion being that its entire surface become wet.

Enclosure of the disk sections has reportedly been required for various reasons, but mostly to protect the biomass from rain, wind, cold temperature, and

[23] *Nitrification Systems for Ammonia-Nitrogen Removal* (Reid, Quebe, Allison, Wilcox & Associates, Inc.)

[24] C. W. Reh, et al., "An Approach to Design of RBCs for Treatment of Municipal Wastewater," paper presented at the American Society of Civil Engineers (ASCE) National Environmental Engineering Conference, Nashville, TN (July 1977).

[25] J. F. Lagnese, "Evaluation of RBC Used to Upgrade Municipal Plant to Secondary Standards," paper presented at the Technical Conference, Water Pollution Control Association, Pennsylvania (April 1978).

[26] R. A. Sullivan, et al., "Upgrading Existing Waste Treatment Facilities Utilizing the BIO-SURF Process," paper prepared for Autotrol Corporation (May 1978).

[27] J. F. Lagnese, "Evaluation of RBC."

[28] G. T. Griffith, R.H.F. Young, and M. J. Chun, *Rotating Disc Sewage Treatment System for Suburban Developments and High Density Resorts of Hawaii,* Water Resources Research Center, University of Hawaii, Honolulu, Hawaii, Technical Memorandum Report No. 56 (January 1978).

direct sunlight. In addition, some installations have been covered to reduce the odor emitted from the disk process.

Final settling and removal facilities for solids are generally incorporated into the total treatment scheme. A biomass generation of approximately 0.4 lb (.16 kg) of dry solids per pound of BOD removal has been reported. Systems used to transport the settled biological solids to storage and treatment facilities include screw conveyors, scraper/bucket schemes, and pumps.

Advantages and Disadvantages of RBC Technology

RBC, like any other treatment technology, has inherent advantages and disadvantages, and potential system users should be aware of these.

Disadvantages

The January 1979 ASCE publication *Civil Engineering* documents several potential disadvantages associated with RBC technology.

> . . . a) The oldest RBCs in the U.S. have been in service for only six years. By contrast, processes like the trickling filter or activated sludge have decades of operating experience. Many engineers may insist on a longer service history before using them.
>
> b) For a good-size plant, many RBCs would be required. For secondary treatment, for every gal/day of wastewater treated, about 0.5 ft^2 of plastic media are required (amount of surface area also depends on BOD loading). Since a standard RBC contains 100,000 ft^2 of surface area, this means a 100 mgd plant may require 500 units. That's a lot of electromechanical drives to maintain—and one reason RBCs will find their greatest use in smaller plants (1 to 20 mgd range).
>
> c) RBCs may be driven by mechanical drives or air drives. Air drives allow the RBC to be rotated at a faster or slower rate to adjust variations in incoming wastewater. With the electromechanical drives, the disk RPM is fixed at 1.5 rpm; and rpm can be changed only by changing pulleys—at great time and expense. With the air drive, however, changing the speed is merely a matter of turning a valve.
>
> Using air-driven disks also means that fewer RBCs would be needed. . . .
>
> . . . Why fewer needed? The air bubbles rising through the RBC tank . . . tend to shear off biomass on the disk, exposing fresh biomass and thereby speeding biological reactions. The thinner biomass also means that RBCs with a more compact arrangement of plastic sheets (50% more surface area/unit) can be used (a thicker biomass would clog the space between sheets). Thus, fewer RBCs would be needed.[29]

Benjes lists other disadvantages:

1. Effluent quality is not as predictable as with the suspended growth process.

2. Heavy load on first cell may cause odors.

3. Multiple drives at larger plants entail proportionally higher operations and maintenance costs.

4. Shaft and drive failures, which require major maintenance, have occurred.

5. Oil leaks from the drive units are common.

6. Larger plants require more space than equally sized suspended-growth systems.[30]

Other disadvantages include: the RBC process must be protected from freezing precipitation, wind, and vandalism; algal growth efficiency is adversely affected by cold temperatures unless the treatment building is heated; disk shaft bearings must be greased weekly; and there is not yet any long-term operating experience with the process in the United States.[31]

To deal with such problems, the Water Pollution Control Federation in 1978 presented an article dealing with "troubleshooting" tips associated with RBC technology; portions of this article are reproduced below. It is worth noting, however, that these or similar difficulties are inherent in trickling filter operations, and, to a great extent, in activated sludge process operations also:

> During operation of the rotating biological reactor system, process operating difficulties may arise.
>
> **Loss of Biomass**
>
> Excessive sloughing or loss of the biological slime on the medium surface during the first 2 wk of start-up operation

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[29]Gene Dallaire, "U.S.'s Largest Biological Contactor Plant to Slash Energy Use 30%," *Civil Engineering*, Series on Water Pollution Control, No. 11 (January 1979).

[30]H. H. Benjes, Jr., *Small Community Wastewater Treatment Facilities—Biological Treatment Systems* (Culp-Wesner-Culp), p 89.

[31]*Environmental Pollution Control Alternatives: Municipal Wastewater*, EPA 625/5-76-012, Environmental Pollution Control EPA Technology Transfer Publication (USEPA), p 23.

is not an unusual occurrence. This event is likely to occur if the unit has been seeded with a biological culture developed in a waste environment different from the operating contacting system. Therefore, during initial start-up periods (about 2 wk), loss of biological slime should be expected.

In the event that severe sloughing or loss of biomass occurs after the start-up period and process difficulty arises, corrective action may be taken as follows.

Cause. Influent waste contains toxic or inhibitory substances that kill biomass.

Prevention and Cure. The solution is to determine the substance that is causing toxicity and its concentration, discharge frequency, and duration. Elimination of the toxic substance is the best solution, although this may not be possible. In the event that the toxic substance cannot be eliminated, loading peaks should be dampened and a uniform concentration of the toxic or inhibitory substance created to permit an acclimatized culture to adapt.

The equalization of the inhibitory substance may be best accomplished at the source. If this is not possible, it must be accomplished at the treatment plant. When the corrections are made at the treatment plant, dampening may be accomplished either by aerated equalization or possibly altering contactor stage configuration.

Cause. Severe and unusual variations in influent pH to the process. Generally, pH in the range of 6.0 to 8.5 will not cause any sloughing problems to occur. However, if unusual variations, consisting of periods of low (below 5) or high pH (above 10.5), occur, loss of biomass may result.

Prevention and Cure. The solution is neutralization of pH by the most economical means. Neutralization is required to ensure that influent pH to the system is maintained within the range of 6.0 to 8.5 at all times during the day. Performance will be optimized by maintaining pH within these limits with as flat a profile as possible.

Development of White Biomass

It is not uncommon to develop organisms on the contactor media that appear white in color. There is no immediate concern if the white organisms (probably thiotrix or beggiatoa) appear in limited areas on the media. If this form of biomass appears to dominate the surface, however, reduced process performance levels may be expected. The probable causes of these organisms and the means by which they may be eliminated are presented in the following paragraphs.

Cause. Influent septic wastewater and/or high hydrogen sulfide concentrations. Septic wastewater and industrial discharges with high H_2S concentrations may cause predomination of a white filamentous growth on the contactor media.

Prevention and Cure. This situation may be solved by preaeration of the influent waste or by the addition of chemicals to increase the concentration of oxidized materials. The exact amount of preaeration required will depend on the original ratio of oxidized and reduced material in the waste and the pH. If chemicals such as hydrogen peroxide or sodium nitrate are used, the dosage is determined by a process of trial and error.

Cause. Overloaded first stage of the reactor system. When severe organic overloads occur on the first stage of the process, it is possible to develop the white filamentous biomass on the first stage.

Prevention and Cure. The solution is to provide a larger amount of surface area on the first stage. This may be accomplished by adjusting the baffles between Stages 1 and 2 to increase the fraction of total surface area on the first stage.

Decrease In Efficiency

Some of the major factors that may affect process efficiency are as follows:

1. Reduced wastewater temperatures. Wastewater temperatures below 13°C (55°F) will result in a reduction of biological activity and decrease in organic removal. The exact amount of performance reduction will depend on the actual operating load and wastewater temperature. Temperature is a very critical parameter in plants designed to accomplish nitrification. Start-up and the development of a nitrifying culture under very low temperature conditions may be accomplished. The time required to achieve maximum nitrification may be substantial, however. Experience has shown that 6 to 8 wk are required to achieve steady-state conditions with wastewater temperature at 7° to 8°C (45° to 47°F).

2. Unusual variation in flow and/or organic loading. In the event that unusually large diurnal flow and/or organic variations occur, a reduction in process performance is likely to result. Before any corrective steps may be taken, the exact extent of the problem retention time must be determined.

Hourly removal efficiencies should be calculated and the influent flow recorded and evaluated with respect to retention time. In most cases, when the influent flow and/or organic load peaks are less than twice the daily average over a 24-hour period, little decrease in process efficiency will result. In treatment plants in which these hydraulic and/or organic parameters are exceeded for a sustained period, the above biochemical oxygen demands (BOD) and solids determination may be necessary to determine if corrective action is required.

3. pH difficulty. Every wastewater has an optimum pH level for best treatability. For domestic wastewaters, variations in pH between 6.5 and 8.5 will result in little effect on organic removal efficiency. If this range is exceeded at any time, however, a decrease in efficiency is likely to result. When dealing with nitrification, pH and alkalinity are very critical parameters, and pH should be kept as close as possible to a value of 8.4 when nitrifying. The alkalinity level should be maintained in the raw wastewater at least 7.1 times the influent ammonia concentration to allow the reaction to go to completion without adversely affecting the microorganisms.

Accumulation of Solids

If grit and primary solids removal is inadequate, suspended solids may result in the development of odors and may exert a deleterious influence on process performance.

In the event that a solids accumulation problem develops, the reactor should be pumped free of the solids, and the type and concentration of solids should be determined to establish the best solution. The equipment manufacturer should be contacted to assist in solving the problem.[32]

Advantages

The advantages of the RBC system are flexibility, high degree of treatment, process stability, low maintenance and power consumption, provisions for nitrification, and improved sludge settling.[33] An EPA publication lists the following advantages:

There are no sludge or effluent recycle streams. The mechanical equipment is low speed, easing maintenance. Higher degrees of treatment are obtained than in a trickling filter. The bulk (95 percent) of the microbes is attached to the discs, making them less susceptible to washout and upset than in an activated-sludge plant. The process requires fewer process decisions by the operator than does activated sludge. Because of the hydraulic headloss through the process, rotating biological contactors frequently can be added to an existing plant to improve performance without the need to add pumping facilities.[34]

It should be noted, however, that recycling of effluent stream can be advantageous in medium-sized to large-sized RBC plants' operations. (See the *New Developments of RBC Technology* section of this report for a discussion of effluent stream recycling.)

Another EPA report lists the following general advantages of the RBC system:

1. Space. Biomass is concentrated on disk surfaces, rather than dispersed throughout the wastewater.

2. Efficiency of oxygen transfer. Power requirements to achieve oxygen transfer are significantly lower for RBC systems than for systems requiring aeration of the waste stream as the biomass absorbs oxygen from the air.

3. Acclimatization. Because the biomass is fixed on the disk surfaces rather than flushed through the system, it can become acclimated to a greater variety of waste streams, resulting in greater overall efficiency.

4. Ease of Operation. Food-to-mass ratios need not be controlled as in activated sludge systems. The system requires little expertise and minimum testing to achieve smooth operation in routine installations. In addition, the RBC unit can be installed at minimum cost in existing facilities to upgrade marginal plant performance.

Other advantages noted in the literature are:

1. Short-circuiting has been eliminated by disk staging.

2. There is no bulking, foaming, or floating of sludge.

3. The large growth of microorganisms on the disks minimizes organic overloading.

4. The depth of excavation is less than for many other processes. Where there is high ground water, bed rock, or poor soil, this advantage becomes increasingly important.[35]

5 REASONS FOR REGULATION CONTROLLING AMMONIA NITROGEN IN SEWAGE TREATMENT PLANT EFFLUENTS

Effluents from sewage treatment plants often contain significant concentrations of ammonia nitrogen. Ammonia can cause many problems in the receiving streams. The concentration of NH_3-N in raw wastewater varies greatly—from 4 to 35 mg/ℓ—with an average value of 20 mg/ℓ. Activated sludge treatment plants generally reduce the concentration to less than 10.0 mg/ℓ. Trickling filters generally reduce NH_3-N concentration to 8.0 mg/ℓ or below. The removal

[32] *Deeds and Data* (Water Pollution Control Federation, January 1978).

[33] James H. Clark, Ethan M. Moseng, and Takashi Asano, *Performance of a Rotating Biological Contactor Under Varying Wastewater Flow* (Washington State University, Pullman, 1976).

[34] *Environmental Pollution Control Alternatives—Municipal Wastewater*, EPA 625 5-76-012, Environmental Pollution Control EPA Technology Transfer Publication (USEPA), pp 21-24.

[35] G. P. Manos, *Field and Lab Evaluation of Roadside Park Waste Treatment Plants*, PB 291-196 (The University of Akron, Institute of Technical Assistance, March 1977).

naturally depends greatly on the degree of nitrification. Nitrification is expected to occur in most trickling filters during the summer. Gakstatter, et al., recently reported that the mean inorganic-N concentration from 244 activated sludge treatment effluents was 8.4 mg/ℓ and from 244 trickling filter effluents, 8.2 mg/ℓ.[36]

NPDES permits do not specify the NH_3-N concentration allowable in secondary treatment effluents. The quality of the receiving water dictates the allowable NH_3-N load, and thus the allowable NH_3-N concentration in the effluent to be discharged. Consequently, each case should be considered individually. Nitrification is beneficial because:

1. It removes ammonia, which even in low concentrations, is toxic to aquatic life.

2. A nitrified effluent will be more effectively and efficiently disinfected, since ammonia increases the chlorine dosage and contact time required for effective disinfection of water supplies derived from surface waters containing ammonia.

3. A nitrified effluent contains less soluble biodegradable organic matter than nonnitrified effluent.

4. Ammonia is corrosive to copper.

5. Ammonia entering a receiving stream may deplete the oxygen supply of the water regime as it undergoes nitrification. Use of existing supplies of instream dissolved oxygen causes anaerobic or low-oxygen situations, which can result in fish kills and a generally unhealthy environmental situation. Theoretically, 4.6 mg of oxygen are required (nitrogenous oxygen demand) for each milligram of ammonia nitrogen converted to nitrate, as shown by Eqs 1 and 2.

First Stage Nitrification:

$$\text{Ammonia-N} + \text{Oxygen} \xrightarrow{\textit{Nitrosomonas sp.}\ \text{Bacteria}} \text{Nitrite-N} \quad \text{[Eq 1]}$$

Second Stage Nitrification:

$$\text{Nitrite-N} + \text{Oxygen} \xrightarrow{\textit{Nitrobacter sp.}\ \text{Bacteria}} \text{Nitrate-N} \quad \text{[Eq 2]}$$

Actually, only about 4.3 mg of oxygen are required for each milligram of ammonia nitrogen converted, since some nitrogen will be synthesized into the cells of growing nitrifying organisms. A wastewater or effluent containing 40 mg/ℓ NH_3-N, as commonly occurs during peak load periods, could then exert a BOD of approximately 172 mg/ℓ in a treatment plant or receiving stream. This demand may represent a much greater load on the receiving stream than the organic carbon discharged in the effluent. By converting the ammonia nitrogen to nitrite and nitrate, this additional oxygen-demanding load will be removed from the stream.[37]

Wang, et al., present an excellent discussion of the history and theory of nitrification in the context of sewage treatment:

> Sewage treatment plants before 1930 were designed to accomplish a relatively high degree of nitrification, at least during the summer months of the year when oxidation rates were highest and stream flows were apt to be minimal. The nitrification process can remove the so-called "nitrogenous oxygen demand" (NOD). Past experience taught that highly nitrified effluents were immune to purification. A two-stage biological system can generally guarantee complete nitrification. The first stage is used for the carbonaceous "biochemical oxygen demand" (BOD) removal, while the second stage is used for converting ammonia to nitrites and nitrates.
>
> From 1940 until the late 1960's American environmental engineers generally attempted to design or use processes that minimized nitrification because of three reasons: (a) it was undesirable to spend additional capital and operating costs to satisfy the NOD; (b) the problems of rising sludge in conventional activated sludge and trickling filter plants were shown to be due to nitrification followed by denitrification; and (c) the NOD of unnitrified effluents was overlooked by the environmental engineers at that time.
>
> Since 1970 the engineers in the U.S.A. have considered both BOD and NOD as potential loads of stream pollution; thus the importance of nitrification is again recognized. . . . Now nitrogen removal from wastewaters is being requested in many states for the conservation of receiving surface waters. . . .
>
> . . . The oxygen consumed in the aforementioned nitrification process is termed nitrogenous oxygen demand (NOD). The NOD of unnitrified sewage treatment plant (STP) effluent also contributes the pollution load to a receiving water. In the past, many environmental engineers dismissed this matter on the basis of three premises: (a) Nitrification is caused by nitrosomonas and nitrobacter, and the population of the nitrifying autotrophic bacteria is minimal in

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[36] J. H. Gakstatter, et al., "A Survey of Phosphorus and Nitrogen Levels in Treated Municipal Wastewater," *Journal of the Water Pollution Control Federation* (April 1978).

[37] James C. Young, "Advanced Wastewater Treatment Concepts," *Conservation for "Better Water,"* p 9.

receiving waters; (b) The reaction constant for nitrogenous oxidation is small in relation to the constant for carbonaceous matter; and (c) Oxidation of ammonia to nitrates simply converts dissolved oxygen to a form from which it is still available to prevent formation of anaerobic conditions. Now many states are requiring that NOD be considered as well as BOD in analysis of pollution loads that receiving streams can bear, particularly during the warmer months of the year when oxidation rates are highest and stream flows are apt to be minimal. Future sewage treatment plants are expected to be designed to accomplish extensive nitrification.[38]

To understand the factors affecting the nitrification phenomenon that are associated with upgrading existing DA sewage treatment plants with RBC technology, the reader should become familiar with basic information related to the nitrification reaction. The following "rules of thumb" have been taken from the literature:

(1) Optimum pH is 8.4 to 8.6, but the pH range of 7.6 to 7.8 is recommended in order to allow carbon dioxide to escape to the atmosphere. (2) Since the nitrification process destroys alkalinity and the pH may fall to levels that inhibit nitrification, sufficient lime may be added to raise and to maintain the pH in the desired range. In any event, sufficient alkalinity should be present to leave a residual of from 30 to 50 mg/ℓ after nitrification is completed; The rate of nitrification increases through the temperature range of 5 to 30 degrees C; Optimum temperature for nitrifying organisms is 30 to 35°C; (3) The retention time for nitrification is directly proportional to the amount of nitrifiers present in the system; (4) Instantaneous increases (from 50 to 110 mg/ℓ) or decreases (from 50 to 5 mg/ℓ) in BOD concentration do not affect the nitrification rate; however, a change in the average BOD concentration of the feed affects the percentage of nitrifiers, and thus affects the retention time to achieve complete nitrification; (5) Carbonaceous BOD concentrations higher than 50 mg/ℓ in the nitrification influent may interfere with winter operation; (6) Approximately each milligram of ammonia nitrogen that is nitrified requires 4.6 mg of oxygen; besides, an additional oxygen allowance must be made for carbonaceous BOD that escapes from the secondary treatment process; (7) There is apparently no significant inhibition of nitrification occurring at dissolved oxygen (DO) levels exceeding 1 mg/ℓ; design based on maintaining 2 to 3 mg/ℓ of DO in the waste under average loading conditions includes a reasonable factor of safety. Under peak loading, the DO concentration may be permitted to fall somewhat, but not below 1 mg/ℓ.[39]

[38]L. K. Wang, M. H. Wang, C.P.C. Poon, and J. Bergenthal, "Chemistry of Nitrification-Denitrification Process," *The Journal of Environmental Science* (November/December 1978), pp 23-27.

[39]Wang, et al., "Chemistry of Nitrification-Denitrification Process," pp 23-27.

Nitrification with RBC technology consists of a population of mostly nitrifying microorganisms growing attached on the surface of a number of closely spaced disks. These disks, partially submerged in the wastewater, are mounted on a common shaft which is rotated, alternately exposing the microbial population to the atmosphere and to the wastewater. The fixed-film of nitrifying biomass on the disks, in the presence of oxygen (from air), continually oxidizes the ammonia nitrogen in the wastewater to nitrate nitrogen (nitrification). New cellular matter (nitrifying bacteria) is synthesized from the energy liberated by the oxidation reaction. The attached mass of microorganism on the disks is continually being acted upon and removed by the shearing force created by the rotation of the disks through the wastewater.[40]

Generally, all the factors discussed above are interrelated, and since an optimum combination of these factors must be maintained, nitrification is often difficult to control in wastewater treatment systems.

Several publications are available to provide further information regarding nitrification and/or RBC technology:

1. T. Hewitt, *Nitrification of a Secondary Municipal Effluent Using a Rotating Biological Contactor*, Research Publication No. 71 (Wastewater Treatment Section, Pollution Control Branch, Ontario, Ministry of the Environment, April 1978).

2. D. J. Ehreth and J. V. Basilico, "An Overview of Nitrogen Control Technology in Municipal Wastewater Treatment," *Water—1974: II. Municipal Wastewater Treatment*, ed. G. F. Bennett, American Institute of Chemical Engineers, AIChE Symposium Series 145, Vol 71 (1975).

3. *EPA Technology Transfer Manual—Process Design Manual for Nitrogen Control* (EPA, October 1975).

4. D. L. Kluge and R. J. Kipp, *Evaluation of the RBC Process for Municipal Wastewater Treatment*, EPA 600/2-78-028 (Municipal Environmental Re-

[40]T. Hewitt, *Nitrification of a Secondary Municipal Effluent Using a Rotating Biological Contactor*, Research Publication No. 71 (Wastewater Treatment Section, Pollution Control Branch, Ontario, Ministry of the Environment, April 1978).

search Laboratory Office of Research and Development, EPA, Cincinnati, OH, March 1978).

5. J. A. Borchardt, S. J. Kang, and T. H. Chung, *Nitrification Secondary Municipal Waste Effluent by Rotating Bio-Discs,* EPA 600/2-78-061 (Municipal Environmental Research Laboratory Office of Research and Development, EPA, Cincinnati, OH, June 1978).

6. M. P. Wanielista and W. W. Eckenfelder, Jr., eds., *Advances in Water and Wastewater Treatment —Biological Nutrient Removal,* papers presented in part at a conference on Biological Nutrient Removal Alternatives at Florida Tech. University (Ann Arbor Science Publishers, March 1978).

7. B.C.G. Steiner, "Take a New Look at the RBS Process," *Water and Wastes Engineering* (May 1979).

8. Steiner Associates, *The New Rotating Disc Process* (C. G. Steiner, August 1, 1978).

Information regarding RBC costs, operations and maintenance requirements, land requirements, and comparing RBC technology with other processes may be found in *Evaluation of Biological Wastewater Treatment Processes,* by H. H. Benjes, Jr., of Culp/Wesner/Culp consulting firm.

6 UPGRADING EXISTING DA SEWAGE TREATMENT PLANTS TO MEET SECONDARY TREATMENT EFFLUENT QUALITY AND AMMONIA STANDARDS

The Federal Water Pollution Control Act Amendments of 1972 require increased pollution abatement activity by municipalities, industries, and states as well as by the Federal Government. Implementing regulations of the Act have been promulgated by the U.S. Environmental Protection Agency (EPA) and discharge permits are issued under the NPDES. Currently, secondary wastewater treatment is required for all publicly owned treatment facilities and Federal installations.

Table 1 lists the minimum level of effluent quality attainable by secondary treatment, as stipulated by NPDES. Special consideration can be given to treatment facilities accepting discharges from combined sewers or industrial wastes. Values for BOD and suspended solids may be adjusted upwards. For such facilities, the decision about what the removal level should be must be made on a case-by-case basis. On the other hand, a more stringent requirement can be applied where a very high quality of receiving water will be maintained. The latter is particularly important in light of the antidegradation policy proposed by the EPA—a policy adopted by many states. In essence, water whose existing quality is better than the established standards, as of the date on which such standards become effective, will be maintained at this high quality unless it has been affirmatively demonstrated to the state that a change is justifiable as a result of necessary economic or social development and will not result in a significant loss of use of these waters. Any industrial, public, or private project or development which would constitute a new source of pollution or an increased source of pollution to high-quality waters will be required to provide the highest and best practical means of wastewater treatment to maintain high water quality. The highest and best practical wastewater treatment is most likely beyond the secondary treatment level; i.e., restricting the amount of nitrogen and/or phosphorus discharge, in addition to lower values of BOD and suspended solids in the treated effluent. Without exemption, treatment plants at U.S. Army installations are subject to the same provisions of the Water Pollution Control Act, as amended, and consequently, the highest or best practical treatment (tertiary treatment) may be required.

Table 1

Secondary Treatment Effluent Quality

Parameter	Quality
Biochemical oxygen demand (BOD_5 day)	30-day arithmetic mean values not exceeding 30 mg/ℓ 7-day arithmetic mean values not exceeding 45 mg/ℓ 85 percent removal on 30-day average
Suspended solids	30-day arithmetic mean values not exceeding 30 mg/ℓ 7-day arithmetic mean values not exceeding 45 mg/ℓ 85 percent removal on 30-day average
Fecal coliform bacteria	30-day geometric mean values not exceeding 200/100 mℓ 7-day geometric mean values not exceeding 400/100 mℓ
pH	Within the limits of 6.0 to 9.0

A trickling-filter treatment system is often used in wastewater treatment plants at U.S. Army bases.

Most trickling-filter systems were built a decade or two ago, and often cannot handle today's higher hydraulic and organic loads. Consequently, the treated effluents may not meet either the secondary treatment effluent quality standards or the ammonia requirements. However, various alternatives can improve the effluent quality, including (1) design and construction of a new treatment plant for existing and near future loads, (2) expansion of the existing plant, and (3) addition of an upgrading retrofit subsystem. The last alternative is deemed more desirable because of its lower cost and because an operation having a subsystem different from trickling filters has greater flexibility.

Most DA wastewater treatment plants consist of primary settling, followed by a secondary biological process. The primary/secondary treatment combination has often been the most economical method of treating effluent entering aquatic regimes. However, the secondary treatment often passes substantial quantities of ammonia-nitrogen into the receiving waters. As a result, protecting the aquatic environment as mandated by law often requires the control of ammonia-nitrogen BOD and SS by some form of post-secondary treatment technology. This treatment brings the effluent into NPDES permit compliance for BOD, SS, and/or ammonia. The trickling filters which the Army predominantly uses for secondary treatment were chosen partly because of their inherent simplicity, and any additional complex post-secondary treatment process for BOD, SS, and/or ammonia removal would destroy the desired level of simplicity in the overall operation. Consequently, after evaluating many types of alternatives for economy, reliability, effectiveness and simplicity of operation, and applicability for upgrading existing DA sewage treatment plants, the rotating biological disk technology was chosen for evaluation via a pilot plant study. Researchers felt that RBC technology was potentially suitable for DA needs, capabilities, and limitations.

A pilot plant using a rotating disk biological wastewater treatment process was set up at a typical Army installation to evaluate its performance as an upgrading retrofit unit process for carbonaceous and nitrogenous BOD reduction and nitrification that would meet NPDES stipulations. The potential of the pilot process as a tertiary treatment of clarified secondary trickling-filter effluent was then evaluated through the following major technical tasks:

Task 1. A 0.5-m rotating-disk pilot plant was set up at a trickling-filter plant.

Task 2. Experiments were conducted to evaluate process flexibility, feasibility, and characteristics for BOD reduction and nitrification potential under a variety of hydraulic loading regimes, using an influent condition containing BOD and ammonia nitrogen concentrations typical of DA secondary trickling-filter facility effluent.

Task 3. Data were analyzed to evaluate system BOD and ammonia nitrogen removal capabilities, cost-effectiveness, and ability to meet current and anticipated tertiary water quality effluent limitations. Emphasis was placed on assessing the following operating factors:

a. System startup

b. Organic shock loading

c. Nuisances (odor, filter flies)

d. Operation and maintenance costs

e. Energy consumption

f. Food-to-microbe ratio (F/M)

g. Biosynthesis

h. Effective rotational velocity of the media

i. Potential need of clarification prior to disinfection and discharge, and design criteria necessary for clarification

j. Extent of nitrification in the system

k. Skill level and manpower requirement for system operation

l. Sludge characteristics such as density, thickening property, and sludge volume

m. Effect of extremely low temperature (near freezing).

Task 4. Design procedures were developed for upgrading U.S. Army trickling-filter sewage treatment plants using a rotating disk retrofit unit.

Task 5. Costs (capital and operating) were estimated for the handling of 1.0, 5.0, and 7.5 mgd (3785, 18 925, and 28 390 m^3/day).

Task 6. The retrofit system's reliability, efficiency, energy requirements and energy effectiveness, life expectancy of major control components, advantages and disadvantages, operational characteristics, and problems were evaluated.

The raw data results, protocol for experimentation, and subsequent detailed analysis of the data associated with Tasks 1 through 4 of this study are on file at CERL/EN. (For information call Dr. Ed Smith, FTS 958-7262 or commercial 217-352-6511.)

This chapter is an assessment of RBC capability for upgrading clarified trickling filter effluent for BOD reduction and ammonia removal. This assessment considers system efficiency, reliability, energy requirements and effectiveness, advantages and disadvantages of the process, operational characteristics and problems, life expectancy of major control components, and other pertinent information necessary for effective system assessment.

System Efficiency

Approximately 10 days to 2 weeks are required to develop enough active biomass for a steady performance in BOD removal. The time required varies slightly with the organic loading, temperature, and the media smoothness. To establish an active nitrifying population on the media coexisting with the carbonaceous BOD oxidizing bacteria, it is preferable to begin operations in the summer. The clarified effluent of most trickling filters is nitrified or nearly nitrified in the summer, therefore providing an excellent acclimated seed of nitrifiers to the RBC unit. The chance of establishing a balanced population of both nitrifiers and carbonaceous BOD oxidizing bacteria is therefore much improved. Lue-Hing, et al., reported that at 21° to 26°C, nitrifying growth was established in 4 to 5 weeks.[41] However, the RBC units used in their studies were designed and operated primarily for nitrification and did not consider concurrent removal of BOD. In northern climates, where trickling filter effluents are seldom nitrified in the winter, establishing an active nitrifying growth can be very difficult during the cold seasons. However, even with pH control, alkalinity supplement, and reduction of influent BOD to below 20 mg/ℓ, success is not guaranteed. It is worth noting that Reid, et al., reported successful startup of nitrifying growth during the winter, but the wastewater temperature in the startup period was 14.7° to 16.4°C (58° to 62°F), which was rather mild.[42]

In assessing the RBC system efficiency, the BOD removal was examined first, followed by examination of the NH_3-N removal. The efficiency of the RBC system to remove BOD can be expressed in (1) BOD removal in lb/1000 sq ft/day (g/m^2/day) and/or percentage removal, and (2) the highest BOD loading allowable for producing an acceptable effluent. For the first part, Figure 2 reveals that soluble BOD removal increases with the soluble BOD loading, both in lb/1000 sq ft/day unit (g/m^2/day). Within the range of 0.4 to 1.85 lb soluble BOD/1000 sq ft/day (1.95 to 9.0 g/m^2/day) loading, a straight line relationship between removal and loading is illustrated. The percentage of removal ranges from 55 to 60. Below the 0.4-lb (0.16-kg) soluble BOD/1000 sq ft/day (1.95 g/m^2/day) loading, the percentage is dropped gradually to approximately 20 percent. The percentage of soluble BOD removal is low in comparison with all secondary treatment processes, including the RBC system itself (Curve C, Figure 2). It should be noted that the RBC unit in this study is intended to upgrade a secondary effluent having a much lower BOD concentration and an expectedly higher fraction of biologically resistant material. The treatment efficiency in terms of BOD removal is expected to be low. Curves B and D in Figure 2 substantiate this finding. Although the remaining percentage of soluble BOD (portion not removed) is high, the effluent-soluble BOD concentration is low, because the influent BOD concentration was low originally.

Figure 3 illustrates the system efficiency in terms of the highest allowable organic loading for producing an acceptable effluent. To meet the standards of a secondary effluent with 30 mg/ℓ total BOD_5 and 30 mg/ℓ suspended solids, and allowing 15 mg/ℓ suspended solids in the RBC clarified effluent which is equivalent to 15 mg/ℓ BOD_5, only 15 mg/ℓ soluble BOD_5 is allowed in the RBC effluent. Figure 3 indicates that the highest allowable loading corresponding to this effluent quality is 1.6 lb/1000 sq ft/day (7.8 g/m^2/day).

If the RBC system is intended to upgrade the trickling filter effluent to meet the standards of a

[41] C. Lue-Hing, et al., "Biological Nitrification of Sludge Supernatant by Rotating Disks," *Journal of the Water Pollution Control Federation*, Vol 48 (January 1976).

[42] *Nitrification Systems for Ammonia-Nitrogen Removal* (Reid, Quebe, Allison, Wilcox and Associates, Inc.).

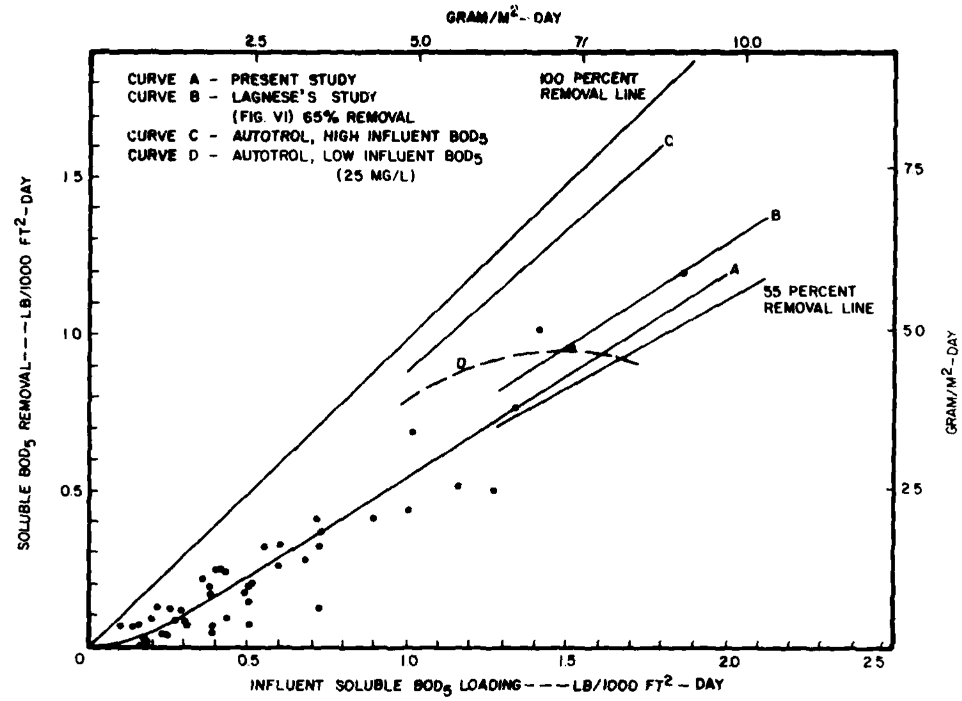

Figure 2. Relationship between soluble BOD5 removal and loading.

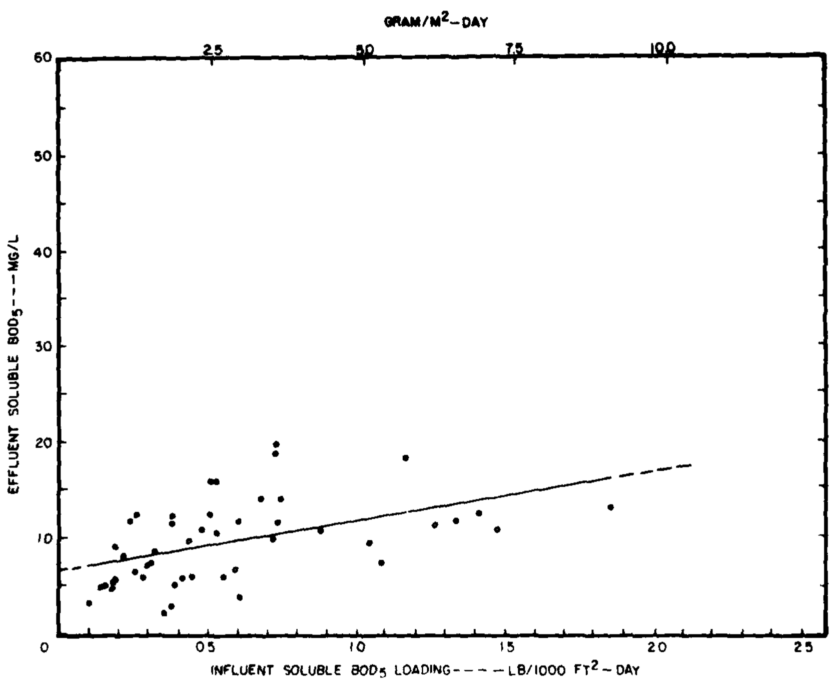

Figure 3. Relationship between effluent soluble BOD5 and influent soluble BOD5 loading.

tertiary effluent, a 10 mg/ℓ total BOD_5 and 10 mg/ℓ suspended solids in the effluent are assumed for system efficiency assessment. Since the RBC clarified effluent contains an average of 15 mg/ℓ suspended solids, the tertiary effluent standards cannot be met unless the clarifier is replaced with a tertiary solid removal process. It is recognized today that filtration, e.g., dual media filter, can be used as a tertiary treatment process to decrease secondary effluent suspended solids concentration to 1.0 mg/ℓ. This has been shown in the EPA-supported demonstration project at Lake Tahoe. Therefore, allowing 1.0 mg/ℓ suspended solids, which is equivalent to 1.0 mg/ℓ BOD_5, only 9.0 mg/ℓ soluble BOD_5 would be allowed in the RBC effluent to comply with tertiary effluent standards. Figure 3 indicates that the highest allowable loading would be 0.5 lb/1000 sq ft/day (2.44 g/m^2/day).

It is not clear whether the NPDES permits specify that the BOD_5 concentration in the secondary effluent can include nitrogenous BOD. That EPA has proposed adopting total organic carbon (TOC) to replace or to use with BOD_5 for secondary effluent standards implies that nitrogenous BOD could be excluded from consideration. Accordingly, the RBC system efficiency is reexamined. If 15 mg/ℓ suspended solids are expected in the clarified effluent, leaving an allowable 15 mg/ℓ soluble BOD_5, an extrapolation of the regression line in Figure 4 would show that as much as 12.5 lb/1000 sq ft/day (61 g/m^2/day) soluble BOD_5 would meet secondary effluent standards. The same consideration cannot be applied to tertiary treatment, since NOD will definitely be included in the effluent standards.

The performance of the RBC unit was steady. For example, the regression line in Figure 3 has a standard deviation of 4.3 mg/ℓ, with 68 percent of all data points falling within ± one standard deviation. Likewise, the regression line in Figure 4 has a standard deviation of 1.9 mg/ℓ, with 68 percent of all data points falling within ± one standard deviation. Thus, the effluent soluble BOD_5 concentration and the effluent soluble carbonaceous BOD_5 concentration can be predicted from Figures 3 and 4 with reasonable accuracy.

The RBC system efficiency drops with low temperatures and short-term hydraulic shock loading. The short-term hydraulic shock loading simulates surge stormwater going through the treatment system. Figure 5 suggests that numerically, the short-term hydraulic shock loading has the same effect on RBC system performance as the low temperature. Only 0.65 lb (0.26 kg) of soluble BOD_5/1000 sq ft/day (3.17 g/m^2/day) loading is allowable to meet secondary effluent standards (including 15 mg/ℓ of suspended solids). The drop from 1.60 lb/1000 sq ft/day to 0.65 lb/1000 sq ft/day (7.81 to 3.17 g/m^2/day), or a correction factor of 0.41, applies to a temperature drop from 20°C to below 10°C (the range is 5° to 10°C, with an average of 7.2°C).

In contrast to low temperatures and hydraulic shock loading, organic shock loadings do not adversely affect RBC system efficiency. (For this study, organic shock loadings are organic loadings that are 24 to 440 percent greater than the average loadings normally received by the RBC system.) The RBC system has a very large reserve capacity to accommodate an organic shock loading associated with trickling-filter effluent. Up to 3.1 lb/1000 sq ft/day (15.1 g/m^2/day) of soluble BOD_5 can be handled.

Because of the interplay between particulate BOD_5, soluble BOD_5, and film biomass in the RBC unit, it may be more realistic and more direct to use total BOD_5 concentrations to evaluate RBC system efficiency. This approach includes the suspended solids concentration within the clarified effluent in the total BOD_5 determination, thus reflecting the efficiency of both the RBC unit and the clarifier for any samples. When using the soluble BOD_5 for evaluation, an average suspended solids concentration in the clarified effluent must be assumed throughout the analysis, which is far less realistic. Figure 6 indicates that to obtain 30 mg/ℓ total BOD_5 concentration in the effluent, a loading of 7.5 lb total BOD_5/1000 sq ft/day (36.6 g/m^2/day) is allowed. Since the suspended concentration in the effluent is always below 30 mg/ℓ, the secondary effluent standards are met.

At lower temperatures (5° to 10°C, with an average of 7.2°C), Figure 7 shows that the allowable loading drops to 1.5 lb/1000 sq ft/day (7.3 g/m^2/day). This is equivalent to a correction factor of 0.2, which is significantly lower than the drop that occurs when soluble BOD_5 is used to evaluate system efficiency. Low temperatures, therefore, not only decrease the oxidation rates but also affect the settling of suspended solids. However, the latter effect is not considered in the soluble BOD_5 analysis, which explains why the correction factor is higher there.

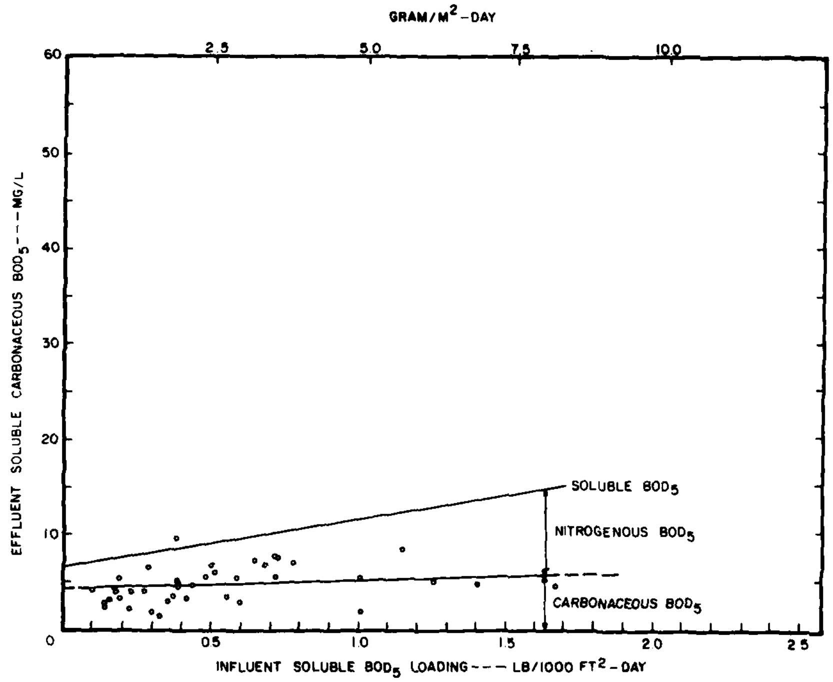

Figure 4. Relationship between effluent soluble carbonaceous BOD_5 and influent soluble BOD_5 loading.

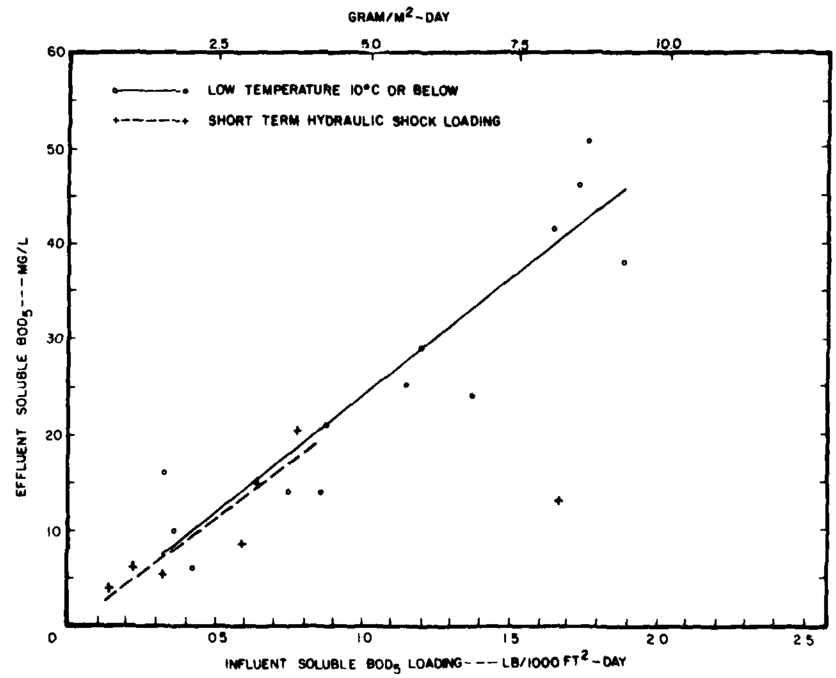

Figure 5. Effluent soluble BOD_5 at low-temperature or short-term hydraulic shock loading.

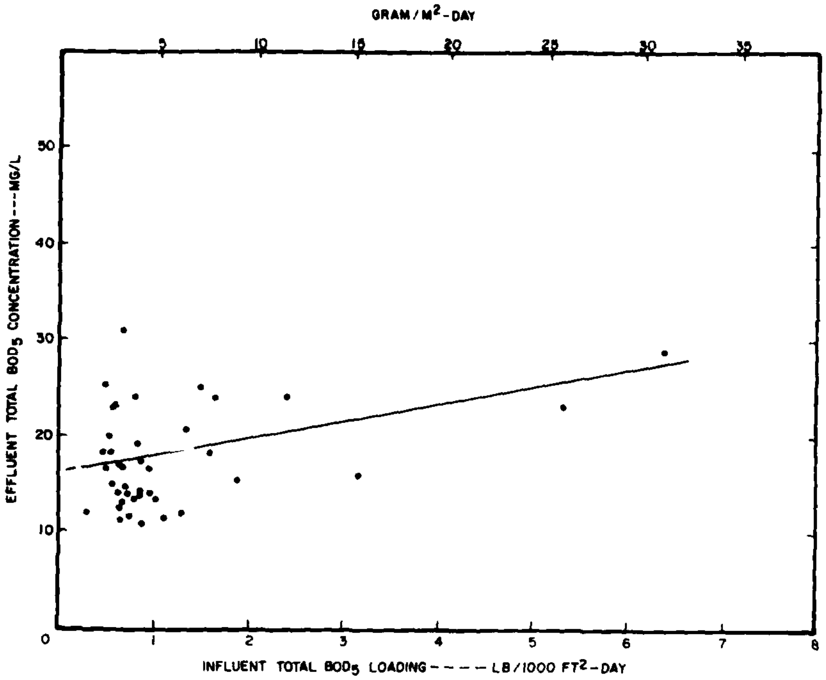

Figure 6. Relationship between effluent total BOD_5 and influent total BOD_5 loading.

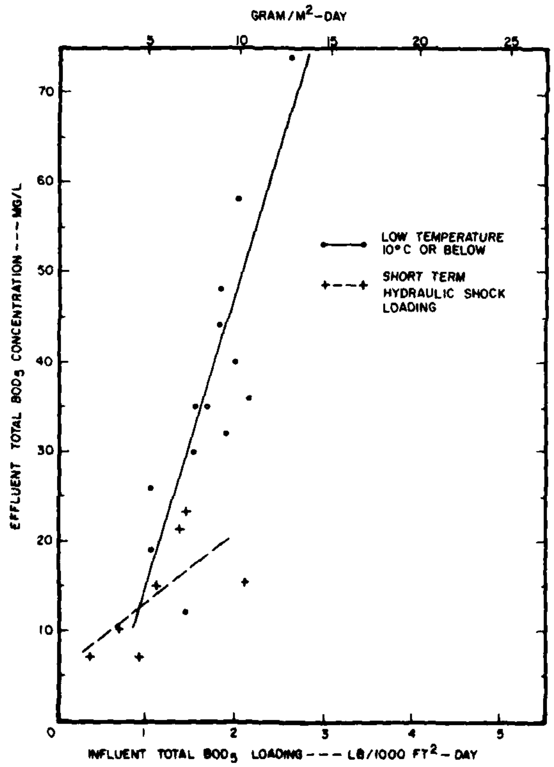

Figure 7. Effects of low-temperature and short-term hydraulic shock loading on effluent total BOD_5 concentrations.

The short-term hydraulic shock loading has less effect on RBC system efficiency than low temperatures. As much as 3.0 lb of total BOD_5/1000 sq ft day (14.6 g/m^2/day) can be allowed and still meet the 30 mg/ℓ total BOD_5 standards of a secondary effluent. The hydraulic shock loading affects only the oxidation but not the clarifier performance because the clarifier used for this study is oversized in terms of hydraulics. It should be noted that in the previous analysis, which used soluble BOD_5 instead of total BOD_5, the effects of low temperatures and short-term hydraulic shock loadings on the system efficiency were the same. Since the clarifier performance is assumed to be the same in all situations, it is not affected by temperature. The results of the study indicate that when all operational conditions of the RBC system (RBC unit followed by a clarifier) are considered, including low temperatures and hydraulic shock loadings, total BOD_5 is a better parameter to use when analyzing the system's efficiency. However, an exception to this occurs when tertiary effluent standards are to be met, and the clarifier is replaced by a more efficient solids removal process. In this case, soluble BOD_5 will be a more convenient parameter to use when analyzing RBC system efficiency.

Data from this study showed that the removal of soluble NH_3-N increases with its loading and takes the form of an S-shaped or logistic S curve when both

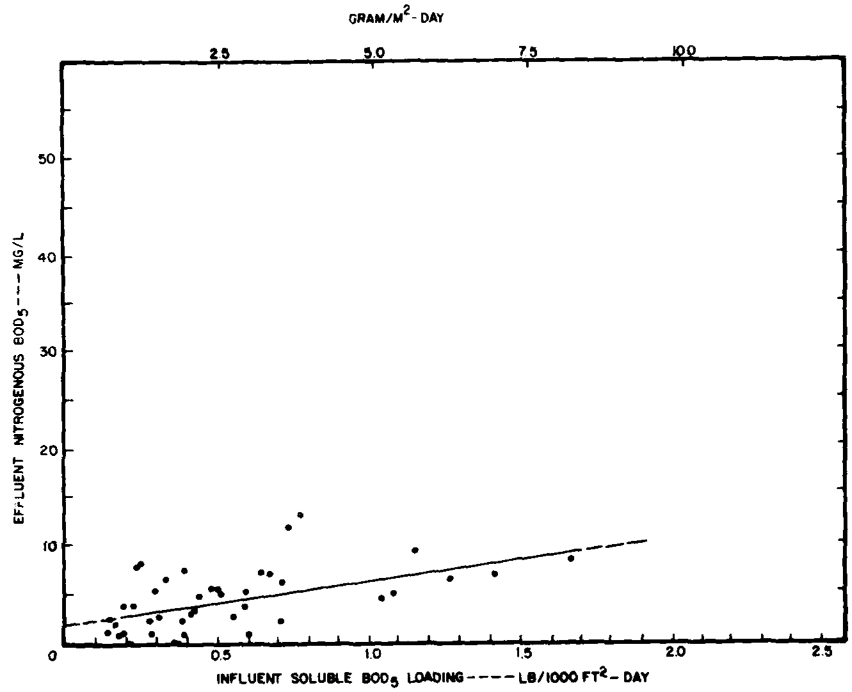

Figure 8. Relationship between effluent nitrogenous BOD_5 and influent soluble BOD_5 loading.

removal and loading are expressed in pounds of NH_3-N/1000 sq ft/day (g/m^2/day). The removal percentage is very small at low loadings, but increases to approximately 53 percent at 0.1 lb/1000 sq ft/day loading (0.49 g/m^2/day), and further increases to 80 percent at 0.55 lb/1000 sq ft/day (2.7 g/m^2/day) loading at loadings above 1.0 lb/1000 sq ft/day (4.88 g/m^2/day) before it levels off. The maximum removal is 0.57 lb/1000 sq ft/day (2.78 g/m^2/day) at loadings above 1.0 lb/1000 sq ft/day (4.88 g/m^2/day). (See the upper part of the solid curve in Figure 8.) The NH_3-N removal drops significantly under adverse conditions such as low temperatures (5° to 10°C) or high hydraulic loading (4.4 gpd/sq ft [0.18 m^3/m^2] and above), particularly when the high hydraulic loading is accompanied by a moderate to high BOD_5 concentration (35 to 131 mg/ℓ). It is worth noting that very little attempt has been made in this study to encourage the growth of carbonaceous matter oxidizing bacteria in favor of nitrifiers. The purpose of this is to maintain a population balance so that BOD removal capability is is not hindered. The NH_3-N removal percentage may not be high for the RBC unit in this study; however, it is possible to obtain a low NH_3-N concentration in the effluent.

Figure 9 shows that if an NH_3-N effluent concentration of 4.0 mg/ℓ is desirable, the allowable loading is 0.27 lb of NH_3-N/1000 sq ft/day (1.32 g/m^2/day). Reducing the effluent concentration to 2.0 mg/ℓ requires that the loading be reduced to 0.11 lb/1000 sq ft/day (0.54 g/m^2/day). Under the previously mentioned adverse conditions, the loading should be dropped to 0.075 lb/1000 sq ft/day (0.37 g/m^2/day). To further reduce the effluent concentration, it is necessary to provide the nitrifiers with the most favorable growth conditions, which include (1) controlling the pH of the wastewater at 8.4, (2) adding alkalinity to the wastewater if necessary to provide more than 7.1 lb (2.84 kg) total alkalinity (as $CaCO_3$) per pound of NH_3-N oxidized, (3) controlling the hydraulic loading so that the retention time in the RBC unit is 60 minutes or longer, and (4) limiting the BOD_5 concentration in the wastewater to 20 mg/ℓ or less. Obviously, this will increase both the level of operational skill and effort required, and the capital and operational costs. If 2.0 mg/ℓ of NH_3-N is allowed in the effluent, the allowable NH_3-N loading of 0.11 lb/1000 sq ft/day (0.54 g/m^2/day) determines the RBC's unit size. Since the BOD loading also determines the unit's size, the larger one should be adopted.

The reliability of producing a prescribed effluent NH_3-N concentration is not as high as in the BOD. The data points are more scattered—as shown in

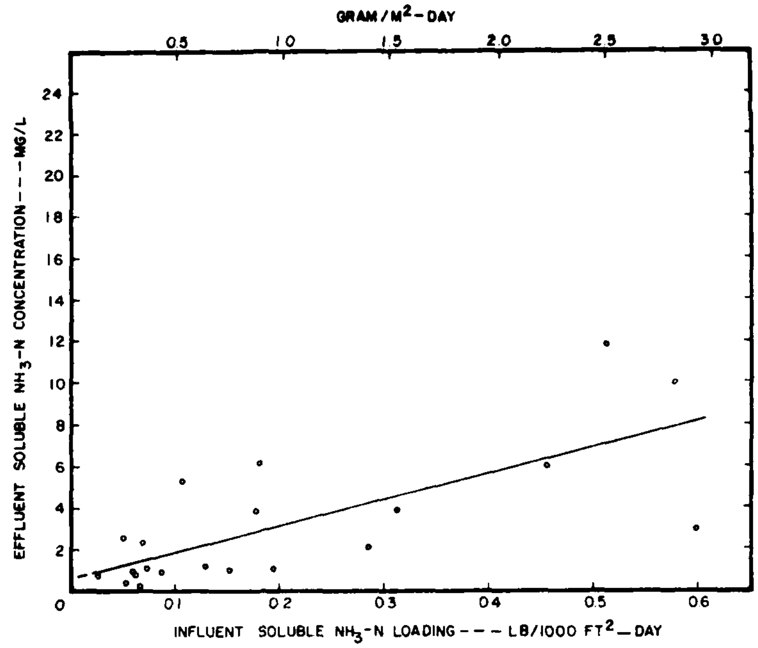

Figure 9. Relationship between effluent soluble NH_3-N concentration and influent soluble NH_3-N loading.

Figure 9 — than those for BOD Figures 3, 4, and 6). The reason, other than the fact that the optimal growth conditions are not given in the pilot plant study, is mostly because of the fluctuation of BOD concentration in the wastewater. Higher BOD concentration results in more growth of carbonaceous-matter-oxidizing bacteria and shifts the balance so that it is unfavorable to the nitrifiers. Although nitrification is consequently slowed down, NH_3-N removal is not reduced by the same proportion, because some NH_3-N is consumed through cell synthesis. In other words, the NO_2-N and NO_3-N formation is reduced, but NH_3-N removal is not reduced as much. Therefore, the ratio of NO_2 and NO_3 nitrogen formed to NH_3-N removed for the pilot plant varies greatly, as shown in Figure 10.

Because the BOD concentration in the wastewater affects the process of nitrification as well as the rate of NH_3-N removal, it is advisable to keep the BOD concentration low in order to encourage additional nitrifier growth. NH_3-N removal through cell synthesis is not significant when the RBC is treating the trickling-filter effluent because the amount of cell synthesis is limited. There is some indication from this study that the soluble BOD_5 concentration in the wastewater at or below 20 mg/ℓ assures a much better chance for active nitrification and NH_3-N removal; however, a soluble BOD_5 concentration at or below 20 mg/ℓ does not guarantee a highly successful or complete nitrification, if NH_3-N loading is above the designed value or if an adverse environment exists. Similarly, a highly successful BOD removal rate does not necessarily guarantee the same level of performance in NH_3-N removal. When RBC is used to treat primary effluents and when BOD removal is highly successful, the later stages of the RBC unit (second, third, and fourth stages) can usually develop nitrifying bacteria, which results in a high amount of nitrification. However, the same phenomenon cannot be applied to an RBC unit treating trickling-filter effluents.

The RBC clarifier's efficiency in removing suspended solids is very low. In terms of percentage removal, the average is only 30.2 percent, a very disappointing performance for a clarifier. Since the RBC system inherits the light biological flocs that escape from the trickling-filter clarifier, the RBC clarifier performance is not surprising. The average of the clarifier effluent suspended solids concentration is 15 mg/ℓ. The improvement of quality over that of the secondary clarifier effluent may seem insignificant; however, it is important to bring the suspended solids concentration to this level so that more soluble BOD_5 is placed in the effluent. Assume that the RBC

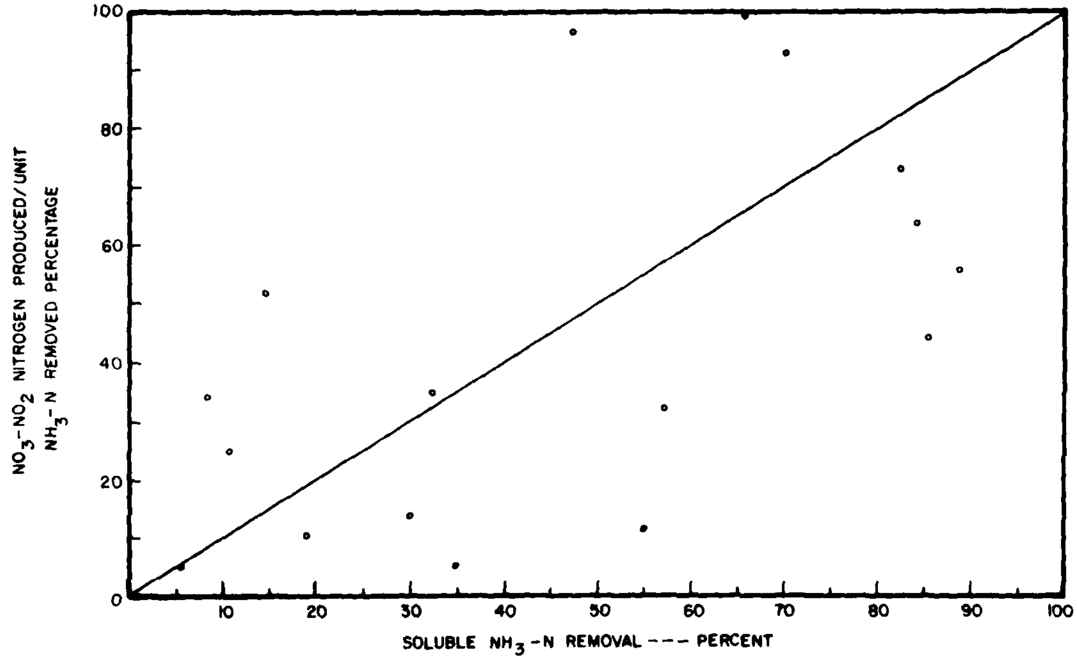

Figure 10. Soluble NH_3-N removal at various loadings.

clarifier is eliminated by putting the RBC unit in the trickling-filter clarifier with a false bottom. Further assume that the secondary effluent standard of 30 mg/ℓ of suspended solids is met. If 85 percent of the suspended solids consists of biological solids, the equivalent biological solids concentration is 25.5 mg/ℓ. With the conversion of 1.0 lb (254 g) of BOD_5/lb of biological solids, the suspended solids alone make up 25.5 of the 30 mg/ℓ of BOD_5 allowed in the effluent by secondary standards. This leaves only 4.5 mg/ℓ of soluble BOD_5 allowable in the effluent, which will greatly increase the size of the RBC unit necessary for the treatment. Using an RBC clarifier for this treatment is less costly than greatly expanding the RBC unit size. However, a clarifier is simply not adequate for the amount of suspended solids removal required by tertiary treatment standards. The option of putting the RBC in the trickling-filter clarifier and using filters to remove the suspended solids appears to be the most logical and cost-effective for this purpose.

Concerning the efficiency of suspended solids removal, it has been noted that the overflow rates for the clarifier used in this study range from 76 to 608 gpd/sq ft (3.17 to 25.36 m^3/m^2). The performance of the clarifier is not affected within this range in terms of the effluent's suspended solids concentration. Thus, it appears reasonable to design the RBC clarifier with an overflow rate of 600 gpd/sq ft (24.5 m^3/m^2/day).

The RBC unit's phosphorus removal efficiency is low. Even with the addition of lime and soda ash, neither total-P nor soluble-P can be reduced to 1.0 mg/ℓ. Soluble ortho-P removal resulting from the addition of chemicals ranges from 40 to 92.8 percent, and the average effluent concentration is 0.85 mg/ℓ. If only soluble ortho-P removal is specified in the effluent standards, then chemical addition will be useful. A low-level chemical additive to pH 10.0 or slightly higher is adequate. It is suspected that the failure of the low-level chemical addition to coagulate the total-P is caused by the lack of rapid mix when the chemicals are added. It has also been observed that significant sloughing of film biomass occurs when the chemicals are added. But as reported by the U.S. Army, the success of total-P removal by low-level lime addition prior to primary clarification and trickling filter seems to indicate that this is a better alternative, since no adverse effect was found for trickling filter operation, and no recarbonation was needed (pH 8.4 to 8.8).[43]

[43]R. D. Miller, R. S. Ryczak, and A. Ostrofsky, *Phosphorus Removal in a Pilot Scale Trickling Filter System by Low Level Lime Addition to Raw Wastewater*, Technical Report No. 7901 (U.S. Army Medical Bioengineering Research and Development Laboratory [USAMBRDL], January 1979).

The RBC unit has been found to have little or no effect on the wastewater's coliform and fecal coliform concentration. The effluent usually contains approximately 10^{3}MPN(most probable number)/100 mℓ.

Energy Requirements and Effectiveness

Estimates of the energy requirements of 0.56 hp/1000 sq ft (0.006 hp/m^2) are based on the manufacturer's data and an assumption of 70 percent efficiency for the motor and the gear reducer combined. From the manufacturer's data, the requirement is calculated to be equivalent to 23.8 hp/1000 lb of BOD_5 removed (0.052 hp/kg). In comparison, the energy requirement of an aeration tank (activated sludge) is approximately 34.8 hp/1000 lb of BOD_5 removed (0.076 hp/kg). The RBC unit requires much less energy (approximately 69 percent of that required for the activated sludge process) and is therefore much more effective.

Process Advantages and Disadvantages

To upgrade DA trickling-filter treatment plant effluent, a new trickling-filter bed can be added. The new filter can be operated in parallel or in series with the existing one. Likewise, an activated sludge process can be added and similarly operated to upgrade effluent quality. Other available alternatives are lagoons and physical-chemical treatment processes. The problems associated with these alternatives are one or more of the following: land availability, high cost, complexity and skill of operation, and extensive modification of the existing plant. Installation of RBC units in the existing secondary clarifiers of the treatment plant is an attractive solution to these problems. The modifications to the existing plant are minimal, and include:

1. The installation of a false bottom, using prestressed concrete planks.

2. The incorporation of RBC units above the false bottom.

3. Modification to the sludge-scraping mechanisms in the existing secondary clarifiers.

If the existing secondary clarifier(s) consistently produces an effluent having a suspended solid concentration of 15 mg/ℓ (30 days average) or less, no additional clarifier is required for the RBC units. Even if an additional clarifier is needed, the proposed scheme is much less costly, requires much less land, and does not add to the complexity of plant operation. This is considered a major advantage of the RBC process used to upgrade the effluent quality of the existing DA trickling-filter plant.

Other advantages of the RBC application are the lower energy requirement and the ease of operation and maintenance, both of which contribute to a lower overall cost for the treatment system. These two advantages are particularly important for remote stations where energy cost may be very high and manpower critically short. Other, less obvious advantages are:

1. The modular construction of RBC units makes it easy to expand the RBC treatment capacity.

2. The RBC unit is easy to install and start up and therefore can fit into a tight schedule.

3. The modules can be relocated with ease, while most other processes are fixed in place.

The following are disadvantages of the RBC system:

1. If the wastewater has a higher concentration of biological resistant organics, the effluent TOC or COD will be high. This disadvantage is inherent for all biological processes, which can be an important factor if future effluent quality standards include TOC or COD parameters.

2. The adaptability of the system to higher effluent quality standards is low unless filters are used to remove suspended solids.

3. The flexibility of operation is low, since there is no scheme for effluent recirculation. The system's adaptability to fluctuating organic loadings and to toxic chemicals is rather limited.

4. Since the biofilm in treating trickling-filter effluents is thin, a cover is needed, even in warm climates, because precipitation can easily wash out the thin biofilm and render the unit useless. A fiberglass cover is always needed in northern climates. In addition, some heating will be required in the winter to eliminate condensation, which increases the corrosion problem.

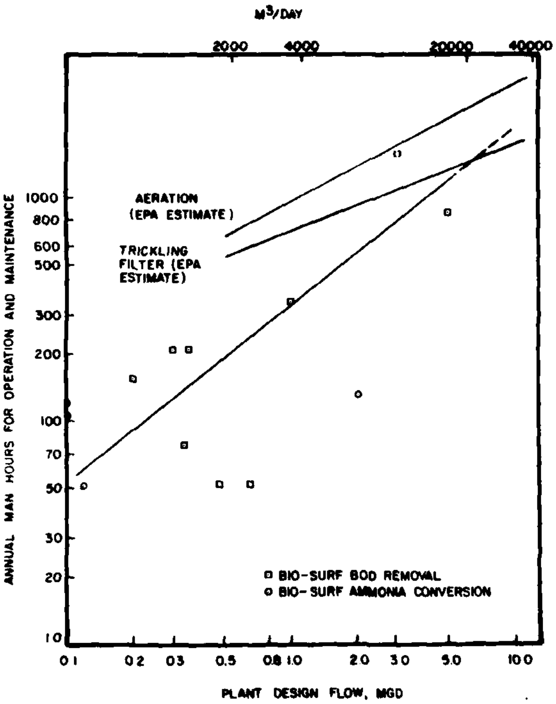

Figure 11. Comparison of manhour requirements for operation and maintenance for various processes (after Autotrol-released information).

Operational Characteristics and Problems

Operation and maintenance of the RBC system are very simple. Simple lubrication and adjustments to chains and sprockets are the only routine requirements. Manhour requirements are very low, as shown in Figure 11; however, this low manhour requirement is possible only at the expense of system flexibility. It does not seem logical that moderate- to large-sized plants using RBC units would not provide the effluent recirculation capability. However, the added capability increases the manhour requirement to that equivalent to trickling filter operations.

There is no nuisance associated with the RBC system operation; problems are few and can be corrected easily.

Life Expectancy of Major Control Components

RBC is a relatively new technology in the United States. Despite the phenomenal growth of this technology and the number of new installations constructed during the past 4 years, there are still uncertainties about the equipment's durability and about the design criteria for equipment sizing. There has been some report of structural failure, and the integrity of the polyethylene plastic after it has been repeatedly immersed in wastewater has been questioned. Because RBC installations in the United States and Canada have been used for such a short time, there is little data on equipment durability. Therefore, it is reasonable to follow the practice of most design engineers who ask for 5-year structural and equipment guarantees. In one case, the Autotrol Corporation has provided a 20-year depreciating warranty for the polyethylene plastic, although the integrity cannot be assured for a 20-year period.

New Developments of RBC Technology

The latest development in RBC technology is the Aero-surf air drive system. An air header installed below the plastic media releases air into cups attached to the media. As the air collects in the cups, the buoyant force turns the shafts. The process reduces mechanical maintenance and allows greater process flexibility. It also maintains a thinner, but highly active, biofilm which requires less energy for rotation and permits the use of high-density media. This reduces the capital cost as well as the operation and maintenance cost, since the number of shafts can be reduced. The high-density media manufactured by Autotrol Corporation has 50 percent more surface area than standard media. On a 25-ft-long (7.5-m) shaft and one stage, a total effective surface area of 150,000 sq ft (13 940 m^2) can be provided for a 12-ft-diameter (3.6-m) media in comparison to the 100,000 sq ft (9295 m^2) of standard media. Epco-Hormel (George A. Hormel & Company of Austin, MN) manufactures density media providing a 200,000 sq ft (18 590 m^2) surface area on a 25-ft (7.5-m) shaft with 11 ft, 3 in. (3.4 m) in media diameter.

If the RBC units are installed in existing aeration tanks of the activated sludge process, there is potentially a significant savings in capital and operations costs as well as in maintenance costs. There is no need to furnish an additional blower, and the major network of air-supply piping needs only a minimal modification. This savings does not occur for RBC application in trickling-filter plants. Also, Autotrol's claim that the performance of the Aero-surf air-drive system is 25 to 30 percent better than the mechanical drive system is mainly for secondary treatment. Since the first stage receives the highest organic loading, and since oxygen transfer sometimes becomes the governing factor in oxidation, the Aero-surf process is very useful for improving oxidation at the first stage. Improved oxidation is needed if a minimum DO of 6.0 mg/ℓ is to be maintained during the summer. Again, this benefit does not occur when an RBC system is used to upgrade trickling-filter effluents; oxygen transfer is never limited in this case. In addition, the low organic loadings create a thin biofilm, which would limit the use of a high-density media. The air supply is not really needed. The cost savings which accrue by reducing the mechanical maintenance can be eliminated by the added maintenance cost incurred for the air supply system. Thus, while the Aero-surf air-drive system appears to be more cost-effective in secondary treatment when used with activated sludge aeration tanks, mechanical-drive RBC units installed in the trickling-filter clarifier are preferable. (Cost estimates for both the Aero-surf and the mechanical-drive systems are presented in Chapter 7.)

Manufacturers or proprietors of RBC equipment currently on the market do not provide facilities for effluent recycling, a provision which would simplify the operations. Simplicity of operation is considered one of the major advantages of the RBC process over the activated sludge process. However, it was demonstrated in a pilot RBC plant study by Poon, et al., that effluent recycling significantly increased the RBC process's operational flexibility.[44] A recirculation factor of 100 to 150 percent improved the treatment performance and allowed an increase of organic loading of 46 percent. Since fluctuating BOD concentration, as well as changing NH_3-N concentrations, have been found to influence the performance of nitrification, an effluent recycle scheme should help minimize this adverse effect. Therefore, because effluent recycling is very simple and does not require the same level of skillful operation for sludge recycling as the activated sludge process, the provision of an effluent recycling capability seems justified.

7 DESIGN PROCEDURE AND COST ESTIMATE OF RETROFIT SYSTEMS

The design criteria and guidance discussed in this chapter were developed from the pilot-scale study which incorporated RBC technology to upgrade a typical DA trickling-filter sewage treatment plant. These criteria are therefore more relevant to the design of such retrofit facilities than are criteria found in Army TM 5-814-3, which addresses *secondary* biological wastewater treatment.[45]

Design Criteria

1. The quality of effluent obtained from the retrofit system will meet current secondary effluent standards of 30 mg/ℓ total BOD_5 and 30 mg/ℓ suspended solids. Because practically all suspended solids in the retrofit system effluent are biological solids, the suspended solids concentration must be lower than 30 mg/ℓ if any soluble BOD_5 is to be allowed in the effluent. When a clarifier is included in the retrofit system, the effluent's suspended solids concentration can be expected to average approximately 15 mg/ℓ. The secondary effluent standards can also be interpreted as 15 mg/ℓ suspended solids and 30 mg/ℓ total BOD_5 (including the 15 mg/ℓ from the suspended solids and 15 mg/ℓ of soluble BOD_5).

2. The effluent quality from the retrofit system required to meet the tertiary effluent standards of NPDES permits in some areas is 10 mg/ℓ total BOD_5, 10 mg/ℓ suspended solids, and 2 mg/ℓ NH_3-N. These standards allow the following amounts of soluble BOD_5: 1.0 mg/ℓ suspended solids, 10.0 mg/ℓ total BOD_5 (or 9.0 mg/ℓ soluble BOD_5 and 1.0 mg/ℓ SS), and 2.0 mg/ℓ NH_3-N.

3. The effluent quality should be maintained throughout the year without any special allowance for cold weather conditions.

4. Because of the thin biofilm in the RBC unit, high-density media will be used. A 12-ft- (3.6-m)-diameter media, 25-ft- (7.5-m)- long shaft with four stages provides 132,000 sq ft (11 880 m^2) of effective surface area in comparison to the 88,000 sq ft (7920 m^2) for a standard 25-4 unit.

5. Two RBC unit options will be considered: units in their own tanks and units installed in existing clarifiers. For the second option, it is assumed that the existing clarifiers can produce an effluent having an average of 20 mg/ℓ of suspended solids.

[44] C.P.C. Poon, et al., "Evaluation of Factors Controlling the Performance of a RBC," paper presented at the ASCE National Environmental Engineering Conference, Nashville, TN (1975).

[45] *Domestic Wastewater Treatment*, Technical Manual 5-814-3 (Headquarters, DA, November 1978).

6. Use 600 gpd/sq ft (24.5 m^3/m^2/day) for the design of the RBC clarifier.

Design Procedure

The following procedure is recommended for retrofit system design:

1. Select the design flow for the trickling-filter treatment plant. Note that hydraulic loading variation adversely affects the RBC system performance, but that the effect is the same or less than that of low temperatures (Figures 5 and 7).

2. Select an average BOD_5 concentration of the clarified trickling-filter effluent (both total BOD_5 and soluble BOD_5 concentrations), as well as the average soluble NH_3-N concentration.

3. Calculate the total BOD_5 load, soluble BOD_5 load, and soluble NH_3-N load, all in terms of pounds per day or grams per day, based on the selected hydraulic flow and BOD_5 concentration or on the soluble NH_3-N concentration.

4. Select the secondary or tertiary effluent quality standards to be met.

5. Select an appropriate curve for sizing the RBC units:

a. Use Figure 5 for soluble BOD_5. Allow 15 mg/ℓ in the effluent if there is an RBC clarifier. Allow 10 mg/ℓ in the effluent if the RBC unit is installed in the existing clarifier.

b. Use Figure 7 for total BOD_5. Allow 30 mg/ℓ in the effluent if there is an RBC clarifier. The largest area requirement from these selections will be used.

c. Use Figure 12 for soluble NH_3-N. Since NH_3-N concentration is imposed only on tertiary effluent quality, and an RBC clarifier is not useful, the RBC unit will be installed in the existing clarifier, followed by a tertiary filtration unit, so that the effluent's suspended solids concentration can be reduced to 1.0 mg/ℓ. Figure 5 will be used to size tertiary removal of BOD_5. Allow 9.0 mg/ℓ of soluble BOD_5 in the effluent. Of these two, the larger size will be used; one size is based on soluble NH_3-N effluent concentration, and the other is based on soluble BOD_5 effluent concentration.

6. Calculate the surface area required for the RBC clarifier based on the selected flow and the overflow rate of 600 gpd/sq ft (24.5 m^3/m^2/day).

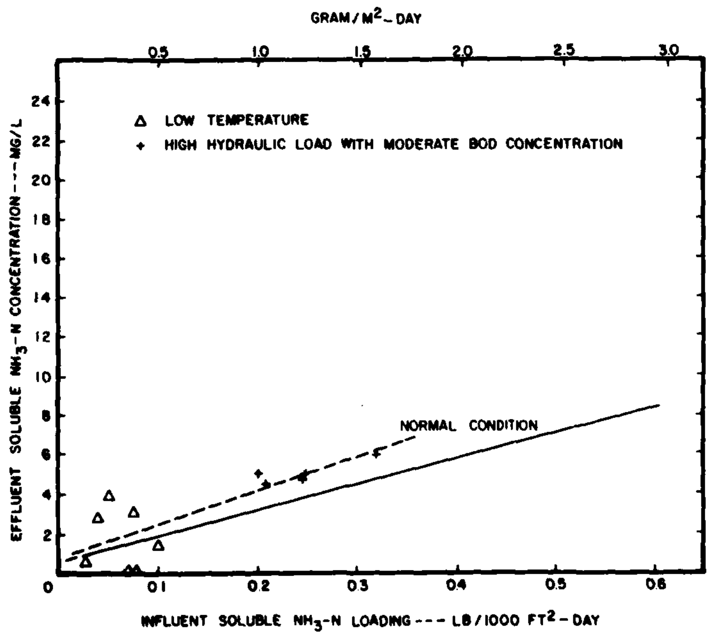

Figure 12. Effects of low temperature and organic shock loading on the effluent soluble NH_3-N concentration.

7. Apply a scaleup factor of 1.5 for BOD removal and 1.0 for nitrification (see the following section).

8. The hydraulic detention time of the RBC flow should be 60 minutes or longer (for a four-stage module). Evidence from the study has demonstrated that at least 40 minutes was required to successfully remove soluble BOD. The extra 20 minutes provide the leeway necessary for reliable BOD removal, as well as nitrification. Therefore, the design engineer must check the tankage volume, as well as the surface area of the growth medium.

Design of 1.0, 5.0, and 7.5 mgd Retrofit Systems

These calculations will be shown only for the 1.0 mgd plant, although the design results for all three plant sizes are presented.

Design flow	= 1.0 mgd (3785 m^3/day)
Clarified trickling-filter effluent characteristics:	
Total BOD_5	= 44 mg/ℓ or 367.0 lb/day
Soluble BOD_5	= 22 mg/ℓ or 183.5 lb/day
Soluble NH_3-N	= 8.0 mg/ℓ or 66.7 lb/day

1. RBC size to meet secondary effluent standards:

a. From Figure 5, allowable loading = 0.63 lb/1000 sq ft/day, which yields:

Soluble BOD_5 15 mg/ℓ
Clarified SS 15 mg/ℓ
Total BOD_5 30 mg/ℓ

Area required = 183.5/0.63 × 1000 = 291.238 sq ft
Applying a scaleup factor of 1.5: A = 436,860 sq ft.

b. Install RBC in existing clarifiers; from Figure 5, allowable loading = 0.43 lb/1000 sq ft/day, which yields:

Soluble BOD_5 10 mg/ℓ
Clarified SS 20 mg/ℓ
Total BOD_5 30 mg/ℓ

Area required, including the scaleup factor:
183.5/0.43 × 1.5 = 640,000 sq ft.

c. Total BOD_5 30 mg/ℓ (with RBC clarifier); from Figure 7, allowable loading = 1.47 lb/1000 sq ft/day. Area required including the scaleup factor: 367/1.47 × 1000 × 1.5 = 374,450 sq ft.

Therefore, for upgrading the effluent quality to the equivalent of secondary treatment standards, the RBC media surface area should be 640,000 sq ft or 436,900 sq ft, followed by a clarifier.

d. Use the 25-ft (7.5-m)-long shaft, four-stage, 12-ft (3.6-m) diameter; each shaft provides 132,000 sq ft (11 880 m^2) of media.

$$\text{Number of units} = \frac{640{,}000}{132{,}000} \simeq 5.0 \text{ units}$$

$$\text{or} \quad \frac{436{,}900}{132{,}000} \simeq 4.0 \text{ units and a clarifier}$$

2. RBC size to meet tertiary effluent standards:

a. From Figure 5, allowable loading = 0.38 lb/1000 sq ft/day, which yields:

Soluble BOD_5 9.0 mg/ℓ
Filtered SS 1.0 mg/ℓ
Total BOD_5 10.0 mg/ℓ

Area required including scaleup factor:
183.5/0.38 × 1000 × 1.5 = 724,300 sq ft.

b. Soluble NH_3-N 2.0 mg/ℓ; from Figure 12, allowable loading = 0.076 lb/1000 sq ft/day.

Area required = 66.7/0.076 × 1000 × 1.2 (scaleup factor: 1.2) = 1,053,480 sq ft.

c. Number of 25-ft (7.5-m), four-stage units: 1,053,480/132,000 = 8.0 units.

3. RBC clarifier size; surface area is:

$$\frac{1{,}000{,}000}{600} = 1667 \text{ sq ft, or } 60 \text{ ft} \times 28 \text{ ft.}$$

According to the latest available information, the recommended scaleup factor ranges from 1.5 to 2.5 for carbon removal and 1.0 to 1.5 for nitrification. Each scaleup factor used in this design is at the lower end of the recommended range, since both the organic and the NH_3-N loadings for the retrofit

Table 2

Summary of Results

Plant Size	**Effluent Standards**	**Number of Units, 25-Shaft, 4 Stages**	**RBC Clarifier Area**	**Dual Media Filter**
1 mgd ($3785\ m^3$/day)	secondary	5 in existing clarifier	0	no
	secondary	4 in tankage	1680 sq ft	no
	tertiary	*8 (half in existing clarifier, half in tankage)	0	yes
5 mgd ($18\ 925\ m^3$/day)	secondary	24 in existing clarifiers	0	no
	secondary	18 in tankage	8400 sq ft	no
	tertiary	*40 (half in existing clarifier, half in tankage)	0	yes
7.5 mgd ($28\ 388\ ^3$ day)	secondary	37 in existing clarifier	0	no
	secondary	25 in tankage	12,600 sq ft	no
	tertiary	*60 (half in existing clarifier, half in tankage)	0	yes

*There will not be enough space to accommodate this number of RBC units in the existing clarifiers. Tankage will also be provided.

system are low. Larger scaleup factors near the upper end of each recommended range are for municipal wastewater at full strength (receiving only primary treatment). Table 2 summarizes the results of scaleup.

Capital Cost and Energy Requirement

Using the latest available information from Autotrol Corporation, the capital cost as well as the power requirement for each plant size were estimated. The unit costs are as follows:

Capital cost for installed, high-density media in concrete tankage, with fiberglass cover, including shipping cost of \$1500 per shaft (unit). Shipping cost could be different for remote areas: \$0.31/sq ft (\$3.34/m^2).

Capital cost of RBC *equipment only*, with fiberglass cover, no transportation: \$0.26/sq ft (\$2.80/m^2).

Existing clarifier modification: \$3.0/sq ft for false bottom and estimated \$3.0/sq ft tank area for shaft installation and modification of sludge-scaping mechanism, assuming four to five units per clarifier: \$0.02/sq ft (\$0.22/m^2)

RBC clarifier capital cost installed, based on \$200/cu yd (\$200/0.7646 m^3) of concrete work and sludge scrape mechanism installed: \$30,000/million gal (\$30,000/3 785 000 ℓ) of hydraulic flow.

The capital costs installed for the 1.0 mgd retrofit systems are:

Option 1, five RBC units in existing clarifier: Equipment (5 × 132,000 sq ft × \$0.26/sq ft) + Clarifier Modification (5 × 132,000 sq ft × \$0.02/sq ft) shipment + (5 × \$1500) = \$192,300.

Option 2, four RBC units in tankage, plus a clarifier: Equipment Installed (4 × 132,000 sq ft × \$0.31/sq ft) + RBC Clarifier (1 × \$30,000) = \$193,680.

Option 3, eight RBC units for tertiary treatment; four in existing clarifier, four in tankage; one dual-media filter: (4/5 × \$192,000) + 4 Units in Tankage Installed (4 × 132,000 sq ft × \$0.31/sq ft) + Cost of a

Dual-Media Filter = $317,280 + the Cost of the Dual-Media Filter.

Similarly, the respective costs for the 5.0 and 7.5 mgd retrofit systems are:

5.0 mgd	Option 1	$923,000
	Option 2	$886,560
	Option 3	$1,586,400 + cost of dual-media filters
7.5 mgd	Option 1	$1,423,000
	Option 2	$1,248,000
	Option 3	$2,380,000 + cost of dual-media filters

For small plants, i.e., 1.0 mgd, installing the RBC units in the existing clarifier requires a slightly smaller capital outlay; no extra land is required to install the retrofit system, except for tertiary treatment, where space for a dual-media filter should be provided. However, it could be difficult to fit the required number of RBC units into the existing clarifier at some plants, e.g., circular clarifiers; furthermore, plant operation is interrupted for clarifier modification. It appears that if land is available, RBC units installed in their own tankage would be a better choice for all sizes of plants. In fact, capital cost for this option (excluding land cost) is less than that of the first option for all larger plants.

The cost estimate given above also applies to Aero-surf units, since high-density media are already used for RBC units in the projected retrofit systems; in addition, the installed capital cost per shaft or per unit is identical for both the mechanical-drive unit and the air-drive unit.

Based on the energy requirement of 0.56 hp or 0.417 kW/1000 sq ft (4.49 W/m^2), the energy requirement to run the RBC unit for the various retrofit systems is projected as follows. (Energy requirements for clarifiers and dual-media filters are not included in the estimation.)

1.0 mgd	Option 1	275.5 kW
	Option 2	220.4 kW
	Option 3: tertiary treatment	440.8 kW
5.0 mgd	Option 1	1322.4 kW
	Option 2	991.8 kW
	Option 3: tertiary treatment	2204.0 kW
7.5 mgd	Option 1	2038.7 kW
	Option 2	1377.5 kW
	Option 3	3306.0 kW

If NOD is not considered in the effluent standards, Figure 4 can be used for the design, which considers only the carbonaceous BOD. The allowable loading could be increased significantly, and this would significantly reduce cost and energy requirements. Unfortunately, a similar plot for a cold temperature study series is not available. However, until the EPA clarifies whether NOD can be excluded, it is not advisable to evaluate the RBC performance and its cost with this approach.

8 CONCLUSIONS

Use of the information provided in this report will (1) allow DA personnel to decide if RBC technology is applicable for upgrading trickling filters at their plants, and (2) allow DA personnel to design RBC technology for retrofit upgrading of existing DA trickling-filter STP facilities in order to meet NPDES effluent requirements.

The biofilm developed on the RBC medium used throughout this study was thin because of the low loading characteristics of this application. Soluble BOD (SBOD) removal increased as SBOD loading increased and followed a straight line relationship within the range of 0.4 to 1.85 lb of SBOD/1000 sq ft day loading (1.95 to 9.0 g/m^2/day). The removal was between 55 and 60 percent within the range. To upgrade a secondary effluent quality in order to achieve 15 mg/ℓ $SBOD_5$ concentration (along with 30 mg/ℓ suspended solids with its equivalent 15 mg/ℓ particulate BOD_5 allowable in the secondary effluent), the highest allowable loading should be 1.6 lb/1000 sq ft/day (7.8 g/m^2/day).

If the objective is to achieve a tertiary treatment quality of 10 mg/ℓ of BOD_5 and 10 mg/ℓ of suspended solids, use of a clarifier after an RBC unit is impractical, assuming that the suspended solids will be removed by a dual-media filter or other tertiary solids removal technology. Data from this study indicate that RBC loading can be as high as 0.5 lb $SBOD_5$/1000 sq ft/day (2.44 g/m^2/day).

A correction factor of 0.41 should be applied to the recommended loadings mentioned above if the RBC unit is subjected to short-term hydraulic shock loads or to low temperatures (5° to 10°C wastewater temperature). Organic shock loadings (24 to 440 percent increase over the average loadings received) do not adversely affect the RBC treatment performance.

The removal of soluble NH_3-N increases with loading and takes the form of a logistic S-curve expressed by the following equation (second order):

$$R = \frac{R_{max}}{1 + m \cdot e^{b \cdot \Delta L}} ; \quad R = \frac{0.564}{1 + 10.28e^{-7.84\,(\Delta L)}} \qquad \text{[Eq 3]}$$

where R_{max} = maximum soluble NH_3-N removal
m = constant
b = constant
ΔL = difference between any applied NH_3-N loading and a base loading of 0.1 lb/1000 sq ft/day
R = soluble NH_3-N removal in lb/1000 sq ft/day.

For low temperatures (below 10°C) and hydraulic shock loadings:

$$R = \frac{0.243}{1 + 13.29e^{-6.44(\Delta L)}}$$

For the trickling-filter effluent used in this study, the maximum soluble NH_3-N removal (R_{max}) was 0.564 lb/1000 sq ft/day. L was the difference between any given loading and the base load of 0.1 lb of soluble NH_3-N/1000 sq ft/day (4887 g/m^2). The values of constants m and b were 10.28 and −7.84, respectively. Second-order reaction of nitrification has been found in national streams and, in this study, was found to apply to RBC as a retrofit unit as opposed to reports in literature that from zero to first-order nitrification was found for activity sludge or RBC processes for secondary treatment or exclusive for nitrification. This study showed a loading up to 0.11 lb/1000 sq ft/day (526 g/m^2) was allowable if an effluent of 2.0 mg/ℓ soluble NH_3-N was obtained.

Synthesis of biological solids in the RBC unit was 0.28 lb mixed liquor volatile suspended solids (MLVSS) per pound of soluble BOD_5 removed. The average film biomass for the four stages was 1.0, 0.73, 0.48, and 0.41 g/sq ft. Using the flowrate data and considering the average MLVSS value of 24 mg/ℓ in the unit, a mass balance calculation showed the average RBC sludge retention time to be 12 days.

Removals of total-P and soluble-P were low, even with chemical addition (lime and soda ash) to the RBC unit. However, ortho-P removal was significant (with chemical addition), ranging from 40 to 92.8 percent, with an average effluent concentration of 0.85 mg/ℓ.

The rotational speed of the RBC unit had no effect on the treatment performance, from the standpoint of both oxygen transfer and substrate transfer, as long as the RBC was employed as a retrofit unit to upgrade trickling-filter effluents.

The pilot plant was easy to start up, maintain, and operate, with no nuisances associated with its activities.

The RBC units can be installed in tankage followed by a clarifier, or installed in the existing secondary clarifier modified for this purpose. This may eliminate the requirement of an RBC clarifier. Both options can be used to achieve the current standards of secondary treatment. For tertiary treatment, a filter instead of a clarifier is required to achieve the effluent quality specified for suspended solids. Design procedures and calculations were presented for 1.0, 5.0, and 7.5 mgd plants, along with costs and energy requirements for these plants at various options.

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