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UPGRADING DA TRICKLING-FILTER SEWAGE TREATMENT PLANTS.(U)

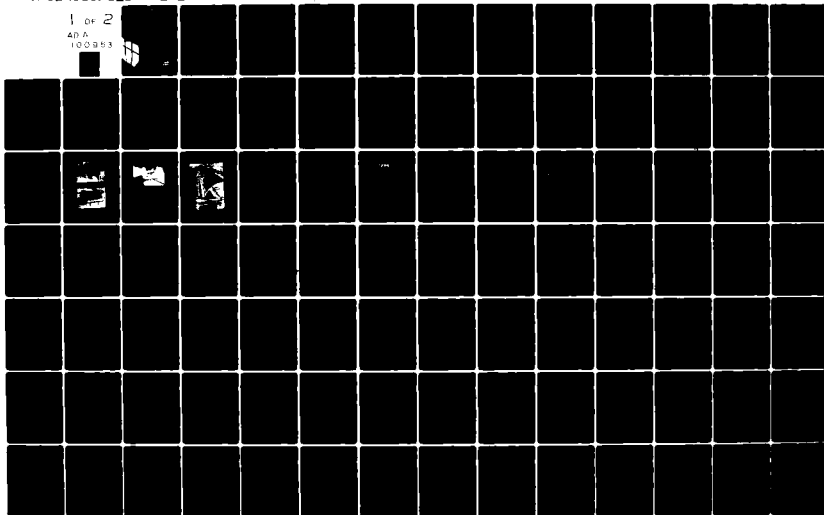
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Technical Report N-102
May 1981

UPGRADING DA TRICKLING-
FILTER SEWAGE TREATMENT PLANTS

AD A100953

by
E.D. Smith
C.P. Poon
R.D. Miller

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upgrading alternatives. A stepwise approach has been provided to enable a more intelligent comparison of alternatives; this approach includes example calculations useful for estimating surface media, land, and energy requirements. Several independent studies were reviewed that have compared actual RBC performance data with the design claims of RBC manufacturers; discrepancies are pointed out and reasons offered for why the manufacturers' criteria should be accepted.

Structural integrity problems (failure of media and/or shafts) have been documented for particular design vintage and certain proprietary RBCs. This report discusses these problems to ensure that DA personnel responsible for selection of pollution abatement technologies are aware of significant and potentially costly past problems associated with RBC technology. Guidance is provided to ensure that any selection of RBC technology by the Army is not plagued with medium/shaft failure incidents.

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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 Control and Treatment"; Work Unit 017, "Tertiary Treatment Using a Rotating Biological Disc System." The applicable QCR is 3.01.004. This investigation was performed by the Environmental Division (EN) of the U.S. Army Construction Engineering Research Laboratory (CERL).

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

Dr. R. K. Jain is Chief of CERL-EN. COL L. J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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UPGRADING DA TRICKLING-FILTER SEWAGE TREATMENT PLANTS

1 INTRODUCTION

Background

Army sewage treatment plants have unique limitations, restraints, requirements, and capabilities which are not common to such facilities in the private sector:

1. About 95 percent of Department of the Army (DA) sewage treatment plants (STP) are the trickling-filter type, with a few activated sludge systems and extended aeration package plants.
2. The relatively small capacity of many Army sewage treatment plants often mandates that operation and maintenance be simple.
3. The facilities are often underloaded because of the decreased Army population during peacetime.
4. The civilian workforce, which contributes waste during normal loading hours, but not at other times, changes diurnal loadings significantly.
5. Significant hydraulic and organic load fluctuations are common.
6. Various activities, such as consolidation of training from several areas to only one installation, summer training, and reserve and national guard groups, can cause significant seasonal changes in sewage loadings to treatment facilities.

Existing DA trickling-filter sewage treatment plants were not designed to handle the National Pollutant Discharge Elimination System's (NPDES)¹ stringent permit requirements for Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO), Suspended Solids (SS), and ammonia.

One viable alternative for meeting NPDES requirements is to upgrade existing STPs, which will be much less expensive than extensive plant renovation and remodeling. When properly designed, constructed, operated, and upgraded, existing trickling filters can meet NPDES discharge requirements, while retaining the advantages of low energy needs and relative ease of operation.

¹ Environmental Protection and Enhancement, Army Regulation (AR) 200-1
(Department of the Army, 20 January 1978).

One upgrading method is the Rotating Biological Contactor (RBC) technology. Although RBC technology exhibits inherent technical and economic advantages and disadvantages, it often appears to be especially conducive to meeting Army needs. In particular, if RBC technology is compared to other processes in terms of energy scenarios, O&M requirements, efficiency, and reliability under various environmental and loading conditions, it becomes evident that RBC technology should be considered for municipal and industrial pollution abatement projects. Some specific advantages to the Army associated with RBC technology are:

1. Low energy requirements.
2. Simpler and less expensive O&M.
3. Ease of transporting and relocating.
4. Low space requirements.
5. Installation costs are minimal, because expensive secondary sewage treatment plant capital equipment can be retained and used with RBCs.

The concept of using RBCs as a treatment alternative is relatively new in the United States, and only a few plants have operated for more than a few years. Consequently, data are scarce regarding RBC retrofitting strategies for upgrading plants to meet current and anticipated NPDES requirements. In fact, until just a few years ago, RBC technology was not even mentioned in college textbooks. This may account for the fact that the latest wastewater treatment guidance documents lack information regarding the RBC unit process, even though American industries and municipalities have spent millions of dollars for RBC process equipment. Many excellent documents provide design and operation and maintenance criteria/guidelines for readily available traditional technologies, such as activated sludge and trickling-filter processes; e.g., the Process Control Manual for Aerobic Wastewater Treatment Facilities.² This publication provides guidance for optimizing the performance of and establishing process control techniques for trickling-filter and activated sludge systems. There is no comparable manual for RBC technology. In addition, commonly used "state-of-the-knowledge" documents which provide economic guidance for selecting wastewater treatment systems either do not give RBC cost curves (capital, O&M, energy, etc.), or give curves that are outdated. This lack of guidance on RBC applicability, design, O&M, and economic considerations results from the relative newness of RBC technology in the United States.

² Process Control Manual for Aerobic Wastewater Treatment Facilities, EPA-403-9-77-006, PB279474 (U.S. Environmental Protection Agency [USEPA], March 1977).

This lack of empirical data and guidance is complicated by the fact that there is no well-defined theory of design and operation accepted by all RBC manufacturers. Design engineers and contractors can design and construct activated sludge, trickling filter, and most other wastewater treatment processes without depending significantly on a very limited number of equipment manufacturers. This is not the case with RBC technology, in which design engineers are extremely dependent on the manufacturer's design curves. Despite these problems, DA currently has (or has planned) RBC facilities at several installations; however, design guidance is often lacking.

Army personnel considering the RBC process must find answers to the following questions:

1. How can I insure that the RBC technology is right for my particular situation?
2. How much does RBC 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 in time to meet a tight compliance schedule?
5. What are RBC's O&M problems/costs?
6. How does the RBC technology compare with other technologies?
7. Is the RBC process reliable and effective under a variety of climatic conditions and under varying hydraulic, organic, and ammonia loadings?
8. What are the appropriate design criteria?
9. What are the system's land requirements?
10. What are the RBC's skill and manpower requirements?
11. What are the process advantages/disadvantages?
12. Can the process be retrofitted to existing secondary equipment to meet biochemical oxygen demand, suspended solids, and ammonia requirements?
13. What about nuisances (odors, filter flies)?
14. How does energy consumption compare to other processes?

15. What are the sludge characteristics?
16. What is the potential need of clarification prior to disinfection and discharge, and what are the design criteria for the clarifier?
17. What is the life expectancy of major RBC control components?
18. What new developments are anticipated for RBC technology?
19. What information is available?
20. What are the opinions of RBC plant operators?
21. What information is available regarding structural failures of RBC components?

Recently, Architect/Engineer (A/E) firms have tended to recommend abandoning existing DA trickling-filter facilities in favor of constructing difficult-to-operate, energy-intensive technologies. Thus, there is a need to examine the alternative of retaining and upgrading existing plants in order to reduce energy consumption and facilitate operations, thereby reducing Army expenditures for sewage treatment.

Objective

The objectives of this study were (1) to develop guidance for Army personnel who must decide whether to use RBCs, (2) to provide case history information on use of RBCs for upgrading trickling-filter sewage treatment facilities, and (3) to provide design guidance for using RBC add-on to upgrade DA trickling-filter secondary sewage treatment plants and thus bring these plants into compliance with existing and anticipated NPDES requirements.

Approach

RBC data were obtained from three major sources: (1) papers presented at the First National Symposium of RBC Technology, (2) a comprehensive literature search of operating RBC systems, and (3) RBC manufacturers. These data were then analyzed and used (a) to develop weighted selection criteria and a ranking system that DA personnel could use to decide whether to use RBCs, and (b) to develop a stepwise approach useful to DA personnel who are seriously considering use of RBCs.

Outline of Report

Chapter 1 provides background information on the Army's need to examine the alternative of using RBCs to bring existing trickling-filter plants into compliance with NPDES requirements and also lists the information most often needed by Army personnel considering use of RBCs.

Chapter 2 describes the RBC equipment available from various U.S. manufacturers and the many existing trickling-filter plants using RBCs as retrofit upgrading systems. Guidance on deciding whether to use RBCs is presented, along with a weighted selection criteria or ranking system.

Chapter 3 presents the most current design guidelines of RBC technology, particularly for the special application of upgrading trickling-filter effluents. Detailed answers to the questions listed in Chapter 1 are provided.

Chapter 4 suggests a stepwise approach that DA personnel can follow when seriously considering use of RBCs. These steps cannot replace detailed design work, but can provide extensive information useful for RBCs with other alternatives.

Chapter 5 provides a step-by-step approach for upgrading trickling-filter plants with RBC.

Chapter 6 describes a possible modification of the RBC retrofit system which could easily incorporate phosphorus removal required by tertiary treatment standards.

Chapter 7 compares RBC performance criteria predicted by the manufacturers with actual performance data.

Mode of Technology Transfer

The information in this report will be issued by OCE as an Engineer Technical Letter and will be used to upgrade TM 5-814-3, Domestic Wastewater Treatment.

2 ROTATING BIOLOGICAL CONTACTOR AS AN ALTERNATIVE RETROFIT SYSTEM FOR UPGRADING TRICKLING FILTERS

General

Most (about 95 percent) DA STPs are the trickling-filter type; the remainder are activated sludge systems and extended aeration package plants. Most of these facilities were designed and constructed between 1935 and 1945, and many are inadequate to handle the present hydraulic and organic loadings. They simply were not designed to handle the stringent current and anticipated NPDES permit stipulations.

Both the 1972 amendments to the Federal Water Pollution Control Act (P.L. 92-500) and the 1977 Clean Water Act (P.L. 95-217) require that all sewage treatment facilities keep their point source wastewater effluents within prescribed quality limits. Treatment performance will be determined on the basis of meeting stream (or lake and estuary) and effluent requirements set by Federal and State governments. Section 4 of TM 5-814-8³ provides guidance for Army coordination with regulatory agencies when treatment requirements for military wastewaters are established.

Recently, two major DA STPs were upgraded to meet secondary or tertiary treatment requirements, and others are being considered for upgrading. As effluent requirements become more stringent, it is anticipated that more DA STPs will require upgrading to meet NPDES permit stipulations.

U.S. and State Environmental Protection Agencies' Treatment and Effluent Standards

AR 200-1 gives treatment regulatory requirements for Army projects. These regulations implement Executive Orders and DOD Directives and generally direct the Army to comply with treatment requirements established by the USEPA and with the State EPA having jurisdiction over an installation. The NPDES permit obtained from the applicable regional EPA office will generally determine the treatment requirements.

Effluent requirements for new Federal facilities will be coordinated by the Corps of Engineers Design Office and the EPA Regional Federal Facilities Coordinator. In countries or areas not under U.S. control or administration, projects or activities are subject to the generally applicable environmental laws, regulations, and stipulations of the foreign government concerned.

³ Evaluation Criteria Guide for Water Pollution Prevention, Control, and Abatement Programs, TM 5-814-8 (Department of the Army, July 1976).

Most states require a minimum of secondary treatment for all domestic wastewaters, and some states require additional removal of nitrogen and/or phosphorus to prevent eutrophication of water bodies, to reduce total oxygen demand, and to eliminate ammonia-nitrogen toxicity to fish. Some states also require that a specified concentration of dissolved oxygen be maintained in the treatment plant effluent. In critical areas, waste load allocations limit the amount of pollutants to be discharged. Consequently, the State regulatory agencies will impose various types of advanced wastewater treatment processes to protect their water resources. The Army must review the applicable State guidelines before setting the treatment level. Generally, local governments do not specify wastewater treatment facility requirements. Construction of wastewater treatment facilities must also conform to applicable zoning and OSHA requirements and to AR 200-1.

DA has recently conducted a comprehensive review of NPDES permits for many Army wastewater discharges.⁴ Of the 78 installations reviewed, 49 had been issued NPDES permits for 64 wastewater discharges. Of the 64 permits received, 37 required only secondary treatment, whereas 27 contained more stringent limitations. (Table 1 provides more specific data on the 27 permits requiring treatment beyond secondary.) Ammonia-nitrogen removal was indicated on 15 permits, while phosphorus removal was listed on 11 permits.

Upgrading DA STP System Alternatives

Numerous system alternatives are available for upgrading STPs; however, since most DA treatment facilities are of the trickling-filter type, this presentation is confined to the upgrading of trickling filters.

Consulting engineering firms tend to recommend abandoning existing trickling-filter units and replacing them with more complex, newer technology. Although such technology should be used when it applies to specific wastewater problems, its processes are usually capital- and energy-intensive. Operating and maintaining newer technology also requires specifically trained operators. Trickling filters have low energy needs and are relatively easy to operate. When combined with other treatment processes, existing trickling filters can meet NPDES discharge requirements. Recent USEPA reports⁵ advocate the continued use of trickling filters where they presently exist, because scrapping them would be uneconomical.

⁴ R. D. Miller, C. I. Noss, et al., RBC Process for Secondary Treatment and Nitrification Following a Trickling Filter, Technical Report 7905 (US AMBRDL, June 1979).

⁵ Upgrading Trickling Filters, 430/9-78-04 (Office of Water Program Operations, EPA [WH-547], June 1978); The Coupled Trickling Filter-Activated Sludge Process: Design and Performance, EPA-600/2-78-116 (USEPA, July 1978).

Table 1
Wastewater Discharge Permits Requiring
Advanced Treatment (64 Permits Reviewed)

	P	NH ₃ -N	Total N	BOD	SS	Total
	2	-	-	-	-	2
	-	2	-	-	-	2
	4	4	4	4	4	4
	1	1	-	1	1	1
	-	5	-	5	-	5
	2	2	-	2	-	2
	2	-	-	2	2	2
	-	1	-	1	1	1
	-	-	-	8	8	8
Total	11	15	4	23	16	27

Another alternative is expanding existing units by adding more trickling filters. With the proper design and operation, such an addition would insure nitrification and effective BOD removal, as well as meet the required effluent standards. However, recent cost-effectiveness studies⁶ of treatment plants show that for small STPs (which are typical of DA facilities), trickling filters are more expensive than RBC units for comparable treatment performance. Furthermore, the land requirement for trickling-filter units is greater, which may limit their use in existing STPs where expansion space may be limited.

A promising alternative is upgrading existing trickling-filter treatment plants with RBC. RBC technology has the potential to upgrade activated sludge plants and trickling-filter units economically and effectively, thus retaining and using DA's expensive secondary STP capital equipment. (Chapter 3 discusses RBC technology and provides case histories of trickling-filter plants upgraded with RBC.)

⁶ J. L. Pierce, et al., An Evaluation of the Cost-Effectiveness of the RBC Process in Combined Carbon Oxidation and Nitrification Applications, paper presented at the First National Symposium on RBC Technology, Pittsburgh, PA (February 1980), Vol 1 -- PB81-124539, Vol 2 -- PB81-124547; P. T. Sun, et al., Computerized Cost Effective Analysis of Fixed Film Nitrification Systems, paper presented at the First National Symposium RBC Technology, Pittsburgh, PA (February 1980), Vol 1 -- PB81-124539, Vol 2 -- PB81-124547.

Questions on RBC Application to the Upgrading of Trickling-Filter Plants

There are currently more than 600 commercial RBC installations 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 STPs in the United States that use RBCs has increased to more than 300, with another 300 in the planning stages.

There is no doubt that RBCs have demonstrated their effectiveness, reliability, and economy in a wide range of applications in the treatment of domestic and industrial wastes. The main advantages of the RBC system appear to be its relatively simple operation and its reduced power costs. These advantages make the RBC system an attractive alternative to trickling-filter and activated sludge treatment plant facilities.

An EPA Waste Pollution series report⁷ notes that the RBC process can achieve secondary effluent quality or better, including nitrification; consequently, the EPA considers the RBC to be a potential municipal wastewater treatment alternative. However, the use of RBCs to upgrade trickling-filter treatment facilities is a new and special application of the RBC technology. DA personnel have many questions when comparing RBC technology with other available processes. Table 2 presents the most commonly asked questions and provides short answers to them; in addition, the table refers the reader to parts of this report containing more detailed answers.

⁷ Environmental Pollution Control Alternatives -- Municipal Wastewater, EPA 625/5-76-012 (USEPA, 1976).

Table 2

Questions and Answers About RBC Application to
Upgrading Existing DA Trickling-Filter Treatment Plants

Question	Short Answer	Where detailed information can be found in this report
1. Can RBCs be retrofitted to existing trickling-filter facilities to meet BOD, suspended solids, and ammonia-nitrogen removal requirements?	RBC effluent 3 to 16 mg/L soluble BOD (>85% removal); 1.6 to 2.3 mg/L $\text{NH}_3\text{-N}$ (81 to 98 percent removal) suspended solids removal is equivalent or better than trickling-filter (TF) effluent solids removal. Overall effluent quality is better than secondary requirements and meets NPDES nitrification permit standards.	Chapters 3 and 4
2. How can one tell if RBC technology is right for a particular situation?	When land requirement for RBC retrofit to existing TF can be met (see question No. 6) and the poor performance of the existing TF is not due to toxic chemicals, RBC technology can be applied. Guaranteed performance can be negotiated with RBC manufacturers.	Chapters 3 and 4
3. Is the process reliable and effective in a variety of climates and under hydraulic, organic, and ammonia loadings?	Properly designed RBC units with covers are effective and reliable in various climates and loadings. (Although effluent $\text{NH}_3\text{-N}$ concentration responds to varying influent $\text{NH}_3\text{-N}$ and org-c concentrations, the NPDES permits for $\text{NH}_3\text{-N}$ can be met).	Chapter 4
4. Will the RBC process require extensive modification to existing DA STPs?	The prevalent scheme of retrofitting TFs with RBC units between primary and secondary clarifiers (in series or parallel to existing TF operation) requires minimal modification, thus retaining and using DA's secondary STP capital equipment.	Chapters 3 and 4

Table 2 (Cont'd)

Question	Short Answer	Where detailed information can be found in this report
5. What are the appropriate design criteria?	Depending on influent soluble BOD and hydraulic loading, total RBC surface area requirement can be determined from design curves or tables supplied by manufacturers to obtain a specified effluent soluble BOD concentration. Temperature correction (below 55°F) is required. Additional area for nitrification (from another design curve or table) can be determined after soluble BOD is reduced to 15 mg/L or below (not >0.5 lb BOD/1000 sq ft-day loading). Staging and configuration will then be selected from available module sizes to minimize the total number of RBCs and shafts to be used. If additional secondary clarifier capacity is needed, use 500 to 800 gpd/sq ft overflow rate.	Chapter 4
6. What are the system's land requirements?	Approximately 500 sq ft/shaft (for the RBC units alone). This is equivalent to 3000 sq ft, including walkways between tankages, required for a 1.0 mgd treatment plant in retrofitting.	Based on the dimensions of the largest sizes of RBC assemblies of manufacturers and adequate walkways in between as well as sidewalks. Chapter 4
7. How much does it cost?	About \$0.3 million per mgd flow present-worth cost range of 1 to 10 mgd (including installation) for upgrading TF effluents.	Chapter 5

Table 2 (Cont'd)

Question	Short Answer	Where detailed information can be found in this report
8. Are RBC units easy to install and start up? What about site preparation?	Site preparation requires only leveling of unloading areas and meeting the minimal road width and overhead clearance for the delivery trailer. Installation requires placing bearing base plates and the drive packages on tankages previously built on-site. Estimated installation time: 1/2 man-day for the first shaft; 1/3 man-day for the second shaft; 1/4 man-day for all others. Startup is very simple, taking 2 or 3 weeks to reach full operation. More time is required to start nitrification during the winter. Storage area for RBC units is required before installation.	Chapter 4 Autotrol Co. design manual Geo. A. Hormel Co. design manual
9. Can the RBC process be obtained and installed in a tight compliance schedule?	Shipment 18 to 20 weeks after receipt of order is common. A tight compliance schedule can be met once installation is begun.	Chapter 4 and Geo. A. Hormel Co. information
10. What are the skill and manpower requirements?	Less than required for any biological treatment processes except oxidation ponds.	Chapter 4
11. What are the operational and maintenance problems?	Minimal compared to other biological treatment processes except extended aeration and oxidation ponds. No odor and filter flies problem when designed and operated correctly.	Chapter 4
12. Will the system require process limitation, applicability, and restraints?	None, other than its inability to remove toxic and nonbiodegradable chemicals.	Chapter 3
13. Can RBC units remove phosphorus?	Phosphorus can be removed to 2.0 mg/L or less by combining low-level lime addition and RBC recarbonation.	Chapter 6

Table 2 (Cont'd)

Question	Short Answer	Where detailed information can be found in this report
14. How does RBC technology compare with other technologies?	RBC technology, particularly when used in conjunction with trickling filters, is relatively new. However, from all indications, the technology is reliable and cost-effective when compared with activated sludge processes for small facilities (0 to 10 mgd) and with all sizes of trickling-filter plants.	Chapter 3 Table 4
What are process advantages/disadvantages?	RBC is simpler to operate and has a potentially lower energy requirement. RBC may be more capital-intensive, but the total cost (capital and O&M) is less, particularly when applied to retrofitting condition.	
15. How does energy consumption compare to that of other processes?	Among RBC, trickling-filter, activated sludge and land treatment processes, trickling filter uses the least energy. The RBC manufacturers' low estimate of energy consumption is slightly higher than that of the trickling filter, but the high estimates are comparable to activated sludge and land treatment processes. However, the EPA (CAPDET) computer cost estimate indicates that RBC is one of the highest energy-demanding treatment processes. With insufficient operational data from existing systems, it may be assumed that for facilities from 0 to 5 mgd capacity, RBC requires an equivalent or slightly smaller amount of energy than activated sludge processes. (Note: some manufacturers provide a rebate if the tested energy consumption is higher than the manufacturer's guaranteed figure.)	Chapters 4 and 5

Table 2 (Cont'd)

Question	Short Answer	Where detailed information can be found in this report
16. What are the sludge characteristics, potential need of clarification, and clarifier design criteria?	Sludge generated from the RBC process has a better settling characteristic than activated sludge. As a retrofit system to upgrade trickling-filter effluents, the RBC sludge characteristic is not much different from trickling filter sludge. Manufacturers recommend 500 to 800 gpd/sq ft as an appropriate loading for clarifiers without nitrification, depending on the desired suspended solids level of the clarified effluent. When nitrification occurs, or when an effluent of less than 15 mg/L of suspended solid is desired, chemical flocculation and a lower loading of 400 to 500 gpd/sq ft should be used. Filtration is required to meet tertiary effluent treatment standards.	Chapter 4
17. What is the life expectancy of major components?	With the very short history of RBC application in this country, the life expectancy of major components is not fully known. Although many manufacturers provide test data on their major RBC components with load cycles (structure) of a 20-year equivalent, the life expectancy on the RBC media is uncertain. The warranty period generally runs from 1 to 5 years for mechanical equipment, 10 years for media, and 20 to 30 years for shafts, depending on the bid documents. Media/shaft failures have been documented, but manufacturers indicate that current designs are much improved. (In fact, one sewage treatment facility which uses RBC technology for secondary/nitrification has experienced significant failure problems.)	Chapter 4 Chapter 3

Table 2 (Cont'd)

Question	Short Answer	Where detailed information can be found in this report
18. What new developments are anticipated for RBC technology?	RBCs with air-drive units instead of mechanical-drive units have recently been placed on the market. This type of unit can be applied to stronger sewage treatment as well as to upgrading trickling-filter effluents.	Chapter 4
19. What are the safety considerations?	Lack of oxygen in the air within the RBC enclosure (cover), which may lead to breathing difficulty unless proper ventilation (forced ventilation in many cases) is provided. Care should be exercised around any operating equipment. Safety considerations are no different from those of trickling-filter processes.	Chapter 4
20. What are the opinions of RBC plant operators?	Most are happy with the RBC facilities, noting that they are easy to operate and maintain. Grease balls formed during the RBC process present only a minor maintenance nuisance. However, certain installations have experienced problems.	
21. What information is available regarding structural failure of RBC components?	See question 17 above.	Chapter 4 Chapter 3
22. Are there any manuals which discuss the operation of rotating biological contactors?	Volume 1 of <u>Operation of Wastewater Treatment Plants -- A Field Study Training Program</u> , 2nd edition, USEPA Office of Waste Program Operations Municipal Permits and Operations Division, Grant No. T900690010.	Appendix D provides a portion of the chapter on RBCs

3 RBC MODULES AND MANUFACTURERS

Equipment Description of Various RBC Manufacturers

The RBC system is one of the many forms of fixed-film biological treatment technology. In this technique, biologically active masses are grown on a series of discs that slowly rotate, alternately exposing the biomass to the wastewater stream and the air above it.

The lightweight, compact, plastic discs provide a very large surface area per unit volume of tankage for the growth of active biomass and yet furnish sufficient space between discs to prevent clogging. The discs can be either mechanically driven or air-driven. Aeration with rotating discs supplies sufficient dissolved oxygen to the attached biomass and prevents development of anaerobic conditions. Figures 1, 2, and 3 are photographs of the media, tank, and enclosure, respectively.

There are several RBC manufacturers in this country. At this time, major manufacturers are:

Autotrol Corp.
1701 West Civic Drive
Milwaukee, WI 53209

Clow Corp.
56 Industrial Div.
Florence, KY 41042

Geo. A. Hormel and Co.
11501 Yellowbrick Road
Coon Rapids, MN 55433

Ralph B. Carter Co.
192 Atlantic Street
Hackensack, NJ 07602

Walker Process Corp.
Div. of Chicago Bridge & Iron
840 Russell Avenue
Aurora, IL 60506

A Canadian company manufactures equipment for package treatment plant systems only:

CMS Equipment Limited
5266 General Road, #12
Mississauga, Ontario L4W 1Z7

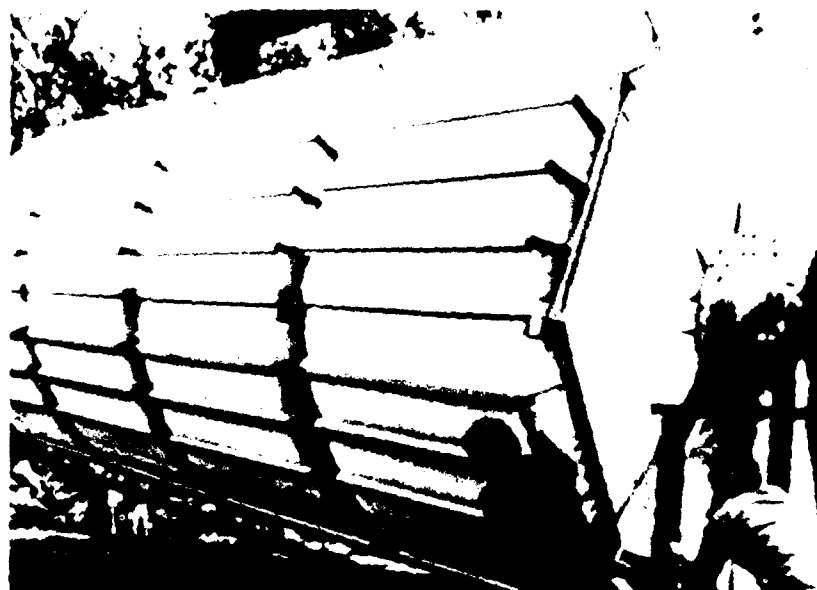


Figure 1. Photograph of plastic media.

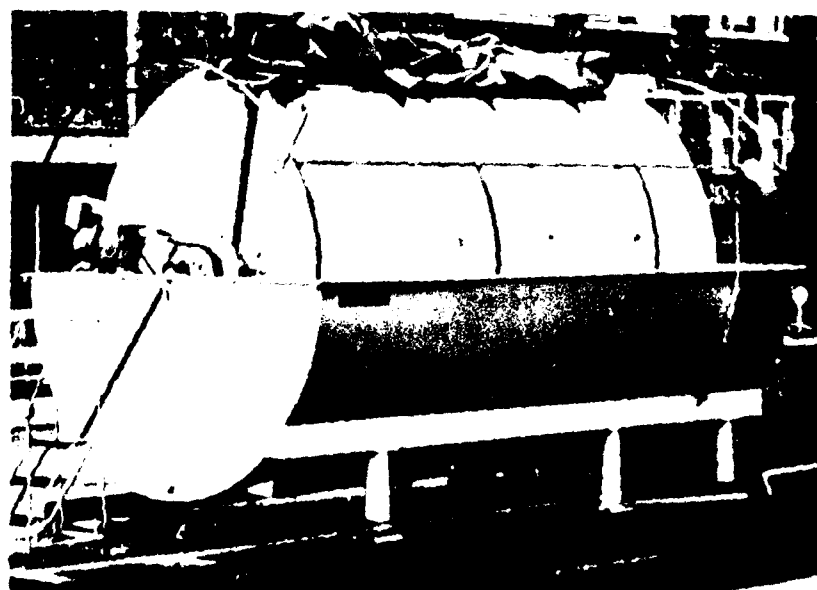


Figure 2. Photograph of plastic media and tank.



Figure 3. Photograph of covered RBC units.

The RBC products can be divided into two categories: rotating discs and rotating drums. The Ralph B. Carter Co. manufactures the rotating Bio-Drum, while all the other manufacturers produce rotating discs of various geometry.

Rotating Bio-Drum

The Ralph B. Carter Co. manufactures the floating Bio-Drum, which is a wire drum (squirrel cage) filled with tightly packed hollow plastic balls (Figure 4). The buoyancy of the plastic balls provides free unit flotation, so all supports are lightweight. The drum is mechanically driven with dual-speed control.

The Rotating Bio-Drum process is different from other RBC processes not only in the unique geometry of its growth media, but also because it recommends that activated sludge be returned to the biomass media. The settled biological sludge from the clarifier (after the Bio-Drum unit) is partially returned so that both the fixed growth and suspended growth biomass are equally responsible for the treatment. The setup is equivalent to installing a unit of rotating discs in an activated sludge tank. Normally a sludge age of 3 to 4 days is maintained. The combination of the fixed and suspended growths provides a very high, active population of microorganisms in the unit.

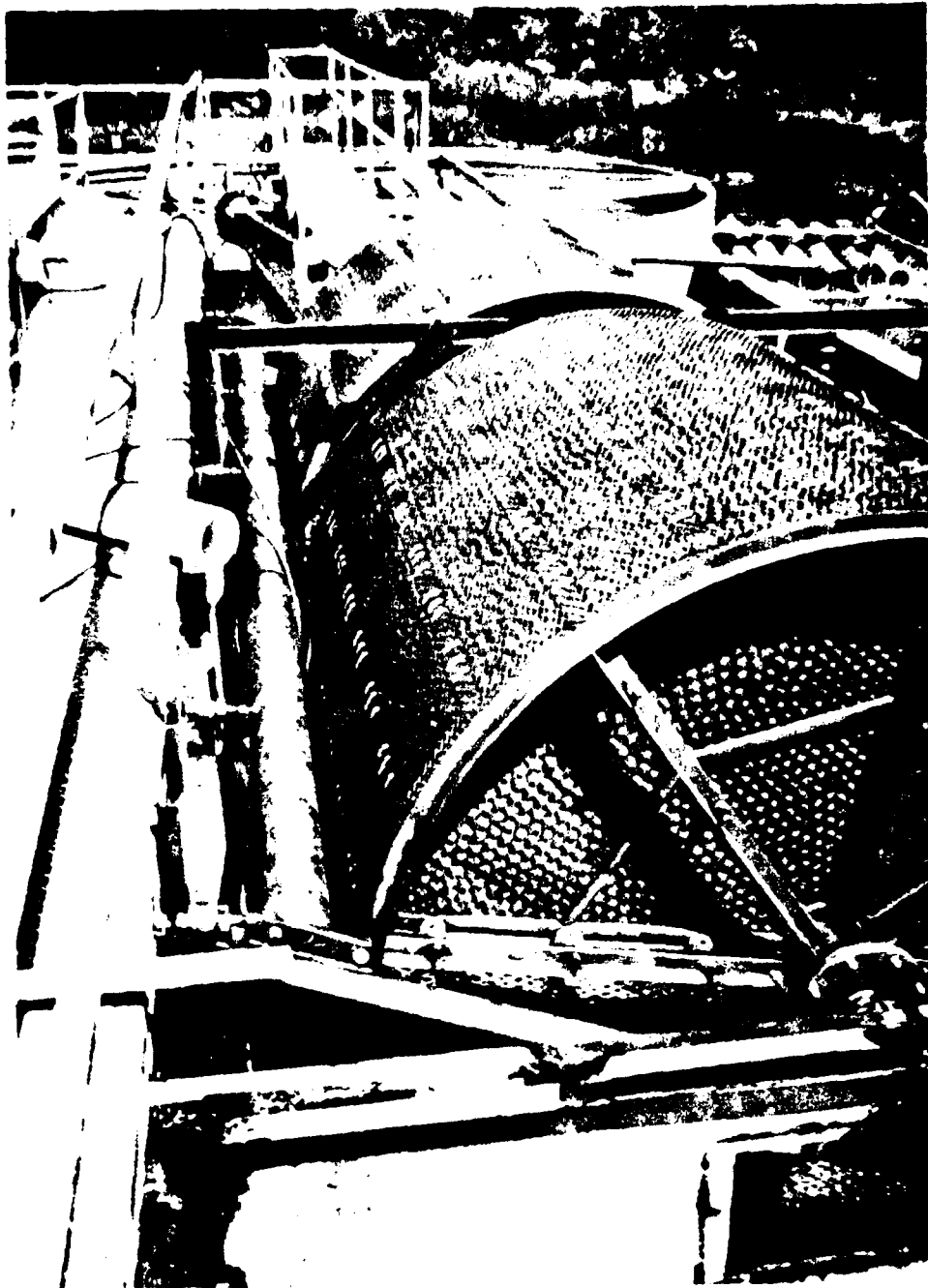


Figure 4. Rotating bio-drum.

(Reprinted with permission of Ralph E. Carter Co.)

(equivalent to 15,000 to 25,000 mg/L MLSS) such that a high organic loading of 500 to 700 lb BOD₅/1000 cu ft-day (10 kg/m³-day) can be applied.

No cover is required for the unit, since most of the fixed growth biofilm in the drum is not exposed to washout by rainfall. The washed off biofilm merely becomes part of the suspended growth in the unit, and treatment capacity remains the same. The Bio-Drum process has been successfully operated without a cover in a very frigid climate (Denmark).⁸ The advantage of incorporating the Bio-Drum with return activated sludge is offset by the complexity of its operation, which requires more skillful control. Thus, capital savings accrued by eliminating the cover will be offset by the increase in capital and operational costs for sludge pumping.

Rotating Discs

This RBC process uses polyethylene (or similar plastic material) corrugated sheets (discs) as the surface media. Carbon black may be added to the plastic material to reduce ultraviolet light attack on the media. The biomass stripped from the rotating discs leaves the unit permanently. The suspended biomass (resulting from the stripping of the fixed biofilm and from the influent to the RBC) generally has a concentration below 150 mg/L. Consequently, only the attached growth biomass is responsible for BOD removal and nitrification. Therefore, fiberglass covers or buildings are necessary to avoid washouts of the attached growth by rainfall.

Figure 5 shows a typical rotating-disc RBC plant. The distance between discs is controlled by spacers. A standard media of 12-ft* diameter and 25 to 26 ft long has a total surface area of 100,000 sq ft per shaft. Where thinner biofilm is expected, high-density media of up to 156,000 sq ft per shaft (12-ft diameter and 26 ft long) are also available from most manufacturers for nitrification. The Clow-Envirodisc system permits on-site replacement of media segments without disturbing the main shaft or removing it from the tank (e.g., replacing segments of damaged discs or replacing standard media with high-density media for nitrification).

Autotrol Corp. provides a new Aero-Surf process in which the discs are air-driven. An Aero-Surf assembly consists of plastic cups welded around the outer perimeter of the media and over the entire length of the contactor. A small air header below the media releases air into the attached cups. The captured air results in a buoyant force which exerts a torque on the shaft sufficient for rotation. The air supply controls the speed of rotation and supplements the supply of oxygen through increased aeration. One blower can

⁸ G. R. Fisette, Operational Advantages Obtained by Incorporating a Bio-Drum in an Activated Sludge, paper presented at the First National Symposium on RBC Technology, Pittsburgh, PA (February 1980), Vol 1 -- PB81-124539, Vol 2 -- PB81-124547.

* Metric conversion factors for English measurements are provided on p 117.

operate many Aero-Surf assemblies, thus reducing overall maintenance requirements and allowing the rotational speed of each shaft to be adjusted individually.

Staging of RBC media is recommended to maximize removal of BOD and ammonia-nitrogen. For normal BOD₅ removals, a minimum of three to four stages should be provided in each flow stream. Additional stages may be added for nitrification or for combined BOD₅ and NH₃-N removals. Four stages can be provided on a single shaft by providing three interstage baffles within the tank. Installations requiring two RBC units may be placed in series with a single baffle in each tank, thus providing four stages. Four or more units are placed in series, with each unit becoming a single stage. Figure 6 shows the various schemes of staging RBC units.

The USEPA has provided recent information regarding RBC technology in a Treatability Manual.⁹ This is included as Appendix C.

Trickling-Filter Plants Using RBC to Upgrade Treatment

Many RBC applications have been developed to expand a plant's capacity or efficiency. When applied to existing trickling-filter plants, the RBC system can be operated in parallel or in series with trickling filters. A third option is placing the RBC units directly within primary or secondary clarifiers. Figure 7 shows the different upgrading schemes, and Table 3 lists the plants where these schemes have been used.

North Huntingdon, PA, initially installed a rock trickling-filter plant designed for 50 percent removal of BOD at a flow of 1.5 mgd. The entire plant was composed of primary clarifiers, high-rate rock trickling filters, secondary clarifiers, chlorine contact tanks, anaerobic digesters, and sludge-drying beds. Increased hydraulic flow and more stringent effluent requirements necessitated increasing the plant's capability to 85 percent BOD removal at a flow of 1.75 mgd; thus, the upgrade consisted of a concurrent increase in hydraulic capacity and treatment efficiency. The Bio-Surf system installed to meet these new requirements consists of four 20-ft-long RBC shafts, providing 305,000 sq ft of effective surface media. Currently, the RBC operates in parallel with the rock filter system (Figure 7). The plant was designed to function either in series or in parallel operation with the trickling filters.

⁹ Treatability Manual Vol III: Technologies for Control/Removal of Pollutants, EPA-600/8-80-042c (USEPA, Office of Research and Development, July 1980).

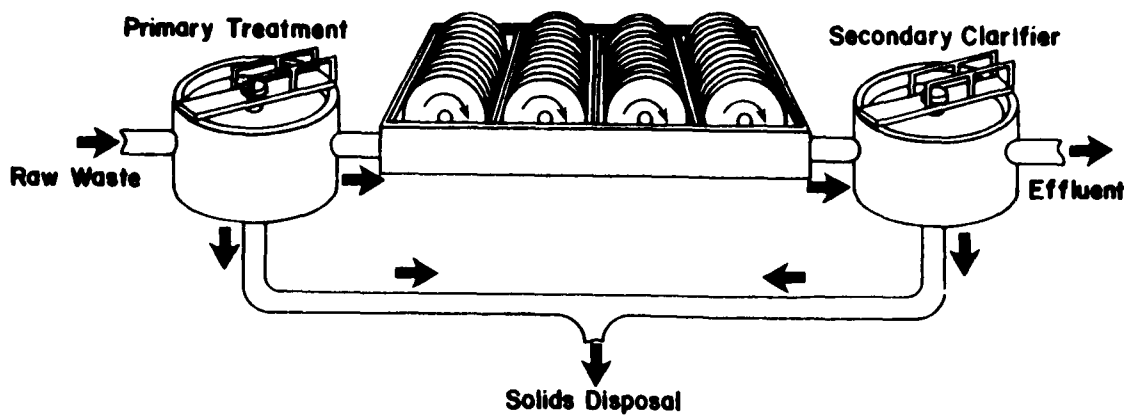


Figure 5. A typical RBC plant using rotating discs for secondary treatment. (Taken from Clow brochure.)

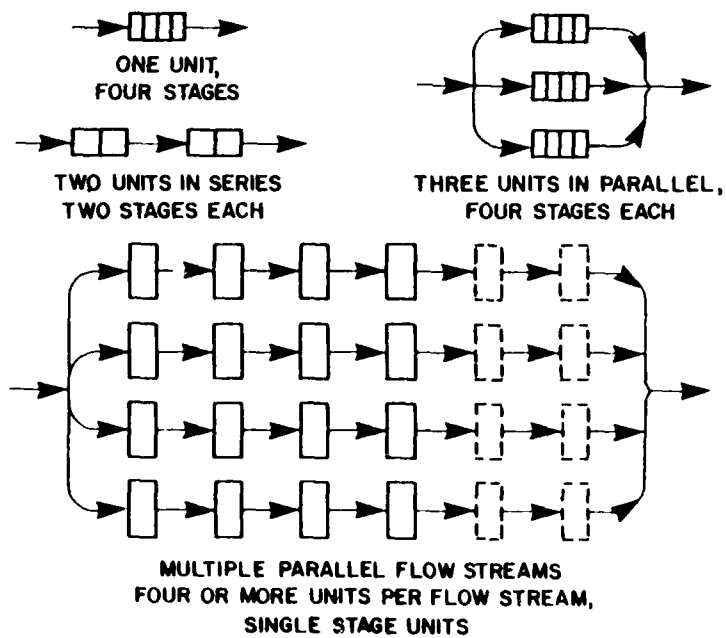
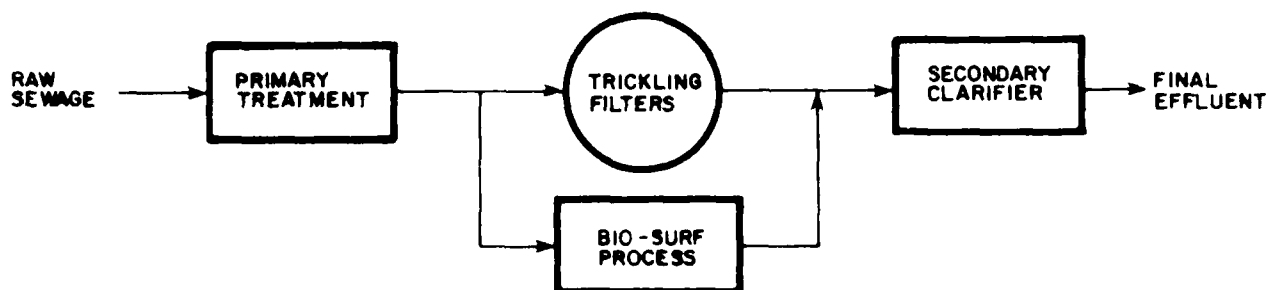


Figure 6. Various schemes of staging RBC units.

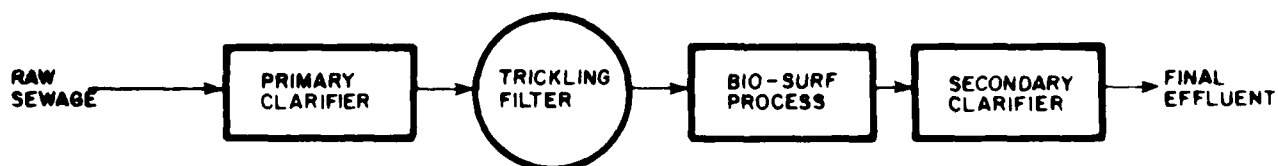
Table 3

Facilities Having RBC Technology Upgrade in Existing Trickling-Filter Plants

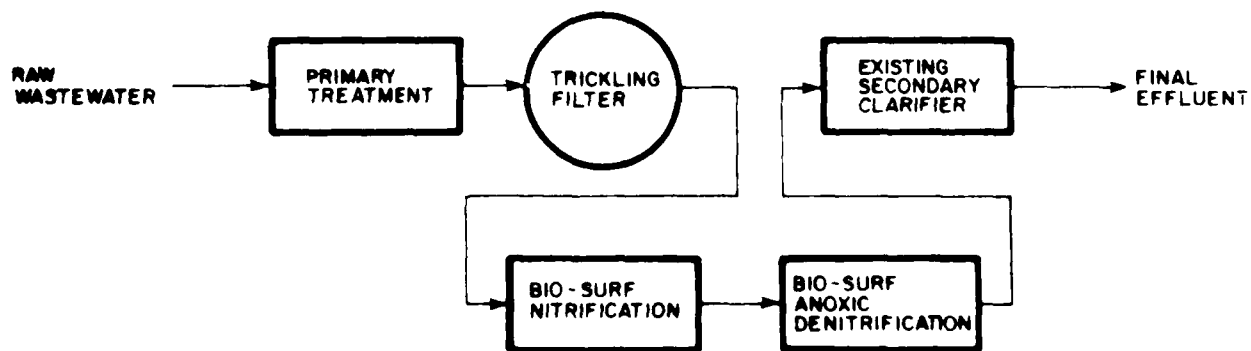
<u>Upgrading Objective</u>	<u>Mode of Application</u>	<u>Location</u>
Increase hydraulic capacity of existing facility	Place RBC in parallel with existing trickling filters	North Huntingdon, PA (Autotrol Corp.)
Increase degree of carbonaceous BOD removal	Place RBC in series with existing trickling filters (see Figure 9b)	North Huntingdon, PA (Autotrol Corp.)
Increase treatment to nitrification capacity	Place RBC in series with existing trickling filters (see Figure 9c)	Birdsboro, PA (Autotrol Corp.)
Increase carbonaceous BOD removal and include nitrification	Place RBC in series with existing trickling filters (see Figure 9b)	Plainville, CT (Clow Corp.)
Increase carbonaceous BOD removal	Place RBC in primary clarifiers (upgrading existing primary treatment only, but applicable to trickling-filter plants that need upgrading) (see Figure 9d)	Edgewater, NJ (Autotrol Corp.)
Increase carbonaceous BOD removal and include nitrification	Place RBC in secondary clarifiers (see Figure 9e)	No existing facility



- a. RBC in parallel with existing trickling filters, North Huntingdon, PA (Autotrol).

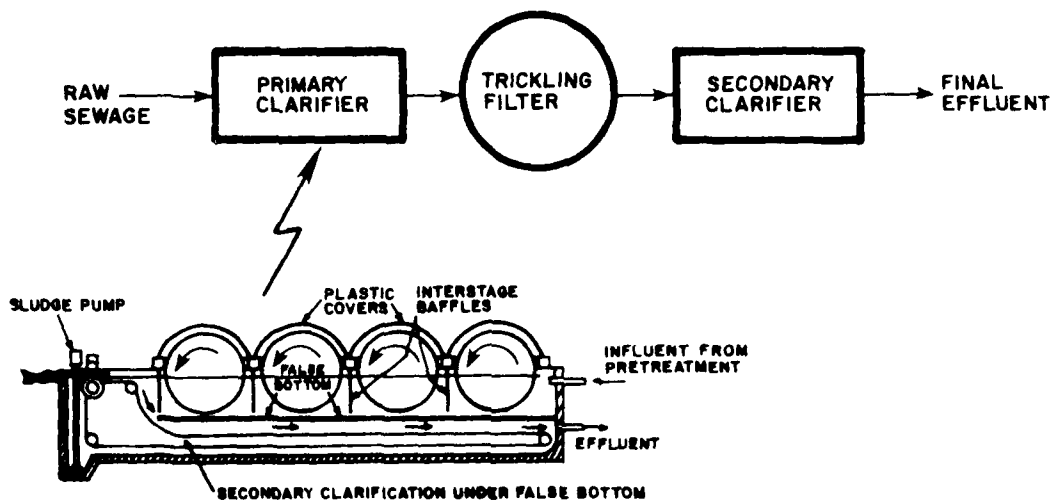


- b. RBC in series with existing trickling filters, North Huntingdon, PA (Autotrol) and Plainville, CT (Clow).

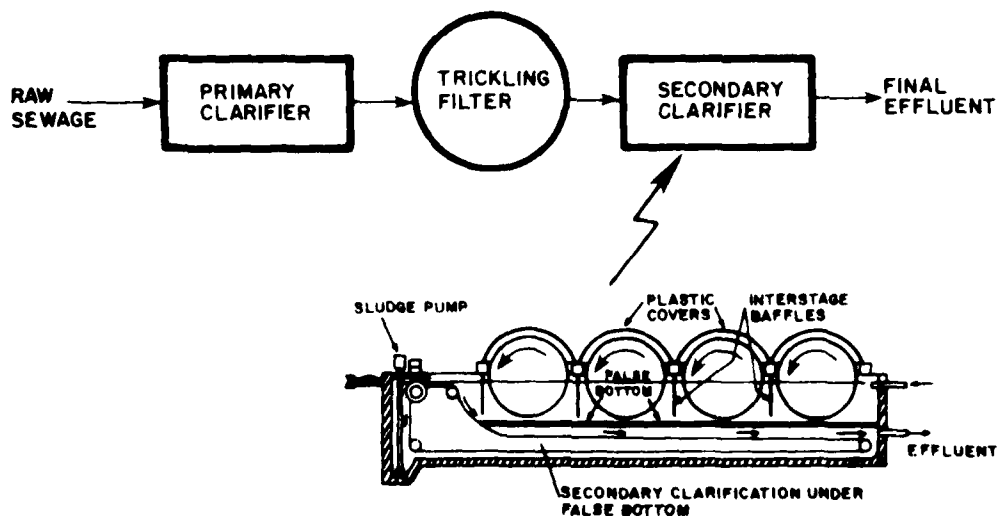


- c. RBC in series with existing trickling filters, Birdsboro, PA (Autotrol).

Figure 7. Various upgrading schemes.



- d. RBC in primary clarifier -- no existing plant except RBC in primary clarifier to upgrade primary treatment in Edgewater, NJ.



- e. RBC in secondary clarifier -- no existing plant.

Figure 7. (Cont'd).

The new plant evaluations showed that effluent quality could be upgraded to meet a total effluent BOD of 29 mg/L for both series and parallel operation.¹⁰

The town of Plainville, CT, had to upgrade its plant to increase BOD removal efficiency and add a nitrification stage before discharging effluent into the Pequabuck River. For a design flow of 3.8 mgd and the expected trickling-filter effluent of 63.8 mg/L BOD and 17.5 mg/L $\text{NH}_3\text{-N}$ (raw influent 180 to 200 mg/L BOD), twenty-four 26-ft-long RBC shafts (Envirodisc of Clow Corp.) were installed, all housed in a building with ventilation and temperature control (minimal temperature to be maintained at 55°F [12.7°C]). Four rows of RBC units, each consisting of six stages, are operated in parallel. The first three stages -- each having 100,000 sq ft of surface media -- are for BOD removal, and the last three stages -- each having 150,000 sq ft of high-density surface media -- are for nitrification. A test in 1977 showed that the RBC units could provide 90 to 93 percent BOD removal and 90 to 95 percent $\text{NH}_3\text{-N}$ removal during the summer; 85 to 90 percent $\text{NH}_3\text{-N}$ concentrations were easily met during the winter (Figure 7). The Plainville Treatment plant uses multiple-media filters; however, the RBC effluents in the secondary clarifiers are subjected to polymer coagulation before they enter the filters. Current daily wastewater flow is about one-third the design flow of 3.8 mgd. Consequently, the trickling filters are disconnected, with the primary effluents fed directly to the RBC units. The treatment plant consistently experiences a 95 percent BOD removal and 98 percent nitrification.¹¹

The Bio-Surf process installation in the City of Birdsboro, PA, is similar to the one at North Huntington, except that the existing trickling filter was initially designed to provide greater BOD reduction. The original facility produced effluent containing about 56 mg/L of BOD and suspended solids. The city wished to upgrade its facility to meet effluents of approximately 25 mg/L ultimate oxygen demand, which required both nitrification and a significant removal of carbonaceous BOD. Eight Bio-Surf units were installed between the existing trickling filter and secondary clarifier (Figure 7). These units are currently operating at an overall hydraulic loading of 1.2 gpd/sq ft with a typical effluent containing 12 mg/L total BOD and 1.6 mg/L of $\text{NH}_3\text{-N}$.

A recent study for the Edgewater, NJ, Sewage Treatment Plant showed that the concept and technique of upgrading can be easily applied to trickling-filter plants with primary clarifiers. A false bottom can be added to an existing clarifier and the RBC units placed on top of it. The wastewater, which passes the RBC units to receive the designed biological treatment, flows to the lower compartment of the clarifier which serves as a secondary

¹⁰R. A. Sullivan, et al., Upgrading Existing Waste Treatment Facilities Utilizing the Bio-Surf Process, paper presented at the First National Symposium on RBC Technology, Pittsburgh, PA (February 1980), Vol 1 -- PB81-124539, Vol 2 -- PB81-124547.

¹¹Personal communication between C. P. Poon and the Chief Operator of Plainville Treatment Plant (1980).

clarifier for the Edgewater facility in the test program (see Figure 7). This RBC/underflow clarifier concept is patented by Autotrol Corporation. Use of this technique for primary treatment at the Edgewater plant met the NPDES effluent level of 30 mg/L of BOD and suspended solids.¹² However, installation of the false bottom and the modifications to the sludge-scraping mechanisms in the primary tank can be costly. In addition, this technique cannot be applied to circular clarifiers. However, the technique is useful if these do not exist, particularly in facilities where land availability is very limited.

Wastewater that has not been given primary treatment adversely affects RBC operation and performance. The Edgewater study showed that some form of pretreatment, such as high-rate gravity settling (using one of the existing clarifiers) with a nominal overflow rate between 7000 and 9000 gpd/sq ft (285 to 370 m³/m²-day) was required in addition to the existing screen/grit chamber. The scheme shown in Figure 7 incorporates this upgrading technique into an existing trickling-filter plant; the added RBC units remove some of the carbonaceous BOD, while the existing trickling filter(s) remove still more.

The concept of placing RBC units in clarifiers can be extended to the scheme shown in Figure 7. Here, the RBC units are installed in the modified secondary clarifiers so that the existing trickling filters are operated primarily for carbonaceous BOD removal, while the RBC units accomplish both BOD removal and nitrification. To date, this scheme has not been used. Table 4 lists other trickling-filter plants in the United States using RBC to upgrade their effluents; however, no data on their operation and performance have been released yet.

Decision To Use or Not To Use RBC

Although RBC is a proven technology and its application to upgrading has been successfully demonstrated, there are conditions under which RBC should not be used:

1. When the wastewater contains chemicals known to attack polyethylene (e.g., chloroform, acetone, benzene).
2. When the existing trickling filters are in such poor condition that they require major repair or modification (e.g., replacing of media) to restore the originally designed performance level.
3. When the existing trickling filters do not produce satisfactory effluent qualities because of the presence of toxic chemicals and not because of underdesign.

¹²Clinton Bogart Assoc. and Hydrosience Assoc., Inc., Preliminary Report to EPA on Upgrading Primary Tanks With RBCs (November 1978).

Table 4

Plants* Using RBC to Upgrade Trickling-Filter
Facilities for Which No Data Are Available

Plant and Location	Design Flow MGD	No. of Shaft	Operating Status	Consulting Engineer
Boynton Beach, Florida	1.40	2	Since Sept. 1975	Russell & Axon Daytona Beach, FL
Huntley, Illinois	0.28	4	Since Nov. 1977	Baxter & Woodman, Inc. Crystal Lake, IL
Longmont, Colorado	8.20	12	Since Feb. 1978	McCall, Illingson, & Morrill, Inc. Denver, CO
Superior, Nebraska	0.67	3	Start-up Aug., 1978	Paul Mousel & Associates McCook, NE

* All use the Bio-Surf process. The use of RBCs to upgrade existing trickling-filter facilities is attractive because of the low hydraulic head loss (less than 6 in. [152 mm] for a six-stage scheme); this facilitates its use in existing treatment flow trains as shown in the various configurations in Figures 7a and 7e.

It would be difficult to destroy or damage certain sewage treatment technologies such as activated sludge or trickling-filter unit processes through improper design or operation. Improper design or operation of RBC units potentially could result in structural failure problems. However, manufacturers indicate that current designs are much improved. Even with these proprietary assurances, with the very short history of RBC technology application in this country, the life expectancy of major components is not fully known. Consequently, any RBC upgrade of existing DA sewage treatment facilities should be accompanied by a negotiated performance warranty and equipment warranty which obligates the RBC manufacturer/proprietor to provide new equipment or a refund (at the Army's option if media, shaft failure, and/or ancillary equipment fails or if design standards are not met). Absence of

this type of guarantee is biased against other technologies which were not selected due to economics, energy requirements, etc. These considerations are important when a pollution abatement engineer wants to be confident in the credibility of any wastewater treatment technology. However, one should keep in mind that if the manufacturers' assurances are accurate, current designs are much improved. Then RBC technology should be the technology of choice wherever it is most applicable. It is significant that hundreds of RBC plants have been in operation for several years without experiencing media/shaft failure problems.

Trickling filters can be upgraded without using RBCs; e.g., addition of more trickling filters, use of the activated sludge process, use of effluent polishing lagoons, or land application of effluents. However, lagoons and land application are not likely candidates because of their large land area requirements. Table 5 compares and ranks the RBC, trickling-filter, and activated sludge methods according to their merits and disadvantages as retrofit systems. The overall ranking indicates that the trickling filter is the least favorable retrofit system. The RBC and activated sludge process is comparable to the trickling-filter system for larger installations. However, for small installations (5 mgd or below), RBC seems to be the best retrofit alternative. For larger installations, the cost differential between RBC and trickling filters or between RBC and the activated sludge process will be larger (see the Cost Estimation section in Chapter 5); thus, they will be a less attractive alternative.

Thus, it appears that installations above 5 mgd should consider alternatives other than RBC. If O&M simplicity is emphasized, a high-rate trickling filter with plastic media and oxidation ditch is a potential candidate. The degree of sophistication in the control and monitoring required for the activated sludge process (with nitrification) would tend to rule out this option unless highly trained personnel are available. An EPA publication¹³ provides guidance on choosing among trickling filters, activated sludge process, polishing lagoons, and other upgrading techniques (filters, microstraining, and activated carbon).

The point is that engineering A/E firms often do not even consider RBC technology as one of many viable alternatives which should be evaluated for technical/economical attributes for a particular site-specific application. DA personnel should request A/E firms to evaluate all viable upgrading technologies, including RBC retrofit strategies.

¹³Process Design Manual for Upgrading Existing Wastewater Treatment Plants (Office of Technology Transfer, USEPA, 1974).

Table 5

Comparison and Ranking of RBC, Trickling-Filter, and
Activated-Sludge Processes

Major Considerations: high ranking 6 Minor Considerations: high ranking 3
 medium ranking 4 medium ranking 2
 low ranking 2 low ranking 1

(A high ranking is considered favorable for upgrading application.)

<u>Major Considerations</u>	<u>RBC</u>	<u>Trickling Filter</u>	<u>Activated Sludge</u>
Installed costs, below 5 mgd above 5 mgd	6 2	2 6	4 4
Simplicity in operation and and maintenance	6	4	2
Process reliability under varying loadings and climate conditions	4	4	6
Power requirement	4	6	2
Land requirement	4	2	6
Sensitivity to shock loadings	4	6	6
<u>Minor Considerations</u>			
Expandability	3	1	2
Nuisance (odor, insects, safety, foaming, etc.)	3	1	2
Tight compliance schedule	2	1	1
Total below 5 mgd above 5 mgd	36 32	28 31	31 31

4 DESIGN GUIDELINES OF RBC TECHNOLOGY APPLIED TO UPGRADING EXISTING TRICKLING-FILTER FACILITIES

Soluble Carbonaceous BOD

Nearly all RBC systems provide large surface media to promote successful growth of an active biofilm which oxidizes wastewater chemicals. The amount of BOD or ammonia-nitrogen that the RBC removes depends on the loading, if all other environmental factors are favorable (e.g., pH, temperature, dissolved oxygen, availability of nutrients, alkalinity, absence of toxic chemicals, etc.). The loading in pounds of BOD/1000 sq ft-day is comprised of the hydraulic load gpd/sq ft and the RBC influent BOD concentration.

Many RBC manufacturers consider only the removal of soluble BOD. Because the concentration of suspended organic matter in the RBC unit is low and the wastewater detention time is short (1 to 2 hours), the suspended solids exert very little oxygen demand. This is perhaps the primary reason that many RBC manufacturers and consulting engineers consider soluble BOD to be the controlling parameter in the RBC process design. The soluble or total BOD removal mechanism is generally accepted as being a first-order reaction up to a limit; i.e., the BOD removal rate in lb/1000 sq ft-day is directly proportional to the BOD concentration applied. All RBC manufacturers have collected enough data from both pilot-plant and full-scale plant studies to show the appropriate loadings at or below which a specified BOD effluent can be obtained for their product. Some manufacturers prepare design curves, while others prepare tables to show the design loadings. Figures 8 and 9 are examples of design curves, and Table 6 is an example of design loadings. Using either the design curves or design loadings prepared by the manufacturer, one can determine the area of surface media required for a specific need. In the Carter Bio-Drum

Table 6

Soluble BOD Loading Rates (Clow Corp.)

Design Effluent Soluble BOD Concentrations	Soluble BOD Application Rate
<u>mg/L</u>	<u>lb/1000 sq ft-day</u>
5	1
10	1 1/2
15	2
20	2 1/4
25	2 1/2
30	2 3/4

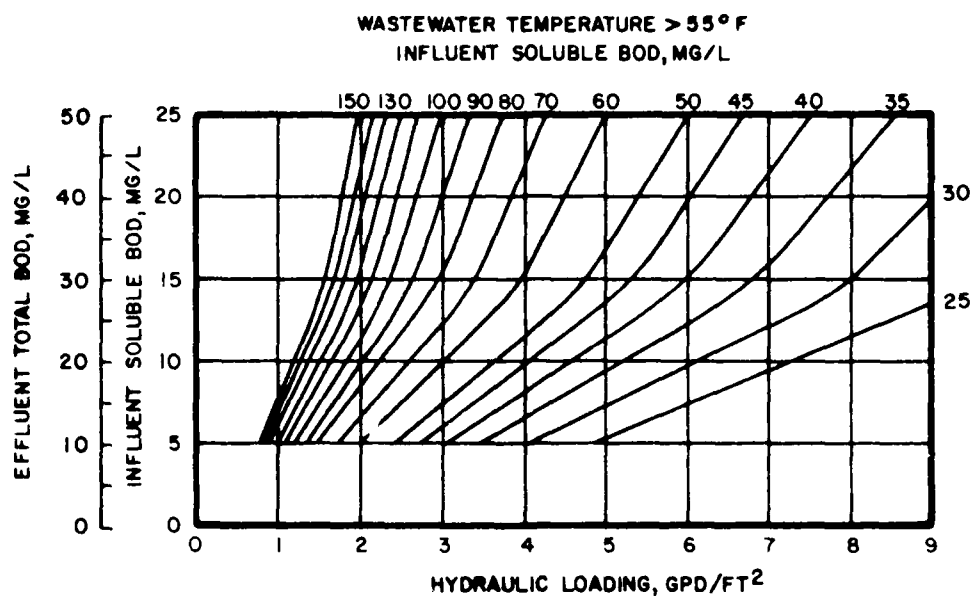


Figure 8. Design curves for BOD removal. (From Autotrol Design Manual [Autotrol Corp., 1979]).

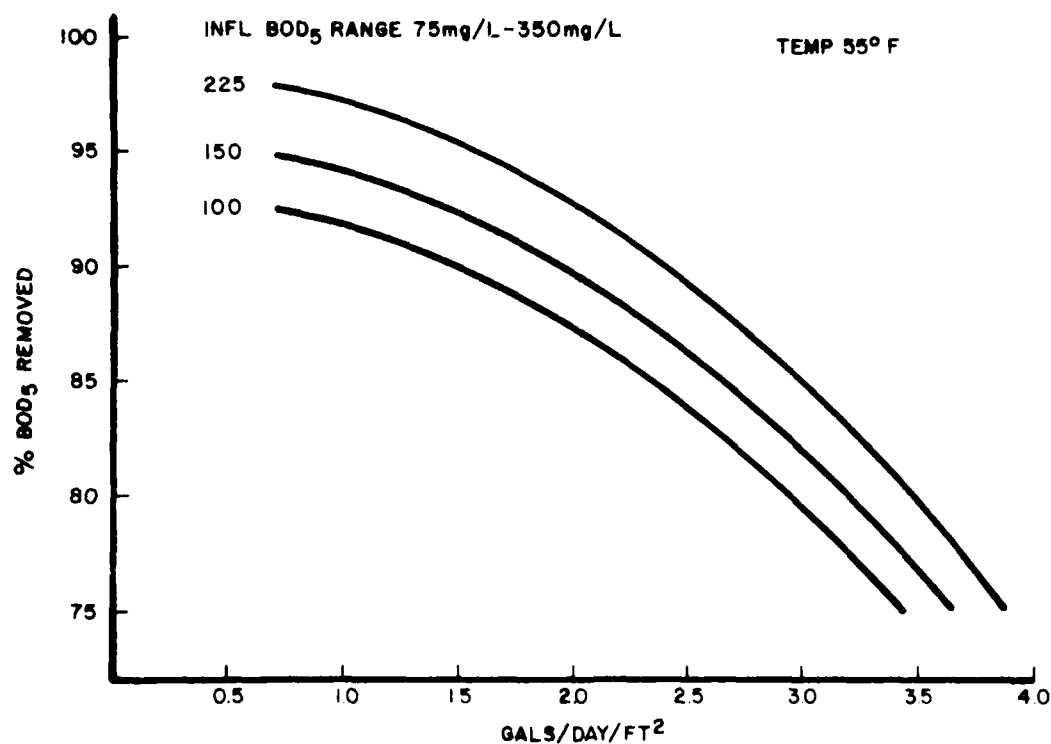


Figure 9. Design curves for BOD removal. (From Design Manual, Catalog Sheet 10.130 [George A. Hormel and Company]).

process, where the area of surface media cannot be accurately assessed, a design loading of lb/day per unit down volume is used. The manufacturer provides a design performance curve.

Hydraulic Flow and Flow Variations

The performance of the RBC process in terms of normal diurnal flow patterns is reflected in the BOD removal design curves or design loadings provided by the manufacturers. Generally, with properly designed RBC units, the hydraulic detention time of the wastewater in the RBC tankage is 1 to 1 1/2 hours. Based on full-scale plant operational experience, this detention time is adequate for the specific BOD removal. It is not necessary to adjust the design hydraulic loading to account for diurnal flow patterns. Slight changes in the treatment levels caused by flow fluctuations do not affect the daily average treatment performance as long as peak-to-average flow ratios do not exceed 2.5. However, for flow ratios above this value, the design average flow should be increased to meet the 2.5 peak-to-average ratio, or flow equalization should be incorporated into the pretreatment scheme.

Nitrification

Wastewater may contain both organic nitrogen and ammonia-nitrogen, and perhaps negligible amounts of nitrite and nitrate. The RBC process is not expected to remove a significant portion of the organic nitrogen because of the short hydraulic detention time provided for such action. However, ammonia-nitrogen can be oxidized successfully in the RBC unit if the BOD concentration is 30 mg/L or less (soluble BOD 15 mg/L or below). At BOD concentrations above this value, the carbon-oxidizing bacteria predominate and out-compete the nitrifiers. Consequently, nitrification can proceed only at a very slow rate, if at all.

Based on their full-scale plant operations, the RBC manufacturers also provide design curves or tables of design loadings from which the required surface media for any level of nitrification can be determined. Similar to BOD removal, the typical design curves (Figures 10 and 11) and the table of design loadings (Table 7) suggest that $\text{NH}_3\text{-N}$ loading (lb/1000 sq ft-day) is the design parameter. ($\text{NH}_3\text{-N}$ loading consists of hydraulic loading in gpd/sq ft and $\text{NH}_3\text{-N}$ concentrations.) No established procedure is given in the design of the Carter Bio-Drum process for $\text{NH}_3\text{-N}$ removal.

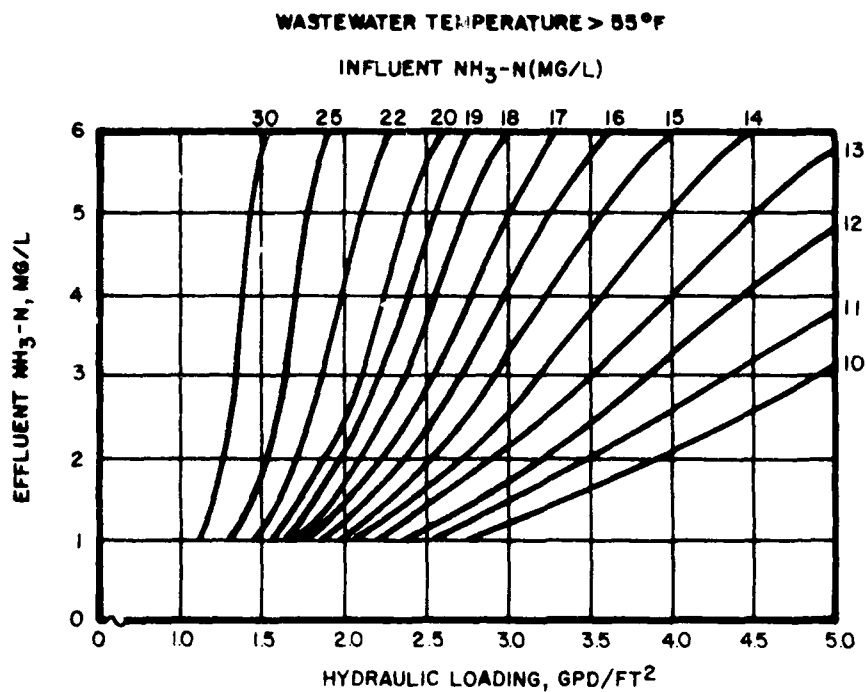


Figure 10. Design curves for $\text{NH}_3\text{-N}$ removal. (From Autotrol Design Manual [Autotrol Corp., 1979])

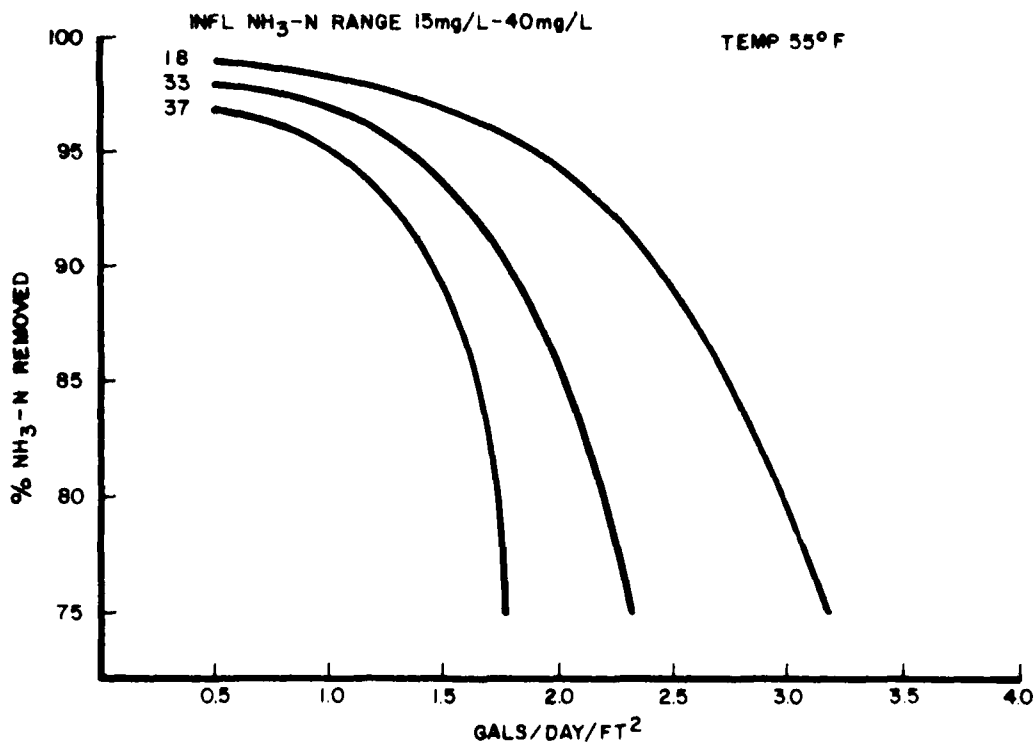


Figure 11. Design curves for $\text{NH}_3\text{-N}$ removal. (From Design Manual, Catalog Sheet 10.130 [George A. Hormel and Company])

Table 7

Nitrification Loading Rates, Clow Corp.
(for approximate and preliminary sizing)

Design Effluent NH ₃ -N Concentration	Leading Rate (Influent 10 to 30 mg/L)
<u>mg/L</u>	<u>lb NH₃-N/1000 sq ft-day</u>
1	0.23 to 0.27
2	0.30 to 0.32
3	0.33 to 0.40
4	0.35 to 0.45
5	0.36 to 0.50
6	0.38 to 0.58
7	0.43 to 0.65
8	0.50 to 0.70

Note: The consideration on hydraulic flow variation given in BOD removal should also be given in nitrification.

High Ammonia Concentration and Alkalinity Requirement

The design loadings for nitrification provided by the manufacturers are based on higher rates of nitrification with higher concentrations of influent NH₃-N. There are indications from both pilot and full-scale plant studies that for wastewater containing more than 30 mg/L NH₃-N, the removal will be at a maximum, constant rate of approximately 0.3 lb/1000 sq ft-day. Therefore, in determining the surface media required for nitrification, one must determine the surface area required to reduce the NH₃-N concentration from the influent value to 30 mg/L at a constant rate of 0.3 lb/1000 sq ft-day. The balance of removal will then be ascertained according to additional surface area, as determined from the manufacturer's design curves or design loadings.

Wastewater alkalinity is another nitrification design factor. Hydrogen ions generated in nitrification neutralize the wastewater alkalinity. In nitrification, about 7.1 mg/L of alkalinity, expressed as calcium carbonate, is required to remove 1 mg/L of NH₃-N. In addition, a residual alkalinity of approximately 30 mg/L should be maintained in the wastewater to avoid fluctuations in plant influent alkalinity and thus minimize the probability of exhausting the wastewater's buffer capacity. Depressing pH below neutrality

will reduce the rate of nitrification. The optimal pH level for nitrification is 8.4, although nitrifiers can grow very slowly at a pH of 6.0. Chemical supplement to increase alkalinity may be necessary if the wastewater alkalinity is low.

Temperature

Temperature affects both the rate of carbonaceous BOD oxidation and the rate of nitrification. Low temperature slows down the biological reaction such that a specific correction factor for each case must be applied to reduce the loading.

All RBC manufacturers provide separate curves or tables of temperature correction factors for BOD removal and nitrification, except the Walker Process Corp., which provides one curve applicable to both cases. Most manufacturers recommend that the temperature correction be applied when the wastewater temperature is below 55°F (12.6°C).

No adjustment to higher loading is allowed for wastewater temperatures higher than 55°F (12.6°C). Only Autotrol Corp. allows adjustment to higher NH₃-N loading when the wastewater temperature is above 55°F (12.6°C) (up to 65°F [18.2°C]). Since NPDES permits usually require lower NH₃-N levels in the effluent, a larger surface media requirement would be needed. Allowing adjustment to higher NH₃-N loading in the design when wastewater temperature is higher will result in some saving of the surface media.

It is much more difficult to establish a significant population of nitrifiers on the surface media during the winter. Consequently, it is preferable to start a new RBC facility in warmer weather. Optimal control of alkalinity and pH may improve cold-weather operational characteristics.

Combined BOD Removal and Nitrification

RBC is often used for combined BOD removal and nitrification, particularly in trickling-filter plants. Here, ammonia-nitrogen can be reduced both through metabolism by the heterotrophic bacteria during BOD removal, and through desorption (stripping) of NH₃-N at a pH of 7.0 or above in the well-agitated environment of the RBC unit. Nevertheless, these two mechanisms are generally not considered in design, since they provide only limited NH₃-N removal. The main mechanism of NH₃-N removal is still nitrification by nitrifying organisms.

When an RBC system is designed for both BOD removal and nitrification, the surface media required should be calculated separately for (1) reduction of soluble BOD to 15 mg/L, (2) reduction of ammonia to the design level, and (3) reduction of soluble BOD to the design level. If the surface media

requirements for (1) and (2) are added and their sum compared with the requirement for (3), the greater amount is the minimum area required for this application.

Staging of Units

It has long been established that a plug flow reactor is more efficient than a completely mixed reactor in chemical and biochemical reactions. Therefore, the arrangement of RBC media in a series of stages significantly increases treatment efficiency when high-quality effluents are required. Retaining the concept of first-order kinetics of substrate removal, organisms on the first stage of the media are exposed to a high substrate concentration (BOD or $\text{NH}_3\text{-N}$) and respond by removing substrate at a higher rate. Although the removal rate decreases from stage to stage as the substrate concentration decreases, the average removal rate is greater than if all the media were in a single completely mixed stage, where the organisms would be exposed to a relatively low substrate concentration.

Staging of surface media also has the advantage of allowing specific microbial cultures to develop during stages most conducive to their purpose. Heterotrophs are established in the first few stages where significant BOD removal occurs; this enables nitrifying organisms to develop during the latter stages, where nitrification occurs.

Since the first stage receives the highest loading of BOD, the biomass may grow to undesirable thicknesses; a significant portion of the mass may then become anaerobic, and cause undesirable forms of microbial life to develop. Many RBC plants have experienced a limited oxygen condition as a result of this situation. To mitigate this situation, the equivalent BOD loading, corrected for temperature and septicity if applicable, should be calculated for the first stage and compared with the allowable limit recommended by the manufacturer. If the first stage equivalent loading exceeds the allowable limit, the first stage should be expanded by one or more units until the equivalent load is less than the allowable limit. The Autotrol Corp. provides a design curve to determine the surface media requirement as a percentage of the total surface media.

High-density media are for thinner biomass growth. Only nitrification and/or latter stages of the RBC system receiving low BOD concentration should use high-density media. The amount of high-density media allowable for a specific application can be calculated (as in the examples in Chapter 5) or determined from design curves provided by the manufacturers.

Generally, a minimum of four stages is provided for any RBC system. The baffle between the first and second stages should be removable. If necessary, the first stage can then be expanded to eliminate an oxygen limiting condition

or to increase the system's capacity to dilute toxic chemicals in the influent.

Recirculation and Step-Feed Control

Most RBC manufacturers do not design for effluent recirculation. Under normal operation with a properly designed RBC system, recirculation does not improve operation or effluent quality. However, it is desirable when the inflow rate is at its high and low extremes.

At small DA STPs, where the wastewater inflow may drop significantly for days, such a lengthy period with very little food will starve the biofilm, and there will be inadequate biomass to provide the desired treatment when the normal inflow restarts. During this extremely low organic loading period, flow should be recycled through the sludge hold/treatment units and then to the RBC units; the organic load from the sludge units will help maintain the biofilm, and, as a secondary benefit, help stabilize and reduce the sludge. If the RBC system receives an unexpected organic load or toxic load above what the designed condition allows for, recirculation of the RBC effluent will dilute the organic or toxic load. Furthermore, the diluted load will be distributed more evenly to the biomass throughout the whole RBC system, and treatment upset can be avoided. Since the recycled flow can be adjusted from a fraction of the inflow to several hundred percent of the inflow, the overload situation, whether small or large, can be controlled without lowering the effluent quality. This adds to the flexibility of RBC system operations;¹⁴ however, recirculation also adds to the first cost of the RBC system.

To some extent, the organic overload or toxic load condition can be relieved by removing baffles between stages or by step-feed of the influent. Step-feed provides lower-quality effluent because of the very short hydraulic detention time allowed for the organic load in the last stages. Also, in comparison to recirculation, the degree to which the organic or toxic load is diluted is limited by using either baffles or the step-feed scheme. However, unlike recirculation, removing baffles or step-feed is not power-intensive.

Supplemental Air and Air-Drive RBC

The addition of supplemental air in the RBC tankage at normal loadings does not improve the RBC process. Supplemental air is beneficial only where the first stages are organically overloaded and there is an oxygen limiting situation. Since supplemental aeration requires large amounts of energy, a more effective use of energy for facilities under design would be to provide additional RBC units rather than large amounts of supplemental air. The

¹⁴C.P.C. Poon, et al., "Factors Controlling the Performance of RBC," J. WPCF, 51 (March 1979), p 601.

air-drive RBC system, marketed only by Autotrol Corp. under the trade name of Aero-Surf Process, provides plenty of air in the entire RBC unit. Consequently, the oxygen limiting situation is completely eliminated. However, the energy expenditure required to supply this air is a concern. The Aero-Surf process design criteria are based on pilot-plant experience. Autotrol Corp. is collecting full-scale plant operating data which will be used to confirm or modify the existing design criteria.¹⁵

For the specific application to upgrading trickling-filter facilities, it is unlikely that RBC design will allow organic overloading in the first stages. Even if organic overloading might occur in an emergency situation, the first choice of remedial actions should be removal of the baffles between the affected stage and the next stage downstream. Supplemental air or air-drive RBC are not likely candidates in this unique RBC application. However, if air-driven RBC units are considered, Autotrol Corp. (currently the only manufacturer of air-driven RBCs) suggests using the same design criteria as used in the mechanical-drive RBCs to determine the surface media requirement for both BOD removal and nitrification. Also, temperature correction factors will be the same as for the mechanical-drive RBC systems.

Air requirements depend on the speed of rotation. The first-stage units are usually rotated at 1.5 rpm, and the latter-stage units at 0.8 rpm. For 25-ft shaft units, usually 190 ACFM (absolute cu ft/min of ambient air) is recommended per shaft for 1.5 rpm rotational speed and 60 ACFM per shaft for 0.8 rpm. However, 250 ACFM per shaft is recommended for installed blower capacity, with the operating blower capacity set at a level 33 percent higher than the estimated consumed air requirements. For small, air-driven RBC installations with less than 2000 ACFM operating blower capacity, one operating blower sized to provide 133 percent of the estimated consumed air requirement and a second stand-by blower of equal size are recommended. On larger installations, three equally sized blowers, each capable of providing 66.7 percent of the estimated consumed air requirements, are generally preferable.

Clarification

Suspended solids from the RBC effluent may be separated by standard-design, secondary clarifiers providing a surface overflow rate of 800 gpd/sq ft ($32.6 \text{ m}^3/\text{m}^2\text{-day}$) for a 30/30 effluent (30 mg/L BOD and 30 mg/L suspended solids). The overflow rate should be reduced for effluents with lower levels of BOD and suspended solids. Table 8 shows the clarifier design criteria recommended by most RBC manufacturers. Typical tertiary filtration uses a 2-ft layer of anthracite coal above a 2-ft layer of sand and a 2-ft layer of gravel with a filtration rate of about 3 gpm/sq ft ($172.8 \text{ m}^3/\text{m}^2\text{-day}$).

¹⁵Autotrol Wastewater Treatment Systems Design Manual (Autotrol Corp., 1979).

Table 8
Criteria of Clarifier Design for RBC Effluent

Effluent Sus- pended Solids mg/L	Condition of RBC Effluent	Clarifier Overflow Rate gpd/sq ft	Additional Suspended Solid Removal Requirement
30	Secondary effluent	800	no
20	Secondary effluent	600	no
15	No nitrification	500	no
10-15	Nitrified	500	Chemical flocculation prior to clarification
<10	Nitrified	800	Chemical flocculation, clarification, and tertiary filtration

Typical tertiary filtration uses a 2-ft layer of anthracite coal above a 2-ft layer of sand and a 2-ft layer of gravel with a filtration rate of about 3 gpm/sq ft (172.8 m³/m²-day).

Sludge Production

Like other biological processes, the quantity of sludge produced by the RBC process depends on the extent of BOD removal. Increased endogenous respiration or increased sludge age decreases the rate of net solids production. Sewage characteristics and temperature also affect sludge production. Generally, sludge production is slightly lower than for suspended growth systems and approximately equal to that of trickling filters. The sludge age of

an RBC system is about 20 days¹⁶ longer than that of activated sludge processes, which helps explain the discrepancy between sludge production in RBC and suspended growth systems.

Data from Autotrol Corp. show a sludge yield coefficient of 0.05 to 0.5 lb per pound of soluble BOD removed. The yield coefficient increases as the soluble BOD concentration in the RBC effluent increases. Adding this sludge yield to the influent suspended solids concentration represents the sludge input to the clarifier. The net sludge production depends on the capture of the suspended solids in the clarifier. About 0.4 to 0.6 lb of sludge are produced per pound of total BOD removed.

Land Requirements

Once a decision is made to upgrade an existing facility, the planner must consider the land requirements of the selected retrofit system. There must be enough space to install the shallow tankage used with the RBC units.

Most RBC units are up to 12 ft in diameter and have up to 26-ft-long shafts, although the customer can specify special sizes. A larger RBC module will provide more surface media per unit of land area. The largest RBC modules available provide 100,000 sq ft of standard surface media (150,000 sq ft of high-density media) and require a floor space from 450 to 500 sq ft including walkways between tankages and other access floor space. An RBC facility designed for both BOD removal and nitrification of typical domestic wastewater will require about 3000 sq ft of land area for 1 mgd of flow. Land area requirement is linearly proportional to flow rates. A smaller surface media requirement may decrease the amount of land area needed depending on the degree of nitrification required. The RBC units for such application, including walkways, may occupy 2500 to 3000 sq ft of land area for 1 mgd/day flow. More detailed information regarding the influent characteristic (soluble BOD concentration, $\text{NH}_3\text{-N}$ concentration, temperature, septicity, etc.) and effluent quality (BOD, suspended solids, $\text{NH}_3\text{-N}$, etc.) will be needed to determine the land area requirement more precisely (see the example calculation in Chapter 5).

The Carter Bio-Drum process has a standard drum size of 8-ft diameter by 8-ft length; usually one shaft serves two drums. A two-drum-per-shaft module occupies approximately 400 sq ft of floor space, including walkways. The Bio-Drum process generally receives a higher organic load per unit volume than conventional RBC units. Therefore, less land space is required; e.g., an

¹⁶C.P.C. Poon, et al., Evaluation of an RBC System to Upgrade Trickling Filter Effluents, paper presented at the First National Symposium on RBC Technology, Pittsburgh, PA (February 1980), Vol 1 -- PB81-124539, Vol 2 -- PB81-124547.

estimated 2000 sq ft of land area is required for a 1 mgd/day flow, including walkways.

RBCs can be installed in existing clarifiers, so no additional land is required. However, this approach is more applicable in situations where land is extremely limited.

Tankage Volume

RBC manufacturers recommend both flat-bottom and contoured tanks for the rotating media. The tanks can be constructed of either steel or concrete. The hydraulic detention time of the wastewater in the tank affects treatment efficiency. Longer detention times of up to 45 min to 1 hour give a higher degree of treatment; however, beyond this amount of extra time, no further improvement of performance will be realized. Data provided by Autotrol Corp. indicate that optimal tankage volume is about 0.12 gal/sq ft of surface media, taking into account the wastewater displaced by the media and the attached biomass in the tank. This value applies to wastewaters with a BOD concentration up to 300 mg/L. Baffles to separate the various stages of RBC can be constructed of a variety of materials, including fiberglass, redwood, and reinforced concrete. Removable baffles should be considered for the first two stages as a possible remedy for the organic overloading condition. Bottom openings of various sizes between the different stages are recommended by RBC manufacturers.

Enclosure

All RBC installations must be enclosed or protected from freezing temperatures and excessive heat loss from the wastewater. Even in warmer climates, a sun roof is required to protect the polyethylene media from ultraviolet light degradation and to minimize algae growth on the media. Some installations are constructed completely within one building, while others use individual covers. Buildings can be constructed of any suitable corrosion-resistant material. Individual, molded fiberglass covers are provided by RBC manufacturers. Each cover is equipped with a man-access-door and an inspection port. The drive mechanism is generally outside the cover, which eliminates the need to enter the enclosure for routine maintenance. When the RBC installation is housed in a building, openings for proper ventilation should be provided. Operators in a few enclosed RBC installations have experienced difficulty in breathing, because oxygen is quickly consumed by the actively growing biofilm.

At low ambient air temperatures, the high humidity in the building will cause condensation on the walls and ceiling. Consequently, insulation and/or heating should be provided to minimize condensation, corrosion, and operator

discomfort. Heating of the enclosure to a minimum temperature of 55°F (12.6°C) is recommended.

The rates of both BOD removal and nitrification decrease during the winter when wastewater temperatures are lower; this will lead to a larger surface media requirement and the need for more RBC units, thus increasing both the first cost and O&M costs. A design engineer can estimate whether the added cost of maintaining a temperature of 55°F (12.6°C) and a forced ventilation in the enclosure can be partially or completely offset by the savings provided by a smaller installation.

Effectiveness Under Changing Climate and Loading Conditions

Operational experience in the United States has shown the reliability and effectiveness of the RBC process under changing climate and loading conditions. However, comparison with the activated sludge process shows that RBC operations lack process flexibility. Activated sludge process can adjust to increased or decreased organic loadings by increasing or decreasing, respectively, the rate of aeration, resulting in more uniform effluent quality. More significantly, the RBC process lacks the important control of food-to-biomass ratio which activated sludge processes can provide through sludge age regulation. However, a properly designed RBC installation that uses the proper loadings, stagings, tankage volume, enclosure, etc., should produce the designed effluent quality.

Since an RBC system resembles a plug-flow process more than a completely mixed process, its effluent quality is more sensitive to influent characteristic changes such as temperature, organic loadings, and toxic loadings.¹⁷ Nevertheless, this problem can be eliminated early in the design stage. It must be noted that the operator of an activated sludge process must have considerable training and skill to exercise the relatively sophisticated controls that provide this system's operational flexibility. RBC's operational simplicity, which is its biggest advantage, must be kept intact and a design feature introduced that could guarantee specification performance under varying climate and loading conditions.

First, the level of effluent quality under the NPDES permits (negotiable with regulating agencies) must be defined clearly. Some permits may include a constant maximum effluent quality limitation, regardless of temperature, stream flow, wastewater peak flow, etc., and may require that the RBC facilities be designed to meet effluent limitations at worst conditions. The required media area can be obtained by calculating the highest organic loading (the maximum multiplication product of the flow rate and the organic concentration). The effluent quality will then meet the requirements at the highest

¹⁷M. P. Fillion, et al., "Performance of an RBC Under Transient Loading Conditions," J. EPCF, 51 (1979), p 1925.

organic loading (pounds of soluble BOD/1000 sq ft-day) and will be of a superior quality at lower or average loadings. It is possible that a lower organic loading in combination with the lowest wastewater temperature will result in a requirement for a larger media area. It is also possible that the lowest temperature will occur with the highest organic loading to create the worst possible condition. This extreme represents the largest media area at which the maximum effluent quality limitation will not be exceeded. However, regulating agencies seldom impose such severe limitations except in critical areas to avoid wasteful under-use of a facility.

Some permits may allow discharge of an effluent whose average quality (monthly, weekly, or daily) meets the effluent limitations, with a higher value designated as an allowable maximum or peak. Design of the RBC facilities can be based on average organic loading, provided that the effluent quality at the highest organic loading condition does not exceed the allowable maximum limit. If the allowable maximum limit is exceeded, the required media area must be adjusted upward accordingly. This situation applies mostly to BOD removal. An additional design consideration is that the peak-to-average flow ratios should not exceed 2.5. As mentioned previously, either the design average flow should be increased so that it always meets the 2.5 peak-to-average ratio, or flow equalization should be incorporated into the pretreatment scheme.

A third permit format, which includes either average or constant daily effluent limitations, may vary the effluent quality limitation between summer to winter to reflect the different temperatures and receiving stream flow rates. This condition is most applicable to $\text{NH}_3\text{-N}$ limitations, since during the winter, receiving streams usually have a higher flow, which provides better dilution; regulation agencies recognize that nitrification is more difficult to accomplish at lower temperatures. Calculations of both summer and winter media area should be carried out, with the larger media area controlling the design.

When all the considerations discussed in this section have been included in the design, the RBC process can be effective and reliable in producing effluents that meet the required quality standards.

Operational and Maintenance Requirements

RBC O&M is very simple, with requirements limited to (1) occasional removal of baffles in the first stages, (2) change of drive-speed (to minimize an oxygen limitation condition in the presence of high organic loadings or when reducing chemical loadings), and (3) occasional partial shutdown of the facility when flow and organic loading over a lengthy period are too low. Small facilities with weekend and holiday zero flow rates may require recirculation of effluent (see p 48). Routine maintenance includes inspection 1 to 2 minutes/day/shift, bearing lubrication once a month (some manufacturers

provide lubrication-free bearings), and changing oil in the drive gears once every 6 or 12 months.

According to Autotrol Corp.'s field data, O&M manpower requirements are approximately 1 manhour per shaft assembly per week for facilities with 4 to 10 shafts. This requirement decreases to 0.5 manhour per shaft assembly per week for facilities with 20 to 30 shafts. The Aero-Surf process indicates that these manpower requirements may be reduced by 50 percent if the multiple mechanical-drive assemblies are eliminated. Figure 12 shows the relative manhour requirements of activated sludge, trickling filter, and RBC plants of various design flows.

Operational Skill Requirement

The simplicity of RBC operation requires no special operator training. Any operator qualified to operate a trickling filter can operate an RBC facility. Occasional checks of organic loadings, flow rates, pH, and alkalinity control in the case of nitrification are the only major operational requirements for RBC units.

Energy Requirement

Data on RBC energy requirements are inconclusive. The low and high estimates supplied by RBC manufacturers vary widely. Installed horsepower varies from 5 hp per shaft (Autotrol's 25-ft shaft, Carter Bio-Drum's dual-drum 20-ft shaft, and Walker's 26-ft shaft) to 7 1/2 hp per shaft (Clow's 26-ft shaft). For typical municipal installations, power consumption is generally cited as 3.0 hp/100,000 sq ft of surface media. Carter Bio-Drum reports 2.5 hp/1000 cu ft or higher power consumption. In terms of horsepower consumption or kilowatt-hour consumption per 1 mgd/day flow, reported values vary greatly, with the high values being as much as 500 percent greater than the low values (8 to 40 hp/mgd).

Several explanations can be offered for these discrepancies. First, higher BOD influent produces greater biomass accumulation on the surface media, which increases the power consumption required to overcome the torque. Lower BOD loadings (pounds of soluble BOD/1000 sq ft-day) therefore consume less power. Second, all manufacturers offer either a constant-speed motor or a two-speed motor in conjunction with a gear speed-reducer. (A gear speed-reducer, which reduces RBC rotational speed, actually increases power consumption.) Finally, many new plants have flows below their design levels, and instead of partially shutting down their facilities, they operate all RBC units to obtain superior effluent. This leads to higher power consumption per 1 mgd/day flow than anticipated. The average RBC value of 24 hp/mgd for secondary treatment, which is equivalent to 1.58×10^5 kWh/yr consumption for

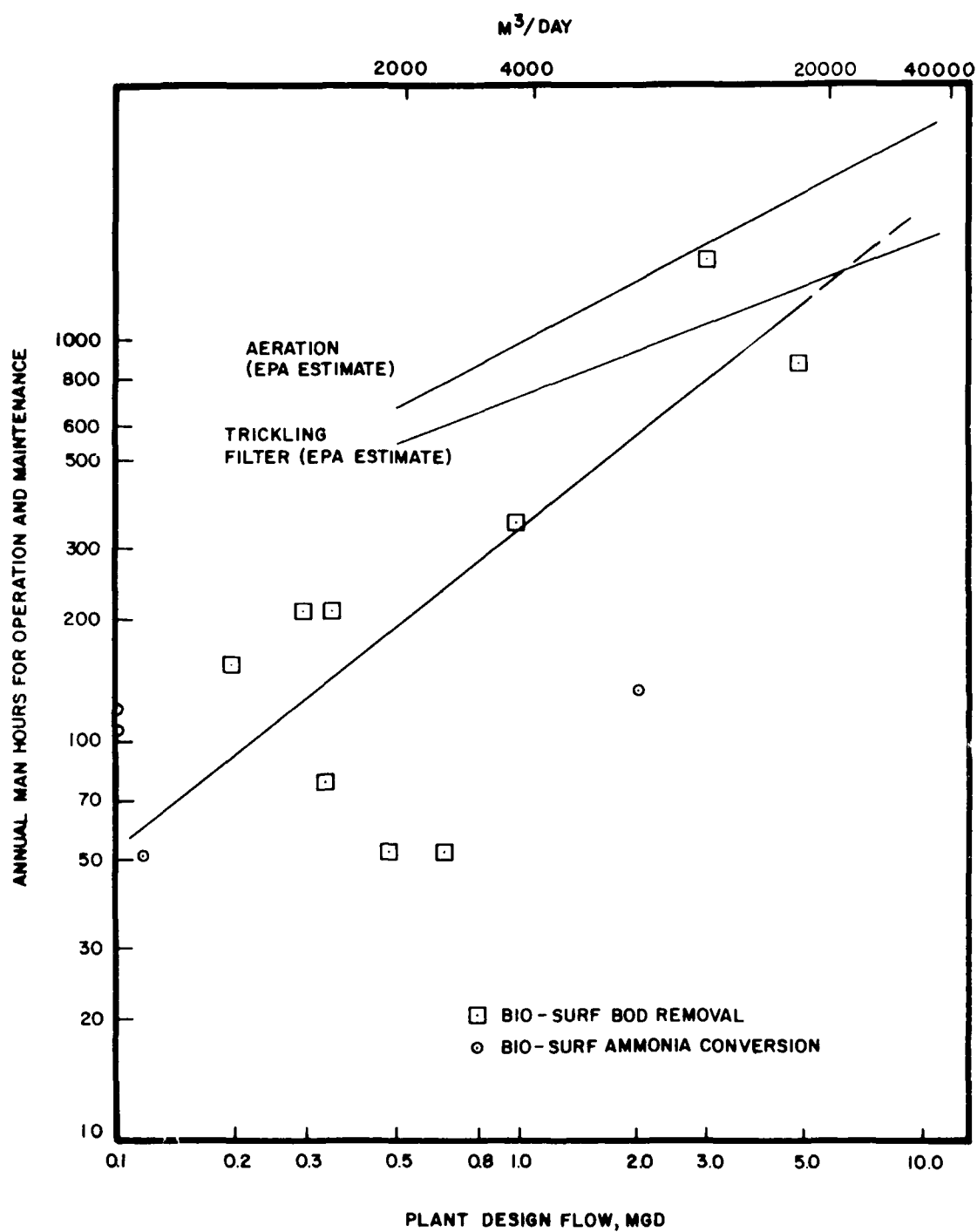


Figure 12. Comparison of manhour requirements for operation and maintenance for various processes. (From Autotrol-released information.)

1.0 mgd flow, is lower than estimated by an EPA report.¹⁸ Table 9 lists some of the EPA estimated power consumptions for various treatment processes. It appears that the EPA estimates of RBC power consumption are high. Using the latest testing data and operational data from the Plainville Plant in Connecticut, BOD removal and nitrification will consume about 2.4×10^5 kWh/yr per mgd/day flow. The EPA estimate in Table 9 for both secondary treatment and nitrification would range from 3.2 to 4.3×10^5 kWh/yr. Information regarding influent BOD concentrations, $\text{NH}_3\text{-N}$ concentrations, and effluent limitations must be known to estimate RBC power consumption more precisely. Chapter 5 provides an example of calculations to obtain this information.

Autotrol Corp. claims that the power consumption of the Aero-Surf RBC system is comparable to that of mechanical-drive RBC systems. However, at lower hydraulic loadings (0.5 to 1.0 gpd/sq ft), the Aero-Surf power

Table 9
Estimated Power Consumptions for Various
Treatment Processes, kWh/yr

Process	Plant Capacity		
	0.1 mgd	1.0 mgd	10 mgd
1. Secondary Treatment			
High rate TF,	7.0×10^3	6.5×10^4	5.5×10^5
rock plastic	$1/8 \times 10^4$	1.7×10^5	1.4×10^6
RBC, standard	3.0×10^4	3.1×10^5	3.3×10^6
high density	2.0×10^4	2.0×10^5	2.0×10^6
Activated Sludge			
coarse bubble	3.0×10^4	3.0×10^5	3.0×10^6
fine bubble	2.3×10^4	2.3×10^5	2.2×10^6
mech. aeration	1.4×10^4	1.5×10^5	1.5×10^6
tur. sparger	2.0×10^4	2.0×10^5	2.0×10^6
2. Nitrification			
Suspended growth	1.7×10^4	1.7×10^5	1.7×10^6
Fixed film	1.5×10^4	1.2×10^5	1.1×10^6

¹⁸Energy Conservation in Municipal Wastewater Treatment, EPA 430/9-77-011 (USEPA, March 1978).

consumption would be as little as one-half that of mechanical-drive processes, because air requirements and rotational speeds would be reduced significantly when loadings are low. Therefore, the application of Aero-Surf to upgrading trickling-filter facilities is promising. Figures 13 and 14, respectively, show the air requirements for various rotational speeds and various organic loadings. Blower sizes and power consumptions can be estimated when air requirements are known (see the example in Chapter 5). Despite the potential of the Aero-Surf process in such an application, no existing plant has used it to upgrade a trickling-filter facility. Consequently, there are no cost and operational data. However, some operational data have been released recently for use of the Aero-Surf process in secondary treatment.¹⁹

Process Scheme Selection to Upgrade Trickling Filters

As discussed previously, RBC units can be placed at various locations in a trickling-filter facility. The following discussion gives the advantages, disadvantages, and practicalities of the various schemes.

RBCs in Primary Clarifiers

Where land for expansion is extremely limited, this scheme is a promising candidate. However, even though it has been demonstrated that RBCs in primary clarifiers can upgrade treatment performance to meet secondary treatment effluent quality, there are difficulties and disadvantages associated with this scheme.

1. The technique is not suitable for facilities with circular clarifiers.
2. Pretreatment of the raw wastewaters is required to remove grit, trash, and floatables which interfere with RBC operations. A rough screening is necessary to remove large fibrous material which passes through high-rate primary treatment. One or more of the existing primary clarifiers must be used as a high-rate primary treatment unit to reduce the number of primary clarifiers available for this scheme. New RBC tankage must be used for some of the RBC units.
3. Placing the RBC units on top of the primary clarifier and an intermediate floor below them reduces the clarifier's suspended solids removal efficiency by 25 percent.

¹⁹M. M. Schirtzinger, et al., First USA Air Drive RBC Units Operational Experience and Performance, Indian Creek Wastewater Treatment Plant, Cincinnati (Cleveland), Ohio, paper presented at the First National Symposium on RBC Technology, Pittsburgh, PA (February 1980), Vol 1 -- PB81-124539, Vol 2 -- PB81-124547.

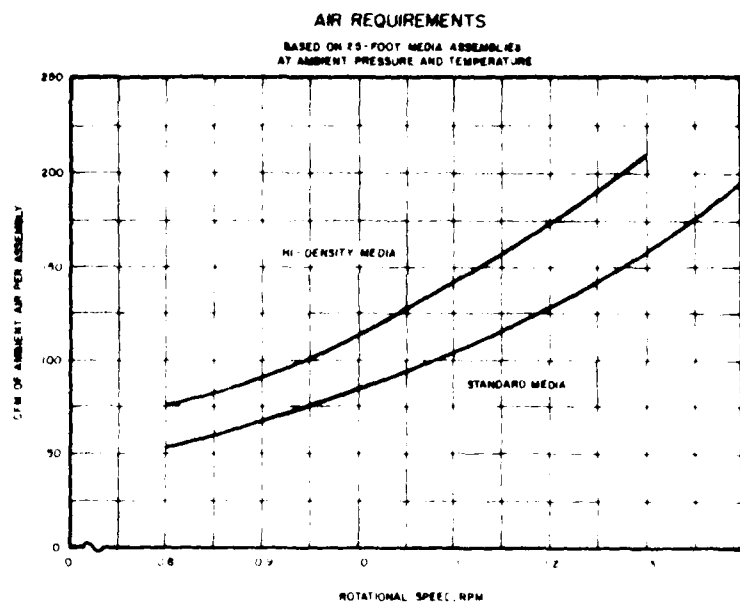


Figure 13. Air requirements at various rotational speeds for the Aero-Surf process. (From Autotrol Corp. data, 1979.)

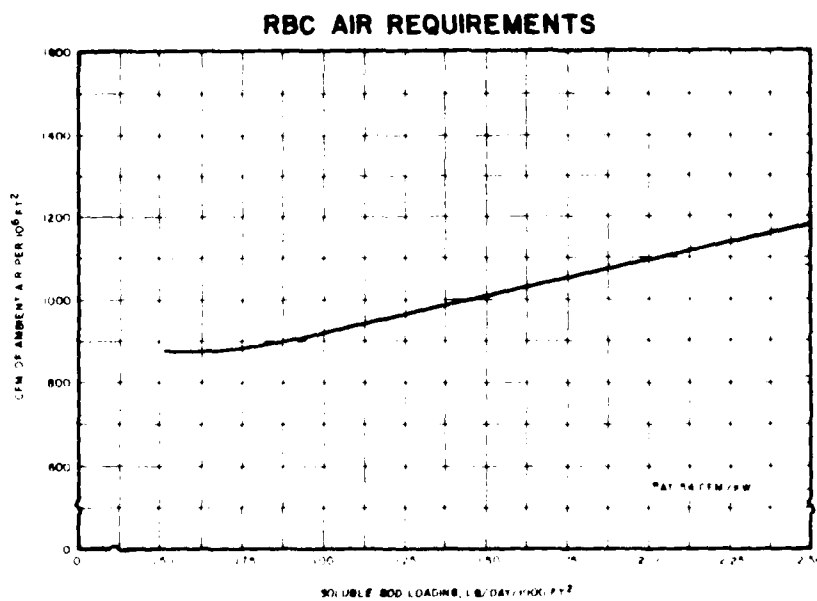


Figure 14. Air requirements at various organic loadings for the Aero-Surf process. (From Autotrol Corp. data, 1979.)

4. Either RBC units must be custom-made to fit existing primary clarifiers, or the primary clarifiers must be modified to fit standard-sized RBC units.

5. There is some design uncertainty regarding what surface media requirement is necessary for the existing filters to remove the remaining BOD and also obtain nitrification commensurate with stipulated effluent qualities.

6. Existing primary clarifiers must be modified significantly (modifications to the sludge scraping mechanisms, installation of the intermediate floor, etc.). A tight compliance schedule is not feasible, so interruption of plant operation is unavoidable.

7. Based on the Edgewater plant experience,²⁰ the cost of converting existing clarifiers is comparable to, if not higher than, the cost of providing new tankage for all RBC units.

8. For most plants, the primary clarifier is the only unit that equalizes flow before the secondary treatment. Such equalization is completely lost in this scheme and would affect RBC performance more than a scheme placing RBCs after the primary clarifiers.

In light of these disadvantages, this scheme should not be used unless absolutely necessary.

RBCs in Secondary Clarifiers

There is no existing plant using this scheme. The disadvantages listed in (1), (3), (4), (6), and (7) of the previous section also apply to this scheme. Consequently, it is not a preferable choice unless land space is severely limited.

RBCs After Primary Clarifiers, in Parallel Operation With Existing Trickling Filters

This scheme can be used as long as sufficient land space and enough hydraulic head (only 6 in. or less head loss for a six-stage RBC system) are available. The advantage of this technique is that a stronger BOD influent will achieve a higher specific removal rate and a superior performance.²¹ The newly installed RBCs will relieve the existing trickling filters. However, the problem of design uncertainty still remains; i.e., how to determine the

²⁰Clinton Bogart Assoc. and Hydrosience Assoc., Inc., Preliminary Report to EPA on Upgrading Primary Tanks with RBCs (November 1978).

²¹R. A. Sullivan, et al., Upgrading Existing Waste Treatment Facilities Utilizing the Bio-Surf Process, paper presented at the First National Symposium on RBC Technology, Pittsburgh, PA (February 1980), Vol 1 -- PB81-124539, Vol 2 -- PB81-124547.

surface media requirement so that both the new RBC units and the relieved trickling filters produce relatively similar effluent quality that meets BOD and nitrification requirements. Filter performance depends on how much relief they receive, and there are no data available to guide the design or to predict the filter effluent BOD and $\text{NH}_3\text{-N}$ concentrations.

RBC After Trickling Filter in Series Operation

This scheme is considered to be the best of the four discussed here. Since data on trickling-filter effluent characteristics are available at each facility, personnel can use the guidelines presented on p 67 to determine their surface media requirements. The difficulties associated with the other schemes do not occur with this technique. This scheme, which produces more predictable effluent quality, is recommended as long as enough land space is available. Another option with this technique is placing RBC in front of the trickling filter in series; here, RBC would be designed for BOD removal, and the trickling filter would remove any remaining BOD and perform nitrification.

Site Preparation

The approach and unloading areas must be leveled and firm to withstand the weight of a fully loaded delivery truck. According to Autotrol Corp., a 25-ft shaft unit has a shipping weight of 23,170 lb. The tractor and trailer for delivery have an overall length of 55 ft, requiring a 46-ft turning radius. The minimum required road bed width is 12 ft, 6 in., and the minimum overhead clearance required is 16 ft. Similar instructions are provided by other manufacturers. Storage area should be provided before the RBC units are installed.

Compliance Schedule

Some facilities demand a tight compliance schedule. George A. Hormel and Company gives the following installation schedule when the tankage is in place and ready for RBC unit installation.

1st shaft	- 1/2 man-day
2nd shaft	- 1/3 man-day
All others	- 1/4 man-day

where one man-day = crane operator, supervisor, and
two workmen.

Contractors with less experience may require a longer installation time. No data are available on the installation time requirements of air-drive RBC units.

Equipment Durability

In the 10-year history of RBC application to wastewater treatment, there have been reports of structural failures at a few facilities, and the industry is trying to rectify such problems. The durability of the equipment, particularly, the polyethylene surface media, is still uncertain because of the short service record (most plants with RBC systems were built during the past 3 years).

All manufacturers offer a warranty against defects in materials and workmanship after delivery or after plant startup. The warranty period and conditions vary, depending on system components and the manufacturer, and are often negotiable. For example, the Plainville plant* in Connecticut was given a warranty period of 30 years for the shafts, 10 years for the surface media, and 5 years for mechanical equipment.

Performance Guarantee

Many RBC manufacturers offer performance guarantees that generally provide a specified effluent with the equipment installed and operating at design conditions. The guarantee usually obligates the manufacturer to provide new equipment or a partial refund if the design effluent standards are not met. This guarantee is predicated on the fact that influent characteristics are within the specified limit. Generally, the manufacturers are willing to negotiate a guarantee as long as they agree with the treatment system design. Appendix A gives the conditions of a typical RBC process performance guarantee.

Media/Shaft Failure

Use of RBC units for purposes other than those intended and designed for is not recommended. The following is a description of an RBC used for an application for which it was not designed.

An existing sewage treatment plant facility chose to upgrade its two existing trickling filters with RBC technology. The RBCs were designed to treat the effluent from the two trickling filters. After the RBCs had been installed and operational for a significant period, a decision was made to "take the trickling filters off-line" for a short time (time enough to replace the old rock media with new rock media). Before the trickling filters were placed on-line again, a controversy arose regarding whether the trickling filter rock media met specifications. Consequently, the trickling filters were not placed on line in a timely fashion and the RBCs were required to treat a wastewater with strength and other characteristics the RBC train

* Equipment manufactured by Clow Corporation.

simply was not designed to handle. This caused the RBCs to be overloaded organically, which resulted in growth of a shaggy, heavy biomass.

Because the RBC plant was not being operated according to its designed purpose, the manufacturer has indicated that certain portions of the warranty may not be valid.

The RBC plant seems to be operating without noticeable structural problems. The facility operators have begun a scheme of periodically reversing the flow of the RBCs into the direction of the wastewater flow. This technique causes large quantities of the heavy, shaggy bacterial growth to slough off, reducing the strain and helping prevent the design load of the media/shaft from being exceeded.

In an incident at another sewage treatment plant, trickling filters were permanently taken out of service in favor of construction of a new secondary/nitrification RBC plant with 36 RBC units. After a few years operation, media began breaking away from the drive shafts in certain units and shaft failures occurred or were suspected in other units. This problem is expected to be very expensive to fix. The media and/or shafts on some of the units will have to be replaced. Supplemental aeration may be added to some of the RBC units.

5 STEPWISE APPROACH IN PROBLEM SOLVING

This chapter explains the steps to be taken when upgrading trickling-filter facilities with RBC. Example calculations show how to estimate surface media requirements, system configuration, land requirements, costs, energy requirements, etc. Since each facility is unique, the calculations are intended only to demonstrate the suggested design approach. The information derived from these calculations can best be used to compare RBC technology with other alternatives.

Characterization of Existing DA Trickling-Filter Plant Wastewater Characteristics

The first step is wastewater characterization -- specifically the quantity and quality of the trickling-filter influent and effluent and the secondary clarifier effluent. Past operational data will provide much of this information. The following data should be collected:

1. Hydraulic flow rates, including daily, weekly, and monthly variations (peak flow and duration, low flow and duration, and average flow, if possible)
2. Ambient air and wastewater temperature
3. Dissolved oxygen
4. pH
5. Alkalinity as CaCO_3 (phenolphthalein and total)
6. Total BOD_5
7. Soluble BOD_5
8. Total suspended solids
9. Volatile suspended solids
10. Presence of toxic chemicals.

Soluble BOD_5 means the BOD_5 of a sample after it has passed through a 0.45-micron filter. Samples taken from trickling-filter effluents and secondary clarifier effluents should also be tested for nitrifying inhibitory chemicals such as allythiourea, if the regulatory agency accepts this practice, so

that the measured BOD₅ truly represents carbonaceous BOD. Partially nitrified effluents exert nitrogenous oxygen demands which would cause soluble BOD₅ values to be too high.

If there is any reason to suspect that the facility might receive some toxic chemical that would interfere with the treatment process, the wastewater should be analyzed for toxic substances. Table 10 lists some toxic chemicals and the concentrations at which they inhibit aerobic processes (including RBC) required for BOD removal and nitrification. Every effort should be made to eliminate these chemicals or to reduce their concentration to below inhibitory levels, either by eliminating the source or by chemical treatment. Adding RBC will be futile if poor effluent quality is being caused by toxic substances. A knowledge of the other data contained in Table 10 is also important to successful RBC design.

Wastewater characterization should reflect the periodic inputs of side stream loadings. Side streams with a high BOD and suspended solids content originating from sludge holding/treatment units may create a transient overloading situation, thus causing a temporary deterioration of effluent quality.

Establish Effluent Quality Standards With the Regulating Agencies

Section 4 of TM 5-814-8²² provides guidance for Army coordination with regulatory agencies to establish wastewater treatment requirements. There are three NPDES permit formats (see Chapter 4), and it is important to clearly define the level of effluent quality required by a specific permit.

Every effort should be made to negotiate for relaxation of the effluent quality during winter operations in cold climate regions. This is particularly important for NH₃-N concentrations, where a higher level can substantially reduce surface media requirements. For example, the State of Connecticut issued an NPDES permit for the Plainville Treatment Plant under which the removal efficiency of NH₃-N can be based on the following influent temperatures:

Influent °C	Temp. °F	NH ₃ -N Removal %	NH ₃ -N Conc. mg/L
>15	59	95	1.1
10-15	50-59	90	2.2
5-10	41-50	75	5.5

²² Evaluation Criteria Guide for Water Pollution Prevention, Control, and Abatement Programs, TM 5-814-8 (Department of the Army, July 1976).

Table 10

Information on Materials Which Inhibit
Biological Treatment Processes

(Information taken from Table 10-3 from TM 5-814-3, AFM 88-11,
Vol. 3, p 10-9, and Table 1 from Preliminary RBC Design
Manual, Clow Corp.)

Pollutant	Inhibiting or Toxic Concentration, ^a mg/L		
	Aerobic Processes	Anaerobic Digestion	Nitrification
Copper	1.0	1.0	0.05-0.5
Zinc	5.0	5.0	0.1-0.5
Chromium (Hexavalent)	2.0	5.0	2.0
Chromium (Trivalent)	2.0	2,000 ^b	*
Total Chromium	5.0	5.0	*
Nickel	1.0	2.0	0.25-0.5
Lead	0.1	*	0.5
Boron	1.0	*	*
Cadmium	*	0.2 ^b	*
Silver	0.03	*	*
Vanadium	10	*	*
Sulfides (S ⁼)	*	100 ^b	500
Sulfates (SO ₄ ⁼)	*	500	*
Ammonia	*	1,500 ^b	*
Sodium (Na ⁺)	*	3,500	*
Potassium (K ⁺)	*	2,500	*
Calcium (Ca ⁺⁺)	*	2,500	*
Magnesium (Mg ⁺⁺)	*	1,000	50
Acrylonitrile	*	5.0 ^b	*
Benzene	*	50	*
Carbon Tetrachloride	*	10 ^b	*
Phenol			5
Chloroform	18.0	0.1 ^b	*
Methylene Chloride	*	1.0	*
Pentachlorophenol	*	0.4	*
2,4 Dinitrophenol			150
1,1,1 Trichloroethane	*	1.0 ^b	*
Trichlorofluoromethane	*	0.7	*
Trichlorotrifluoroethane	*	5.0	*
Cyanide (HCN)	*	1.0	0.3-2.0
Total Oil (Petroleum origin) ^c	50	50	50
Cresol			5

* Insufficient data available to determine effect.

^a Raw wastewater concentration unless otherwise indicated.

^b Digester influent concentration only; lower values may be required for protection of other treatment processes.

^c Petroleum-based oil concentration measured by API Method 733-5R for determining volatile and nonvolatile oily materials. (The inhibitory level does not apply to animal or vegetable oil.)

When the influent temperature drops from 55°F (average) to 45°F (average) no extra surface media is required if the percentage of $\text{NH}_3\text{-N}$ removal can be decreased from 90 to 75 percent (effluent $\text{NH}_3\text{-N}$ concentration increases from 2.2 to 5.5 mg/L). If 2.2 mg/L of $\text{NH}_3\text{-N}$ were to be maintained at a 45°F average influent temperature, the surface media requirement would have to be increased by a factor of 1.75.²³ Lower nitrification rates and more dilution water in receiving rivers during the winter are the legitimate reasons for requesting relaxation of effluent quality standards. For the same reasons, negotiation for higher suspended solids and BOD concentrations in winter effluents is also possible.

Determination of RBC Surface Media Requirement and System Configuration

The scheme of placing RBC units after a trickling filter in series operation is considered to be best, because it requires the least physical modification to the facility and provides the most efficient and economical upgrading of effluent. The following type of data can be obtained from existing plant records and by recent samplings and analyses:

Inflow = 1.0 mgd design average, 2.0 mgd peak rate

Trickling Filter Effluent = 40 mg/L soluble BOD₅

18 mg/L $\text{NH}_3\text{-N}$

48-60°F temperature

pH 7.0

200 mg/L total alkalinity as CaCO_3

5.0 mg/L dissolved oxygen

Effluent Requirements:

Winter - Suspended Solids and BOD₅ = 15 mg/L (7.5 mg/L soluble BOD)

$\text{NH}_3\text{-N}$ = 4 mg/L

Summer - Suspended Solids and BOD₅ = 10 mg/L (5 mg/L soluble BOD)

$\text{NH}_3\text{-N}$ = 2 mg/L

Either design curves or design loading factors can be used to determine the media requirement and surface configuration, following the general procedure of design suggested by the manufacturers.

²³Autotrol Wastewater Treatment Systems Design Manual (Autotrol Corp., 1979); Preliminary Design Manual (Clow Corporation, 1980).

The of Design Curves

1. Winter Condition.

To reduce soluble BOD₅ from 40 mg/L to 15 mg/L (to allow nitrification in latter stages, see Chapter 4), the hydraulic loading (HL-BOD) = 6 gpd/sq ft (from Figure B1).

The temperature correction factor for winter conditions averages 48°F = 0.825 (from Figure B3).

$$\begin{aligned}\text{Temperature corrected HL-BOD} &= 6 \times 0.825 \\ &= 4.95 \text{ gpd/sq ft}\end{aligned}$$

For nitrification, the influent NH₃-N concentration is less than 30 mg/L. Therefore, the maximum removal rate of 0.3 lb/1000 sq ft-day is not achieved. To remove the NH₃-N concentration from 18 mg/L to 4 mg/L, the hydraulic loading (HL-NH₃) = 2.55 gpd/sq ft (from Figure B4). The temperature correction factor (to 48°F) = 0.7 (from Figure B5).

$$\text{Temperature corrected HL-NH}_3 = 2.55 \times 0.7 = 1.79 \text{ gpd/sq ft}$$

Overall hydraulic loading (OAHL) is:

$$\frac{1}{\text{OAHL}} = \frac{1}{\text{HL-BOD}} + \frac{1}{\text{HL-NH}_3} = \frac{1}{4.95} + \frac{1}{1.79} = 0.76$$

$$\text{OAHL} = \underline{1.32 \text{ gpd/sq ft}}$$

Hydraulic loading to reduce soluble BOD₅ from 40 mg/L to 7.5 mg/L and with temperature correction = 3.8 gpd/sq ft x 0.825; (Figures B1, B3) = 3.14 gpd/sq ft). Therefore, NH₃-N removal controls the design.

2. Summer Condition.

To reduce soluble BOD₅ from 40 mg/L to 15 mg/L (to allow nitrification in latter stages), the hydraulic loading HL-BOD remains at 6 gpd/sq ft (from Figure B1).

There is no temperature correction for HL-BOD during the summer.

For nitrification, to reduce NH₃-N concentration from 18 mg/L to 2 mg/L, the hydraulic loading HL-NH₃ = 2.2 gpd/sq ft (from Figure B4).

The temperature correction factor (to 60°F) = 1.21 (from Figure B5).

$$\text{Temperature corrected HL-NH}_3 = 2.2 \times 1.21 = 2.66 \text{ gpd/sq ft.}$$

Overall hydraulic loading (OAHL) is:

$$\frac{1}{\text{OAH}} = \frac{1}{\text{HL-BOD}} + \frac{1}{\text{HL-NH}_3} = \frac{1}{6.0} + \frac{1}{2.66} = 0.54$$

$$\text{OAH} = 1.84 \text{ gpd/sq ft}$$

Hydraulic loading to reduce soluble BOD₅ from 40 mg/L to 5 mg/L with no temperature correction = 3 gpd/sq ft (Figure B1).

Again, NH₃-N removal controls the design.

3. Surface media requirement = $\frac{1,000,000 \text{ gpd}}{1.32 \text{ gpd/sq ft}} = 758,000 \text{ sq ft}$. Because the peak-to-average flow ratio is 2.0 (less than 2.5), no increase of surface media is necessary (see Chapter 4). Normally, an RBC system design calls for a larger first stage to minimize organic overloading and oxygen limitation conditions. Even though it is highly unlikely that these adverse conditions would occur in RBC units following trickling filters, it is still a good practice to base the size of the first stage on the overall soluble BOD₅ loading as in the following:

The overall soluble BOD₅ loading =

$$\frac{40 \text{ mg/L} \times 8.34 \frac{\text{lb}}{\text{mg/L million gal}} \times 1 \text{ mgd}}{758,000 \text{ sq ft}} = 0.44 \text{ lb/1000 sq ft-day}$$

This is a very low organic loading, and from Figure B2:

Size of first stage = 12 percent and is sufficient

Permitted amount of high-density media = 80 percent

When first-stage media = $0.12 \times 758,000 = 90,960 \text{ sq ft}$,
use one standard media assembly (25-ft shaft), 100,000 sq ft

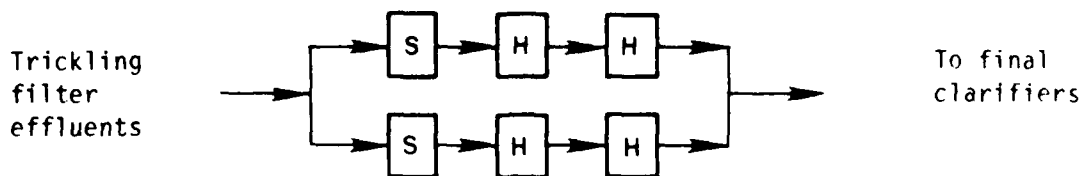
When permitted amount of high-density media = $0.8 \times 758,000 = 606,400 \text{ sq ft}$,
use four assemblies (25-ft shaft), 150,000 sq ft each
or 600,000 sq ft total.

Remaining standard media assembly (25-ft shaft) = 100,000 sq ft

Total surface media = 100,000 sq ft + 600,000 sq ft + 100,000 sq ft
= 800,000 sq ft > 758,000 sq ft.

Therefore, the surface media requirement is adequate.

4. Choice of configuration is 2 (S+H+H), or two parallel flows; each uses one standard media (S) assembly as the first stage, followed by two high-density media (H) assemblies.



Use of Design Loading Factors

1. Determination of soluble BOD₅ and NH₃-N loadings:

$$\begin{aligned}\text{Soluble BOD}_5 \text{ loading} &= 1 \text{ mgd} \times 40 \text{ mg/L} \times 8.34 \frac{\text{lb}}{\text{mg/L-million gallon}} \\ &= 333.6 \text{ lb/day}\end{aligned}$$

$$\begin{aligned}\text{NH}_3\text{-N loading} &= 1 \text{ mgd} \times 18 \text{ mg/L} \times 8.34 \frac{\text{lb}}{\text{mg/L-million gallon}} \\ &= 150.12 \text{ lb/day}\end{aligned}$$

2. Determination of loading factors (from Clow Corp. Preliminary Design Manual):

Soluble BOD₅ loading factor - 2.0 lb/1000 sq ft-day (effluent
SBOD₅ = 15 mg/L)

- 1.25 lb/1000 sq ft-day (SBOD₅ = 7.5 mg/L)

- 1.0 lb/1000 sq ft-day (SBOD₅ = 5.0 mg/L)

Temperature correction factor for SBOD₅ for 48°F = 1.22

Standard soluble BOD₅ loading rate for standard media = 2.5 lb/1000 sq ft-day

NH₃-N loading factor - 0.35 to 0.45 lb/1000 sq ft-day
(effluent NH₃-N = 4 mg/L)

- 0.30 to 0.32 lb/1000 sq ft-day
(effluent NH₃-N = 2 mg/L)

Temperature correction factor for NH₃-N for 48°F = 1.47

3. Calculation of winter and summer surface media requirements:

Winter

To reduce soluble BOD₅ from 40 mg/L to 15 mg/L (to allow nitrification in latter stages), the surface media requirement

$$= \frac{333.6 \text{ lb/day}}{2 \text{ lb/1000 sq ft-day}}$$

To correct for temperature, the calculation is

$$\frac{333.6 \text{ lb/day}}{2 \text{ lb/1000 sq ft-day}} \times 1.22$$
$$= 203,500 \text{ sq ft}$$

Nitrification to reduce NH₃-N to 4 mg/L =

$$\frac{150.12 \text{ lb/day} \times 1.47}{\frac{(0.35 + 0.45)}{2} \text{ lb/1000 sq ft-day}}$$

(with temperature correction [1.47 in the equation]) = 551,700 sq ft

Overall requirement = 755,200 sq ft

To reduce soluble BOD₅ from 40 mg/L to 7.5 mg/L, the surface media requirement

$$= \frac{333.6 \text{ lb/day}}{1.25 \text{ lb/1000 sq ft-day}} \times 1.22$$

(with temperature correction [1.22 in the equation]) = 325,600 sq ft

Therefore, NH₃-N removal controls the design.

Summer

To reduce soluble BOD₅ from 40 mg/L to 15 mg/L (to allow nitrification in latter stages), the surface media requirement

$$= \frac{333.6 \text{ lb/day}}{2 \text{ lb/1000 sq ft-day}}$$

(No temperature correction because summer temperature is greater than 55°F.)

Nitrification to reduce NH₃-N

$$= \frac{150.12 \text{ lb/day}}{\frac{(0.3 + 0.32)}{2} \text{ lb/1000 sq ft-day}}$$

to 2 mg/L. (Clow's approach does not allow temperature adjustment above 55°F.)

$$= 484,300 \text{ sq ft}$$

Overall requirement

$$= \underline{651,100 \text{ sq ft}}$$

To reduce soluble BOD₅ from 40 mg/L to 5.0 mg/L, the surface media requirement (no temperature correction)

$$= \frac{333.6 \text{ lb/day}}{1.0 \text{ lb/1000 sq ft-day}} = 333,600 \text{ sq ft}$$

Again, NH₃-N removal controls the design.

4. Comparing the summer and winter conditions, it can be seen that the winter condition and NH₃-N removal control the overall design. The overall surface media requirement = 755,200 sq ft. The answer is practically identical to that obtained previously by using design curves (758,000 sq ft).

5. Choice of configuration. The same configuration used previously can be applied, since the total surface media requirements are identical, and both Autotrol Corp. and Clow Corp. offer the same size assemblies (100,000 sq ft media for a 25-ft shaft standard media, and 150,000 sq ft for high-density media).

Air-Driven RBC

1. Surface media requirement and configuration are identical to those given for mechanically driven RBC design (see Chapter 4 and Autotrol Design Manual, 1979). Normally, more high-density media are allowed in air-driven RBC units. This choice is also preferable for RBC units used to upgrade trickling-filter effluents.

2. Blower selection:

<u>Stages</u>	<u>RPM</u>	<u>No. Units</u>	<u>ACFM*</u>
1	1.4	2	2 x 190 = 380
2	0.8	2	2 x 75 = 150
3	0.8	2	2 x 75 = 150
			<u>680</u>

*See Figure 13 for air requirements.

$$\text{Power consumption} = \frac{680 \text{ ACFM}}{44 \text{ ACFM/hp}} = 15.45 \text{ hp (11.51 kW)}$$

$$\text{Operating blower capacity} = 680 \times 1.33 = 904 \text{ ACFM}$$

$$\text{Installed blower capacity} = 250 \times 6 = 1500 \text{ ACFM}$$

It is recommended that a small installation of less than 2000 ACFM operating capacity use two blowers, each supplying 133 percent operating capacity. Each should be sized for 904 ACFM at the required pressure.

In this design example, pH, dissolved oxygen, and alkalinity do not pose any problems. If dissolved oxygen of the RBC influent is close to 0 mg/l, the overall surface media requirement must be increased by 50 percent, according to the Clow Corp. Preliminary Design Manual.

Cost Estimation

Once the size of the RBC system has been determined, it is possible to estimate its installed cost. Figure B6, taken from Autotrol's Design Manual, provides a guide for estimating installed cost. The installed costs include the following:

1. RBC unit assemblies
2. Fiberglass enclosures
3. Concrete tankage at \$250 per cu yd
4. Freight cost of RBC unit assemblies and enclosures (average freight cost within the contiguous United States)
5. Installation costs of \$1500 per shaft (cranes, millwrights, electricians).

The total installed costs are expressed per unit of wastewater flow treated and are shown in Figure B6 as a function of hydraulic loading. The example calculation in the previous section indicates that the hydraulic load (HL) is:

$$HL = \frac{1,000,000 \text{ gpd}}{800,000 \text{ sq ft}} = 1.25 \text{ gpd/sq ft}$$

From Figure B6, the installed costs will be \$0.3/gpd capacity or \$300,000 for 1.0 mgd. Information from Autotrol Corp. (August 1978) indicates a cost of \$0.41/sq ft and \$0.31 sq ft for high-density media assembly and standard media assembly, respectively, or \$308,000 for the 1 mgd flow. The expenses for any added pretreatment modification to existing clarifiers or modification to existing sludge treatment units are not included. The cost estimation is useful for alternatives comparison only. The Edgewater Treatment Plant study²⁴ showed that modifying existing clarifiers for RBC installations can be very costly.

Since both the mechanical-drive and the air-drive systems use the same amount of standard high-density media in an upgrading application, the estimated cost applies to both systems; Autotrol Corp. suggests that the cost

²⁴Clinton Bogart Assoc. and Hydrosience Assoc., Inc., Preliminary Report to EPA on Upgrading Primary Tanks with RBCs (November 1978).

of the blower and air distribution piping system, air headers, and air cups will offset the cost of the mechanical-drive package, motor starter/control system, and electrical wiring.

The estimated cost of \$308,000 for 1 mgd flow can be scaled for larger installations, since RBC systems do not exhibit economies of scale due to their modular design. Therefore, a cost of \$1,540,000 is projected for a 5 mgd flow retrofit system and \$3,080,000 for a 10 mgd flow retrofit system. For comparison, one can also estimate the cost required to replace all existing trickling filters with RBC assemblies, new trickling filters, or activated sludge aeration tanks. Each alternative unit process must remove the BOD from the existing primary clarifier effluents and also provide nitrification. Therefore, the new facility is designed as a secondary treatment unit plus nitrification, but retains the services of both the primary and secondary clarifiers.

More RBC surface media are required for BOD removal. Assuming a soluble BOD concentration of 70 mg/L in the primary effluents, the additional surface media must reduce the soluble BOD from 70 mg/L to 40 mg/L in the example calculation. Following the previous procedure, the additional surface media required is slightly more than 200,000 sq ft, or 2 shafts or 25-ft standard media. The revised hydraulic load is:

$$\frac{1,000,000 \text{ gpd}}{(800,000 \text{ sq ft} + 200,000 \text{ sq ft})} = 1.0 \text{ gpd/sq ft}$$

The installed costs taken from Figure B6 are therefore \$0.37/gpd capacity or \$370,000 for the 1 mgd flow. The cost will probably be \$400,000 when modification of pipings, open channels, and valves, etc., is included; however, this figure does not include demolition cost (taking the existing trickling filters off line without destroying them). For 5 mgd and 10 mgd plants, the respective costs are \$2,000,000 and \$4,000,000.

Several sources provide total construction costs for treatment plants; however, data on construction costs for various unit processes are scarce. A one-step process is assumed for an activated sludge process to accomplish BOD removal and nitrification (activated sludge and nitrification aeration followed by final clarification). The existing secondary clarifiers can be used immediately following the aeration tanks. Data from an EPA report²⁵ estimate construction costs to be \$450,000/1 mgd, \$1,800,000/5 mgd, and \$3,400,000/10 mgd. Assume that the aeration tank size must be doubled to achieve one-step BOD removal and nitrification and retain the use of existing final clarifiers. (The following section provides a cost estimate for multiple-media filtration after nitrification.)

²⁵Construction Costs for Municipal Wastewater Treatment Plants 1973-1977, EPA 430/9-77-013, MCD-37 (USEPA, January 1978).

For trickling filters, assume that two-stage filters will obtain the desired BOD removal and nitrification, with no intermediate clarification provided. The construction costs are estimated to be \$560,000/1 mgd, \$1,140,000/5 mgd, and \$1,600,000/10 mgd. Table 11 summarizes the costs for comparison.

Clarification Requirement

Since a need for nitrification is assumed in upgrading trickling-filter plants, the capability of the existing final clarifiers must be examined more closely. Table 8 indicates that efficient removal of suspended solids in nitrified effluents requires more than plain settlement. The overflow rate of the clarifier must be 500 gpd/sq ft or even less for chemically flocculated effluents. Most, if not all, clarifiers of existing plants were designed for overflow rates of 800 gpd/sq ft without the benefit of chemical flocculation. Consequently, these clarifiers are not adequate for nitrified effluents if the effluent suspended solids concentration is expected to be between 10 to 15 mg/L.

Instead of expanding the existing clarifier capacity, it is advisable to build multiple-media filters to provide more reliable removal of suspended

Table 11

Cost Comparisons of Various Upgrading Retrofit Systems
(cost excludes multiple-media filtration)

(1978 dollar value)

<u>Upgrading System</u>	<u>1 mgd</u>	<u>5 mgd</u>	<u>10 mgd</u>
RBC following existing trickling filter	$\$3.1 \times 10^5$	1.5×10^6	3.1×10^6
Replace existing trickling filters with RBC	$\$4 \times 10^5$	2.0×10^6	4.0×10^6
Replace existing trickling filters with one-step activated sludge-nitrification	$\$4.5 \times 10^5$	1.3×10^6	3.4×10^6
Replace existing trickling filters with new two-stage trickling filters	$\$5.6 \times 10^5$	1.14×10^6	1.6×10^6

solids. A filtering rate of 3.0 gpm/sq ft is adequate. For example, the 1.0 mgd flow requires a filter area of $1 \times 10^6 / 3 \times 24 \times 60 = 231.5$ sq ft, or two filters of 11 x 11 ft each. The construction cost of the filters, including controls, is estimated to be \$180,000 (1977 dollar value).²⁶ For 5 and 10 mgd flows, the respective costs are \$700,000 and \$1,250,000.

Land and Energy Requirements Estimation

For the number and configuration of RBC units used to upgrade trickling-filter effluents as given in the calculations section, an area of 47 x 64 ft, or 3000 sq ft is required, including walkways. Another 200 sq ft would be required for the blower house if air-driven units were used. Multiple-media filters with controls and chemical clarification equipment add another 800 sq ft to the area requirement.

RBC units receive lower BOD concentration wastewaters, and most of the surface media are used for nitrification. Therefore, the biofilm over the media is expected to be thin. Based on the experience of the Plainville Treatment Plant in Connecticut, a motor-driven unit (460-volt) draws about 6.2 amperes with thin biofilm (150,000 sq ft high-density media, or 100,000 sq ft standard media with more growth). Using this information, the power consumption for the 1.0 mgd flow RBC retrofit units would be:

$$6 \text{ units} \times \frac{460 \times 6.2}{1000} \text{ kW} \times 24 \text{ hr} \times 365 = 1.5 \times 10^5 \text{ kWh/yr.}$$

The highest current drawn by the motor-drive unit is 9.5 amperes. The maximum power consumption is therefore 2.3×10^5 kWh/yr. One can use this range from 1.5 to 2.3×10^5 kWh/yr to estimate the power consumption for a 1.0 mgd RBC retrofit system. However, this estimate does not include the energy required to operate the multiple-media filters and chemical clarification, which require an additional power consumption of about 14,000 kWh/yr.²⁷ Autotrol Corp. claims that their air-drive RBC units use less power under low loading conditions; however, confirmation with field data is not yet available.

Negotiation of Performance Guarantee

When the RBC system design is completed and the effluent quality standards are set, the customer may request a performance guarantee. The terms of such guarantees are different, depending on the manufacturer and on the specific case. The RBC manufacturer will review the design with the potential customer (surface area requirements and general design). If they are in

²⁶Construction Costs for Municipal Wastewater Treatment Plants 1973-1977, EPA 430/9-77-013, MCD-37 (USEPA, January 1978).

²⁷Energy Conservation in Municipal Wastewater Treatment, EPA 430/9-77-011 (USEPA, March 1978).

agreement, a guarantee can be negotiated to provide a specified effluent with the equipment installed and operating at design conditions.

It is extremely important to determine a plant's wastewater characteristics (see Chapter 5) before negotiation, because even if the installed system fails to meet the performance requirements, it is not considered a breach of the performance guarantee if the wastewater characteristics are not within the limits set forth in the design conditions. DA personnel should contact various RBC manufacturers for information concerning the performance guarantee negotiation procedure and the terms of guarantees that are now in effect. Appendix A gives the general terms of a performance guarantee from an RBC manufacturer.

Some manufacturers also provide an energy use guarantee. If the average kilowatt power consumption per RBC assembly, as obtained from power tests after installation, exceeds the guarantee figure, the RBC manufacturer will give the owner a rebate equivalent to the present-worth value of the energy difference between the guaranteed and actual values. However, the manufacturer may require that the power tests be conducted under conditions quite different from actual operating conditions (e.g., with an RBC assembly free of biomass, rotating at a peripheral velocity of 1.0 ft/sec in water with a temperature of 20°C, as opposed to an RBC with biomass, rotating at a different speed in wastewater and at a different temperature). Under such conditions, the power consumption would be lower than under actual operating conditions.

Equipment Warranty

An RBC assembly has three main parts, and each is likely to be covered by a different warranty period. Shaft failure has been reported in a few RBC facilities. All manufacturers submit independently conducted test data of their shafts' structural integrity before giving bids. These tests are all accelerated, full-scale endurance tests which demonstrate the durability of the shaft and its supporting structure. Simulated loads and testing conditions representing load cycles of 20 years or more have been reported by many manufacturers. Thus, a warranty for the shaft and its supporting structure would cover 20 or more years, depending on the bid documents. Twenty- to thirty-year warranties are not uncommon.

RBC manufacturers are less certain about the durability of their surface media. The industry is only about 10 years old, and the majority of RBC facilities in the United States were built only 3 to 4 years ago. Although the structural integrity of the surface media have been tested and proven durable, the test conditions do not simulate chemical attack by wastewaters and light degradation over the long period of actual operation. Therefore, few manufacturers would provide a warranty period longer than 10 years for surface media.

The normal warranty period for the mechanical-drive unit ranges from 1 to 5 years.

Installation, Startup, and Acceptance of the System

A service engineer from the RBC manufacturer should be present during installation check and startup. RBC units need a few days to 3 weeks to reach the designed treatment performance for BOD removal, and 3 weeks to a few months to obtain full nitrification, depending on the wastewater temperature and pH.

Once the system is operational, but before wastewater is introduced, the power consumption test can be conducted (in water and with no biomass if this test condition is specified in the contract agreement). After the system has been operational for some time, and both heterotrophic bacteria and nitrifiers have become well-established, performance guarantee tests can be carried out for the length of time and under the testing conditions specified in the contract. System modifications may be carried out at the manufacturer's expense until the test results demonstrate that the specified performance has been obtained. The owner should accept the system only after it is known that the effluent qualities specified at the design condition can be obtained.

6 POSSIBLE MODIFICATION OF RBC RETROFIT SYSTEM

Phosphorus Removal

This report has addressed the capability of designing RBCs for upgrading trickling-filter effluents. Only BOD removal and nitrification have been considered. As shown in Table 1, 27 NPDES permits issued for Army wastewater discharges require better than secondary treatment. Of these, phosphorus removal is required at 11 installations.

Phosphorus can be removed biologically in trickling filters, activated sludge plants, and RBC systems. Phosphorus is incorporated into bacterial cells during synthesis. Consequently, when the biomass in the biological treatment system is wasted periodically, phosphorus is removed from the system. Thus, overall phosphorus removal depends on the rate of uptake and biomass wastage. The phosphorus uptake rate, in turn, depends on the phosphorus capacity of the cells, the rate of cell growth, and the phosphorus concentration in the wastewater. Trickling filters and activated sludge plants generally are not expected to remove more than 35 to 40 percent of phosphorus from the influent wastewater. Even less phosphorus removal can be expected of the RBC system. Noss²⁹ has reported 24 percent phosphorus removal, while Poon²⁹ has reported 17 percent removal. RBC systems produce less biomass (lower yield coefficient) because of longer sludge age (particularly for RBC application to upgrading trickling-filter effluents), and consequently, remove less phosphorus.

Chemical Removal of Phosphorus

Chemical removal of phosphorus is much more effective than biological methods. Aluminum salts and iron salts are particularly effective, with the dosages depending on phosphorus concentration and alkalinity. Lime treatment can also be used to precipitate the phosphorus. For simplicity of operation and control, lime treatment is preferred, because the lime feed system requires only pH monitoring, whereas aluminum or iron salts feed requires both pH and dosage monitoring. Daily jar tests are required to determine the dosage requirements for aluminum salt and iron salt over or below which a proper precipitation of phosphorus will not occur.

²⁹RBC. I. Noss, et al., Recarbonation of Wastewater Using the RBC, paper presented at the First National Symposium on RBC Technology, Pittsburgh, PA (February 1980), Vol 1 -- PB81-124539, Vol 2 -- PB81-124547.

²⁹E. D. Smith, C. P. C. Poon, W. Mikucki, and J. T. Bandy, Tertiary Treatment of Wastewater Using an RBC System, Technical Report N-85/ADA082502 (U.S. Army Construction Engineering Research Laboratory, February 1980).

Low-level lime dosing to achieve a pH of 9.5 to 10 can reduce phosphorus levels to 2.0 mg/L or lower in the primary clarifier. The primary effluent can enter activated sludge aeration tanks³⁰ or trickling filters³¹ without affecting the biological processes. Activated sludge aeration tanks and trickling filters generate CO₂ through microbial activity, which reduces the elevated pH to a level (below 8.5) acceptable for biological treatment (biological recarbonation). The residue phosphorus in the primary effluent is sufficient to support the biological activity and is subjected to further removal by cell synthesis. The Noss study demonstrates that an RBC system can also carry out biological recarbonation.

Low-Lime and RBC Recarbonation System

In Noss' study using a pilot-scale RBC system, the low-lime treatment technique not only significantly removed phosphorus, but also decreased the organic loading (soluble BOD removal by lime treatment was more than 90 percent). This lower organic loading reduced the RBC surface media requirement for BOD removal, leaving more media available for nitrification. The primary effluent produced an excellent environment for nitrification (low BOD, adequate alkalinity, pH between 7.0 and 8.0). As a result, more than 80 percent NH₃-N removal was obtained with the hydraulic loading between 2 to 3 gpd/sq ft (with soluble BOD concentration of RBC influent at about 35 mg/L). At or above 4 gpd/sq ft loading, recarbonation was not successful in suppressing pH, leading to poor NH₃-N removal; however, BOD removal was not affected.

The results of the low-lime and RBC recarbonation system need confirmation from a full-scale operation. However, the potential of such a simple technique is very promising for upgrading DA STPs.

³⁰ L. A. Schmid, et al., "Phosphate Removal by a Lime-Biological Treatment Scheme," J. WPCF, (1969) p 1259.

³¹ R. D. Miller, et al., Phosphorus Removal in a Pilot Scale Trickling Filter System by Low-Level Lime Addition to Raw Wastewater, Technical Report 7901 (U.S. Army Medical Engineering Research and Development Laboratory, 1979).

7 EVALUATION OF RBC STUDIES WITH SPECIFIC APPLICATION TO UPGRADING TRICKLING-FILTER TREATMENT

Reported Studies

There have been very few independent studies of RBC applications to upgrading trickling-filter treatment plants. The few such studies that have had results released are reviewed here, particularly in reference to system capability for BOD removal and nitrification under varying climate and loading conditions. Design criteria developed from these results will be compared with those obtained from RBC manufacturers. Suggestions will then be made about whether the manufacturers' design criteria should be changed.

The four independent studies reviewed were:

1. J. F. Lagnese of Duncan, Lagnese & Associates, Inc., Pilot RBC Study for the North Huntingdon Treatment Plant in Pennsylvania.³²
2. H. M. Wexler of the Minges Associates, Inc., Pilot RBC Study for the Plainville Treatment Plant in Connecticut.³³
3. R. D. Miller, C. I. Noss, A. Ostrofsky, and R. S. Ryczak, Pilot RBC Study for DA Fort Detrick Treatment Facility in Frederick, Maryland.³⁴
4. E. D. Smith, C. P. C. Poon, W. Mikucki, and J. T. Bandy, Pilot RBC Study in Rhode Island for DA.³⁵

In the following discussion, the studies are designated as the N. Huntington study, the Plainville study, the US AMBRDL study, and the CERL study, respectively. The N. Huntington study tested the RBC system both in series and in parallel with the existing trickling filters, while all other studies tested the operation in series with trickling filters only. Both the US AMBRDL and CERL studies placed the RBC system downstream from the trickling-filter clarifiers.

³²J. F. Lagnese, Evaluation of RBCs Used to Upgrade Municipal Plants to Secondary Standards, paper presented at the Technical Conference, WPC Association of Pennsylvania, Pittsburgh, PA (April 1978).

³³H. M. Wexler, RBC Pilot Plant Test for the Town of Plainville, Report to Town of Plainville, CT (December 1978).

³⁴R. D. Miller, C. I. Noss, A. Ostrofsky, and R. S. Ryczak, RBC Process for Secondary Treatment and Nitrification Following a Trickling Filter, Technical Report 7905 (US AMBRDL, June 1979).

³⁵E. D. Smith, C. P. C. Poon, W. Mikucki, and J. T. Bandy, Tertiary Treatment of Wastewater Using an RBC System, Technical Report N-85/ADA082502 (U.S. Army Construction Engineering Research Laboratory, February 1980).

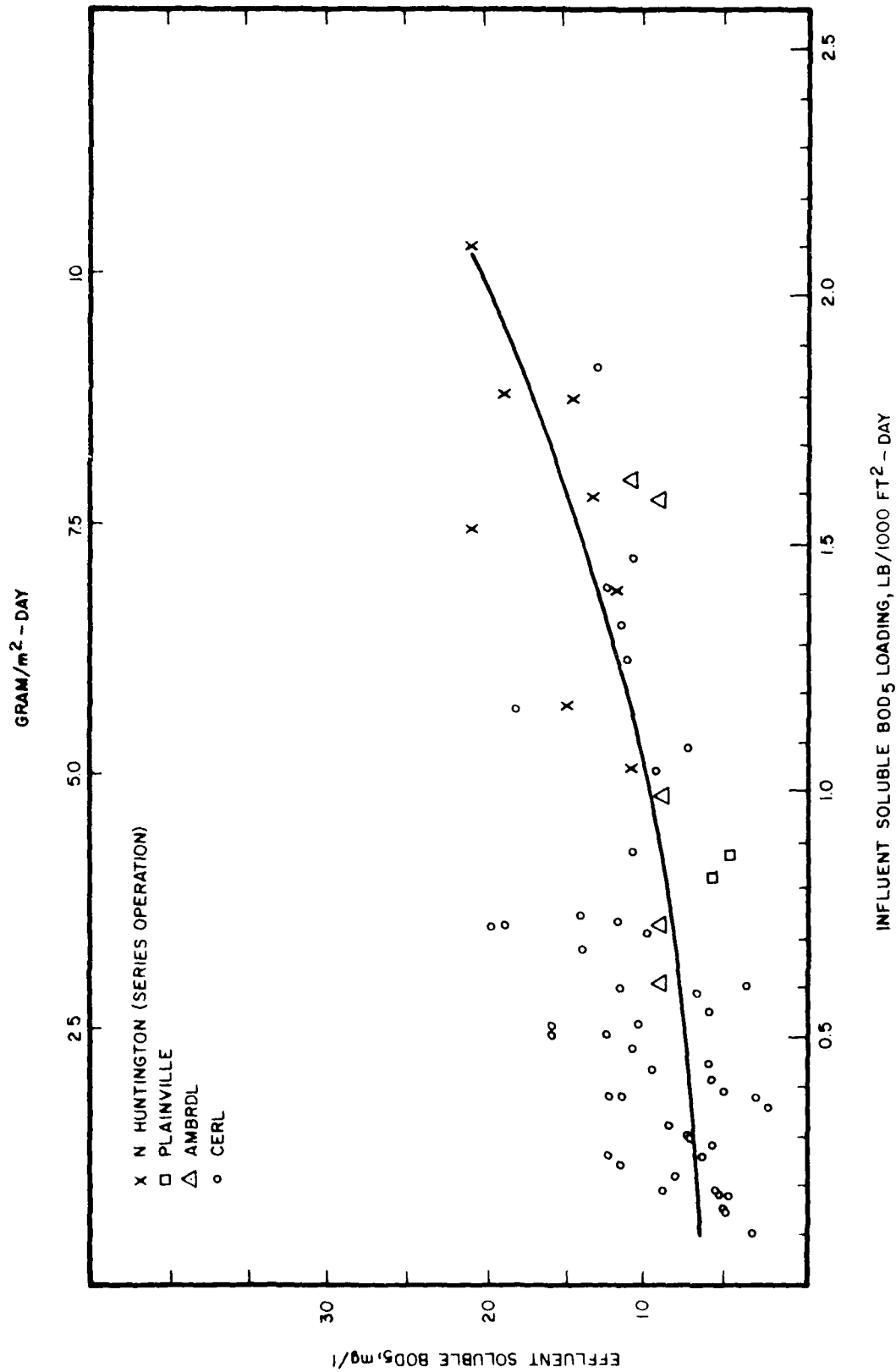
RBC Performance in BOD Removal

The influent soluble BOD loading can be calculated for all studies from the RBC influent soluble BOD concentration and hydraulic loading data. By plotting the influent soluble BOD loadings against the effluent BOD concentrations (Figure 15), RBC performance is revealed under varying loading conditions. The plot clearly shows that effluent soluble BOD increases as loading increases. On the average, an effluent of 10 mg/L soluble BOD₅ can be obtained if the influent soluble BOD₅ loading is kept at or below 1.0 lb/1000 sq ft-day. Doubling the loading will also double the effluent soluble BOD concentration.

BOD removal data from the design manuals of many RBC manufacturers were calculated and plotted for comparison (Figure 16). The RBC manufacturers' data appear to show consistently better performance than the four reported studies (soluble BOD₅ is about 5 mg/L lower). The manufacturers' design curves or design loadings for BOD removal supposedly apply to both secondary treatment and beyond. In using these curves or loadings, no distinction is made between use of the RBC for secondary treatment or for upgrading trickling filter effluents. This practice is questionable for two reasons. First, in the upgrading of trickling-filter effluents, the feed to the RBC system in series contains a greater portion of the more biologically resistant BOD₅ substrates (the less resistant ones have been removed by the trickling filters), which leads to a slower rate of bio-oxidation and BOD removal. Second, secondary treatment using RBC exhibits a higher BOD removal rate because there is a higher influent BOD concentration (primary effluent instead of trickling filter effluent).

The RBC system described in the N. Huntington study was at one time operated in parallel with the existing trickling filters. Therefore, since the RBC system received a higher BOD influent with less resistant substrate (primary effluent which had not yet received biological treatment), a higher percentage of BOD removal was obtained. The data plotted in Figure 16 indicate that the performance was indeed comparable to or even slightly better than the manufacturers' predicted performance. Consequently, the findings of these four studies show that the manufacturers' design curves and design loadings may not be directly applicable to RBC upgrading of trickling-filter effluents.

Another complication of RBC application to upgrading is that the degree of nitrification varies in the RBC effluent. Obviously, much stronger nitrification occurs in effluents from RBC used to upgrade trickling filters than from RBC used for secondary treatment. Therefore, much of the effluent BOD is made up of nitrogenous oxygen demand (NOD). Both the CERL and N. Huntington studies showed significant amounts of NOD in some of their RBC effluent to the extent that the BOD values were too high. Therefore, it is difficult to compare the BOD removal between RBC systems of different applications unless the



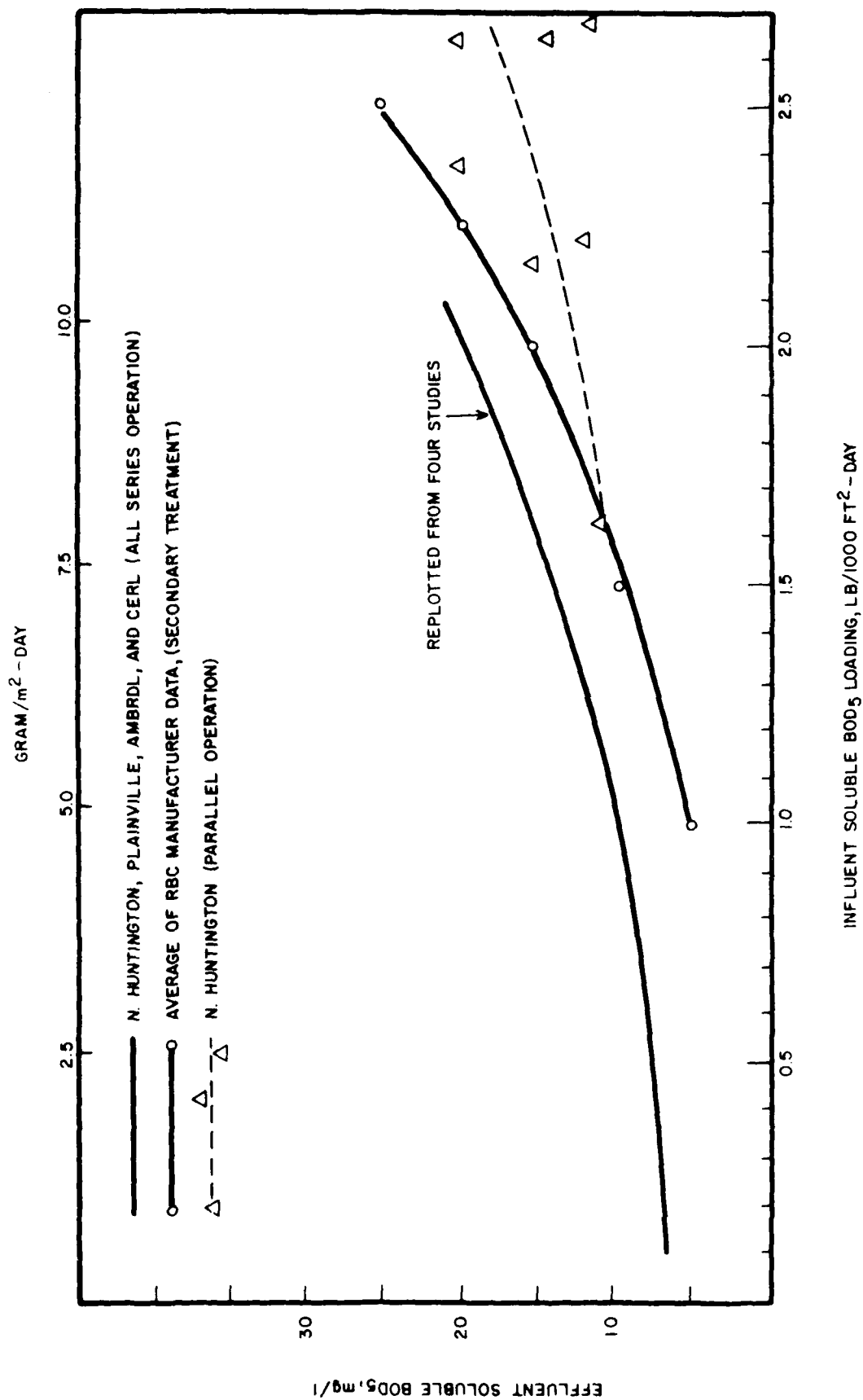


Figure 16. Effluent SBOD₅ concentration vs. influent SBOD₅ loading comparison of RBC performance (RBC as secondary treatment unit, RBC in series with trickling filter, and RBC parallel with trickling filter).

degree of nitrification is identical in all cases, or unless nitrification can be eliminated in the BOD bottles during the incubation period.

Considering the complication of nitrification on effluent BOD, and the fact that the manufacturers' data are not overly optimistic (compared to N. Huntington data in parallel operation), it is suggested that the manufacturers' design curves or design loadings be used without adjustment for BOD removal and for temperature corrections in the system design.

RBC Performance in Nitrification

The procedure described in the previous section on BOD removal was used to plot nitrification data from several RBC systems (see Figure 17). However, nitrification data from the N. Huntington study was available. The curve in Figure 17 represents the average condition. From the scattering of points, it can be seen that nitrification performance was not as steady as BOD removal, most likely because of fluctuations in influent BOD. Although a properly designed RBC system can treat fluctuating BOD successfully, the higher BOD loading is pushed further downstage for removal, which reduces nitrification at these locations (see the section in Chapter 4 on nitrification design).

Manufacturers' average data on nitrification were plotted in Figure 18 for comparison with data from the independent studies as presented in Figure 15. The manufacturers' predicted performance is better than the performance noted in the private studies, following the same pattern as BOD removal. Therefore, since RBC manufacturers are willing to negotiate a performance guarantee, their design curves or design loadings should be used.

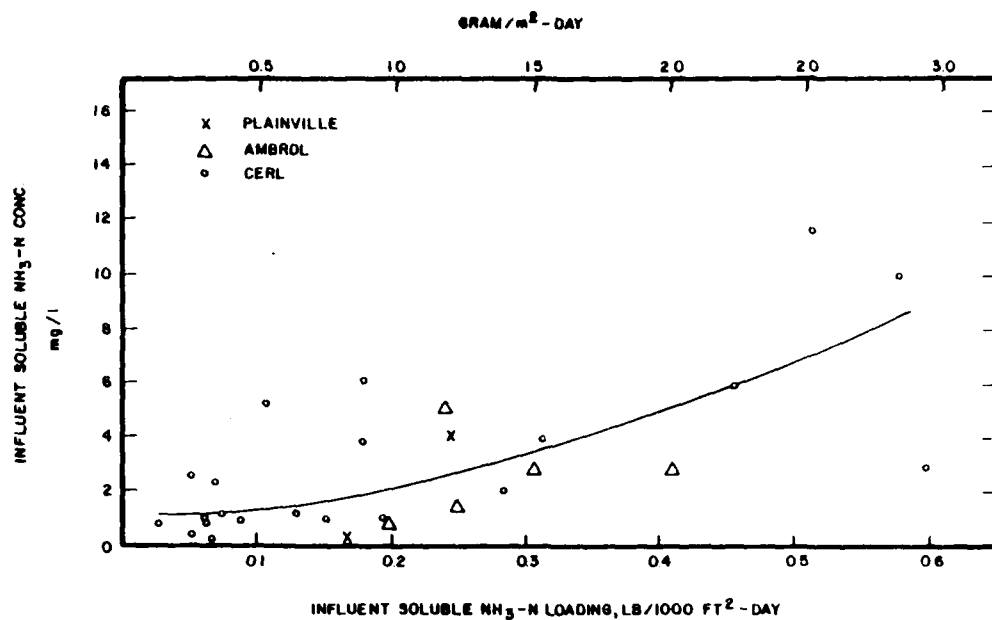


Figure 17. Effluent soluble NH₃-N concentration vs. influent soluble NH₃-N loading (RBC upgrading trickling-filter effluents).

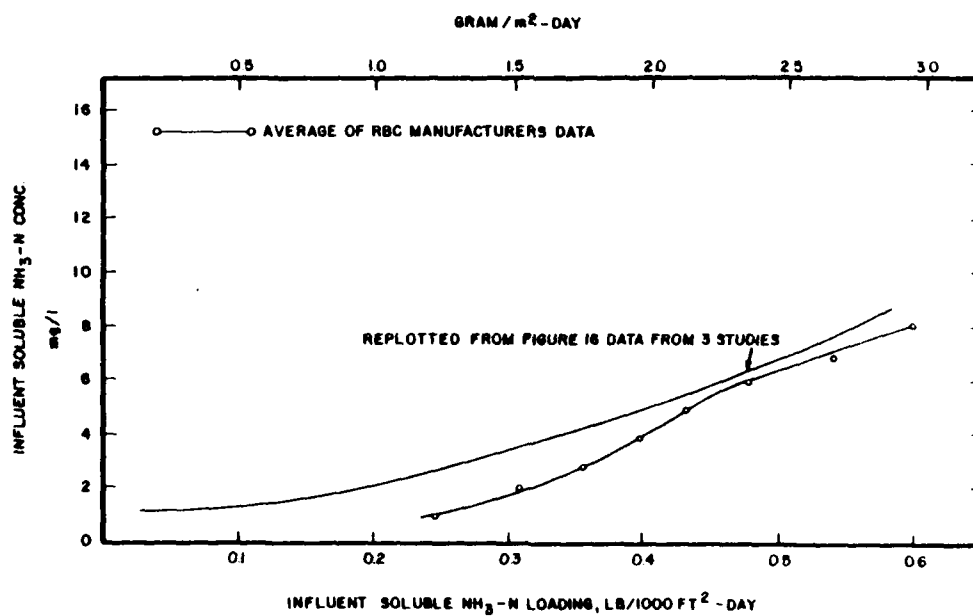


Figure 18. Comparison of nitrification performance, pilot plant studies vs. RBC manufacturers' design data.

8 SUMMARY

This report has provided information, case histories, and design guidance useful to DA personnel who must decide whether to use rotating biological contactors to upgrade their installations' trickling-filter sewage treatment plants. Answers have been given to the questions DA personnel most commonly ask about RBC equipment, costs, installation time, manpower requirements, land requirements, energy consumption, and effectiveness in upgrading effluent to NPDES standards.

RBC equipment produced by U.S. manufacturers was described, and weighted selection criteria were provided that will help the Facility Engineer decide whether an RBC system will be useful at the installation.

The most current RBC technology design guidelines have been described in terms of their special application to upgrading trickling-filter effluents. A stepwise approach has been provided to enable DA personnel to compare various upgrading alternatives. Several independent studies were reviewed that have compared actual RBC performance data with design claims of RBC manufacturers. Discrepancies have been pointed out, and reasons for accepting the manufacturer's design criteria are offered.

REFERENCES

- Autotrol Wastewater Treatment Systems Design Manual (Autotrol Corp., 1979).
- Clinton Bogart Assoc. and Hydrosience Assoc., Inc., Preliminary Report to EPA on Upgrading Primary Tanks With RBCs (November 1978).
- Construction Costs for Municipal Wastewater Treatment Plants 1973-1977, EPA 430/9-77-013, MCD-37 (United States Environmental Protection Agency [USEPA], January 1978).
- The Coupled Trickling Filter-Activated Sludge Process: Design and Performance, EPA-600/2-78-116 (USEPA, July 1978).
- Energy Conservation in Municipal Wastewater Treatment, EPA 430/9-77-011 (USEPA, March, 1978).
- Environmental Protection and Enhancement, Army Regulation (AR) 200-1 (Department of the Army, 20 January 1978).
- Environmental Pollution Control Alternatives -- Municipal Wastewater, EPA 625/5-76-012 (USEPA, 1976).
- Evaluation Criteria Guide for Water Pollution Prevention, Control, and Abatement Programs, TM 5-814-8 (Department of the Army, July 1976).
- Filion, M. P., et al., "Performance of an RBC Under Transient Loading Conditions," J. EPCF, 51 (1979), p 1925.
- Fisette, G. R., Operational Advantages Obtained by Incorporating a Bio-Drum in an Activated Sludge, paper presented at the First National Symposium on RBC Technology, Pittsburgh, PA (February 1980), Vol 1 -- PB81-124539, Vol 2 -- PB81-124547.
- Lagnese, J. F., Evaluation of RBCs Used to Upgrade Municipal Plant to Secondary Standards, paper presented at the Technical Conference, WPC Association of Pittsburgh, PA (April 1978).
- Miller, R. D., et al., Phosphorus Removal in a Pilot Scale Trickling Filter System by Low-Level Lime Addition to Raw Wastewater, Technical Report 7901 (U.S. Army Medical Engineering Research and Development Laboratory, Fort Detrick, MD, 1979).
- Miller, R. D., C. I. Noss, A. Ostrofsky, and R. S. Ryczak, RBC Process for Secondary Treatment and Nitrification Following a Trickling Filter, Technical Report 7905 (US AMBRDL, June 1979).

- Noss, C. I., et al., Recarbonation of Wastewater Using the RBC, paper presented at the First National Symposium on RBC Technology, Pittsburgh, PA (February 1980), Vol 1 -- PB81-124539, Vol 2 -- PB81-124547.
- Pierce, J. L., et al., An Evaluation of the Cost-Effectiveness of the RBC Process in Combined Carbon Oxidation and Nitrification Applications, paper presented at the First National Symposium on RBC Technology, Pittsburgh, PA (February 1980), Vol 1 -- PB81-124539, Vol 2 -- PB81-124547.
- Poon, C. P. C., et al., Evaluation of an RBC System to Upgrade Trickling Filter Effluents, paper presented at the First National Symposium on RBC Technology, Pittsburgh, PA (February 1980), Vol 1 -- PB81-124539, Vol 2 -- PB81-124547.
- Poon, C. P. C., et al., Tertiary Treatment Using an RBC System, technical report for CERL, 1978.
- Preliminary Design Manual (Clow Corporation, 1977).
- Process Control Manual for Aerobic Wastewater Treatment Facilities, EPA-403-9-77-006, PB279474 (USEPA, March 1977).
- Process Design Manual for Upgrading Existing Wastewater Treatment Plants (Office of Technology Transfer, USEPA, 1974).
- Schirtzinger, M. M., et al., First USA Air Drive RBC Units Operational Experience and Performance, Indian Creek Wastewater Treatment Plant, Cincinnati (Cleves), Ohio, paper presented at the First National Symposium on RBC Technology, Pittsburgh, PA (February 1980) Vol 1 -- PB81-124539, Vol 2 -- PB81-124547.
- Schmid, L. A., et al., "Phosphate Removal by a Lime-Biological Treatment Scheme," J. WPCF (1969), p 1259.
- Smith, E. D., C. P. C. Poon, W. Mikucki, and J. T. Bandy, Tertiary Treatment of Wastewater Using an RBC System, Technical Report N-85/ADA082502 (U.S. Army Construction Engineering Research Laboratory, February 1980).
- Sullivan, R. A., et al., Upgrading Existing Waste Treatment Facilities Utilizing the BIO-SURF Process, paper presented at the First National Symposium on RBC Technology, Pittsburgh, PA (February 1980), Vol 1 -- PB81-124539, Vol 2 -- PB81-124547.
- Sun, P. T., et al., Computerized Cost Effective Analysis of Fixed Film Nitrification Systems, paper presented at the First National Symposium RBC Technology, Pittsburgh, PA (February 1980), Vol 1 -- PB81-124539, Vol 2 -- PB81-124547.

Treatability Manual Vol III: Technologies for Control/Removal of Pollutants,
EPA-600/8-80-042c (Office of Research and Development, USEPA, July 1980).

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

Wexler, H. M., RBC Pilot Plant Test for the Town of Plainville, Report to Town
of Plainville (December 1978).

APPENDIX A:

TYPICAL CONDITIONS OF CONTRACT PERFORMANCE GUARANTEE

PERFORMANCE GUARANTEE

(Geo. A. Brown)

1. The bio-disc equipment manufacturer shall furnish a process performance bond equal to 100 percent of the equipment contract price. Said bond to be issued by a responsible surety approved by the Owner/Engineer and shall guarantee the performance of the bio-disc installation as specified. The term of said process performance bond shall not be for more than two (2) years after start-up of the RBS units, and until the process has been demonstrated to comply with the specifications. Said process performance bond shall guarantee the bio-disc system to perform under the conditions specified under design conditions, the testing procedures, and the bio-disc equipment is erected, operated, and maintained in accordance with manufacturer's normal instructions. Letter from surety shall be attached to manufacturer's quotation.
2. Objective - The objective of this guarantee is to provide a specified effluent with the equipment installed and operating at design conditions. The contractor and equipment manufacturer may witness all phases of the process performance guarantee test and shall provide any necessary guidance.
3. Start-Up - All unit processes and auxiliary equipment necessary for satisfactory operation of the bio-disc system shall be operational before any tests are performed. The treatment plant shall then be operated to develop suitable conditions for a performance test which will equal or simulate the design parameters.
4. Data Collection and Test Method - The performance test shall be for a 30 consecutive day period and the RBS performance shall be determined from the average of the 30 consecutive days. Should the results of this test prove to be unsatisfactory, a second test may be required. After receiving notice of unsatisfactory performance, the contractor shall have 90 days in which to make necessary corrections and prepare for another 30-day performance test. Any modifications to the bio-disc equipment or appurtenances shall be at no expense to the Owner. The additional test, if required, shall be conducted by the Owner, as above.

The Engineer shall notify the Contractor and equipment manufacturer that the system has been prepared for performance testing and when the performance test is to begin. Within 15 days of this notification, the Contractor and equipment manufacturer shall propose any changes they feel are necessary prior to the test. When the treatment system is operating under conditions acceptable to the Contractor and equipment manufacturer, notice shall be delivered to the Engineer that the performance test may commence.

During the performance test, flows will be monitored, wastewater temperature determined, and laboratory tests will be conducted for pH, suspended solids, dissolved solids, total solids (etc. per spec para. 3.2, page 15W-2), to determine all of the bio-disc influent parameters listed in the design basis. In addition, BOD₅ and COD concentrations of the bio-disc effluent will be determined. Plant personnel shall be responsible for gathering all samples and performing all laboratory tests.

Laboratory work shall conform to the procedures in the latest edition of Standard Methods with weekly and final test results transmitted to the Contractor and equipment manufacturer as soon as they become available. Equipment as provided for in these specifications shall collect 24-hour, proportional-to-plant-influent-flow, composite samples of the rotating disc influent wastewater. Samples of the rotating disc effluent shall be obtained by portable, time clock controlled, 24-hour composite samplers provided by the Owner or Contractor for the duration of the performance test. The portable samplers shall operate on 110 volt, single phase, 60 hertz power supply, with one to be mounted over the rotating disc effluent channel by the Contractor. All samples shall be stored at 4°C during and prior to any laboratory analysis, and a minimum of 60 minutes settling time on a one liter graduated cylinder shall be provided for the disc effluent samples before testing. Samples that cannot be held in a stable state for 24 hours at 4°C shall be preserved in accordance with the latest edition of Standard Methods, or equivalent method acceptable to Owner and equipment manufacturer. Daily test analyses may be performed by an independent laboratory at the option of the Owner and subject to approval of the Contractor and RBS equipment manufacturer.

5. Liability - If the bio-disc system does not meet the process performance requirements, and wastewater characteristics are not within the limits set forth in the design conditions, then the failure to meet the performance requirements shall not be considered a breach of the performance guarantee. Under these conditions, the Owner may promptly make corrections so that the wastewater requirements are met, and again run the performance test. Owner shall continue to make corrections, as necessary, and continue to run the performance tests as often as necessary until influent wastewater characteristics meet the specified requirements. If the RBS system does not meet the process performance requirements, and the wastewater characteristics are within the limits set forth in the design conditions, the bio-disc manufacturer shall be notified, in writing, thereof.

and shall, within 90 days after said notification by Owner, make necessary corrections and remedy defects, and another thirty (30) day performance test shall be conducted by the Owner if desired.

Upon successful verification of the process performance requirements, the manufacturer shall have no further process performance liability to the Owner.

APPENDIX B:

RBC MANUFACTURERS' DESIGN CURVES AND DESIGN LOADINGS USED IN EXAMPLES SHOWN IN CHAPTER 5

The following graphs are Figures C-1, C-2, C-4, C-5, C-7, and E-16 taken from the Autotrol Design Manual (reprinted with permission).

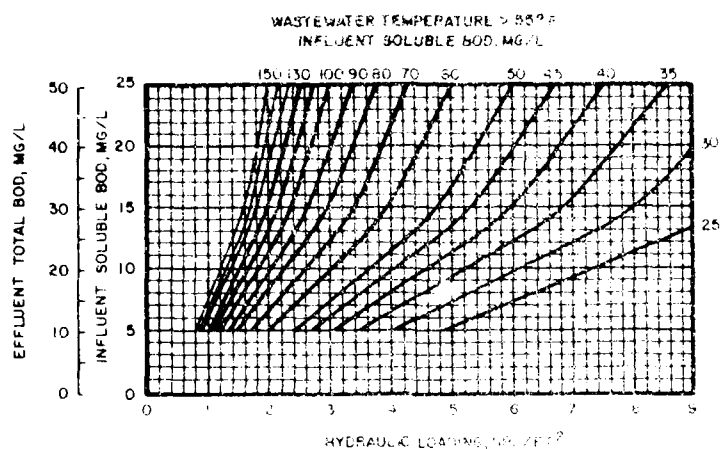


Figure B1. Bio-Surf process domestic wastewater for BOD removal.

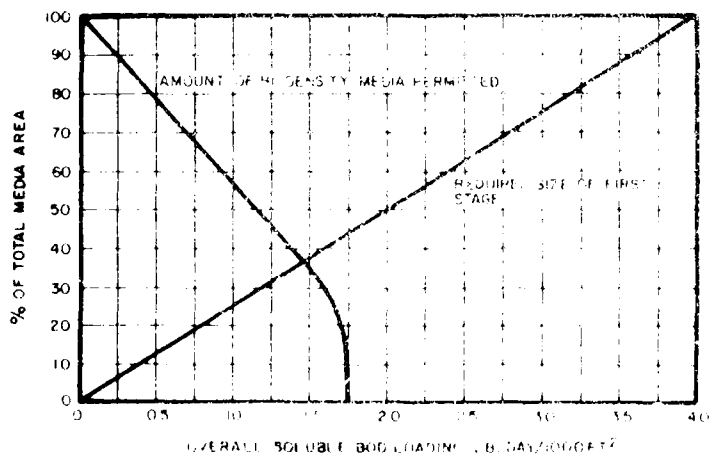


Figure B2. Bio-Surf process design curve for media area.

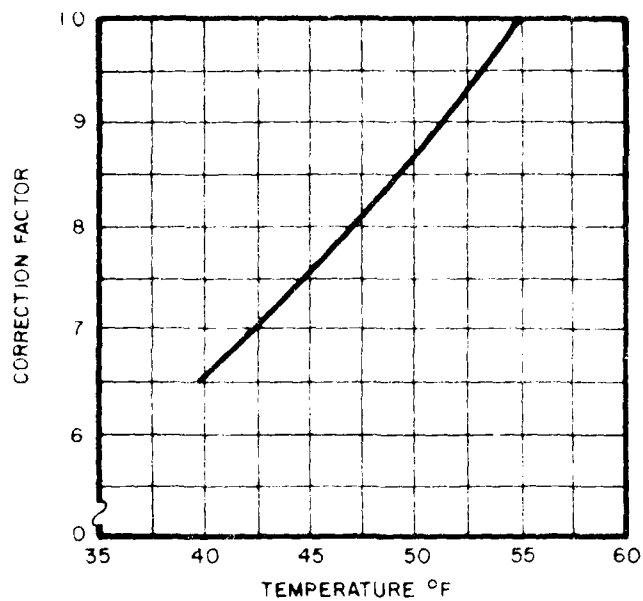


Figure B3. Bio-Surf process temperature correction for BOD removal.

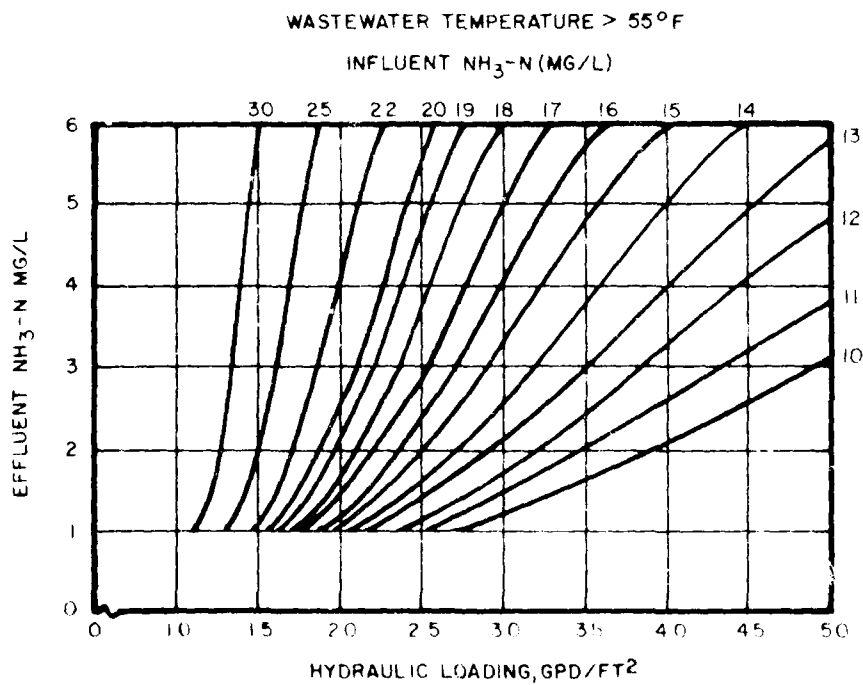


Figure B4. Bio-Surf process nitrification of domestic wastewater.

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CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY) CHAMPAIGN IL F/G 13/2
UPGRADING DA TRICKLING-FILTER SEWAGE TREATMENT PLANTS.(U)

MAY 81 E D SMITH, C P POON, R D MILLER

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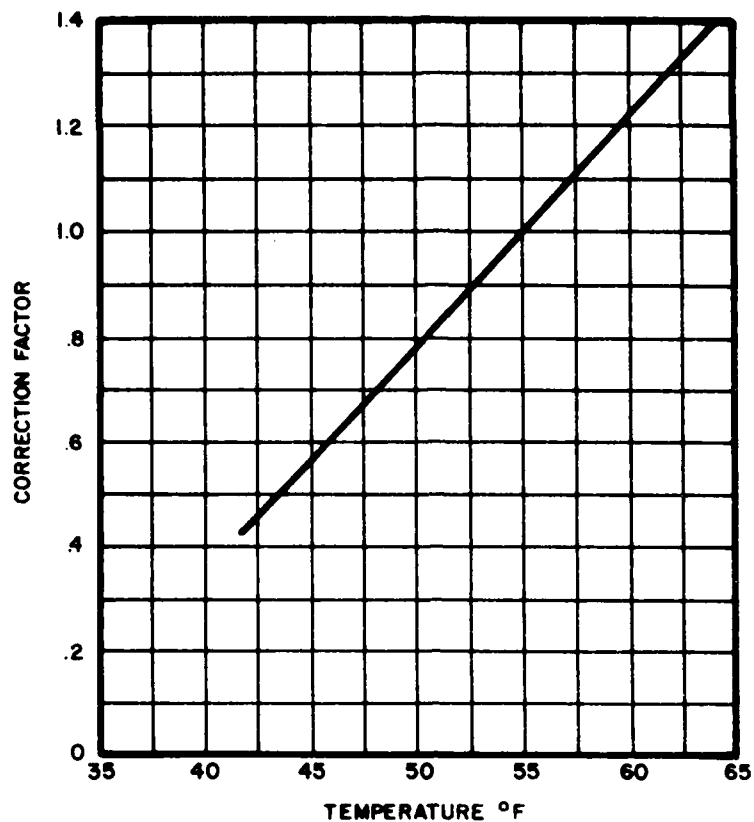


Figure B5. Bio-Surf process temperature correction for nitrification.

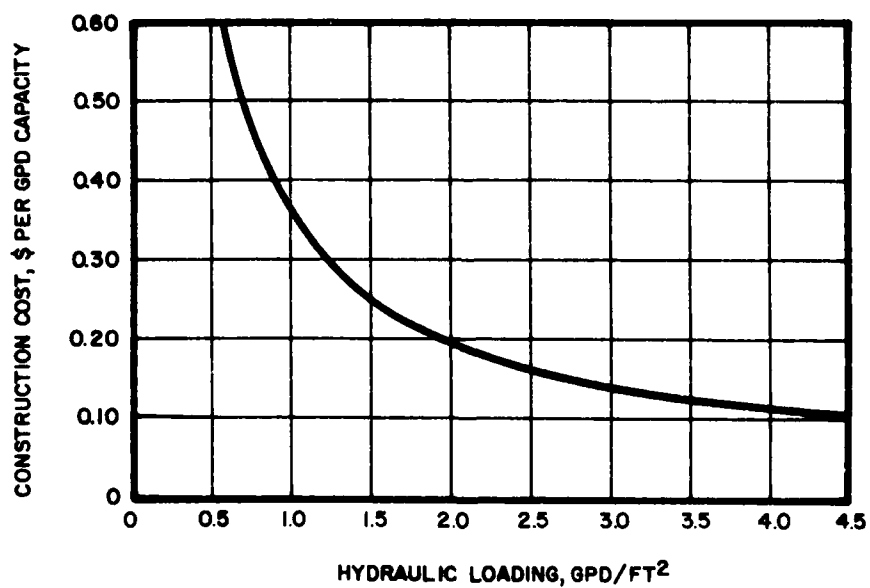


Figure B6. Bio-Surf process total construction cost.

The following are Tables III and IV from the Clow Corporation's Preliminary Envirodisc Design Manual.

Table B1

Soluble BOD₅ Loading Rates

Design Effluent SBOD ₅ Concentrations mg/L	SBOD ₅ Application Rate lbs/SBOD/1000 sq ft/day
5	1
10	1 1/2
15	2
20	2 1/4
25	2 1/2
30	2 3/4

TEMPERATURE CORRECTION FACTORS
(Multiply Calculated Area for BOD Removal by T_B)

°F	T _B
55	1.0
50	1.15
45	1.33
40	1.5

Table B2

Nitrification Loading Rates

(These loading rates are approximate and for preliminary sizing only. Contact Clow Enviroidisc for loading rates for specific conditions.)

Design Effluent NH ₃ -N Concentration mg/L	Loading Rate (Influent = 10 to 30 mg/L)
	lb/1000 sq ft/day
1	0.23 - 0.27
2	0.3 - 0.32
3	0.33 - 0.4
4	0.35 - 0.45
5	0.36 - 0.5
6	0.38 - 0.58
7	0.43 - 0.65
8	0.5 - 0.7

TEMPERATURE CORRECTION FACTORS
(Multiply Calculated Area for Nitrification by T_N)

°F	T _N
55	1.0
50	1.28
45	1.75
42 1/2	2.25

APPENDIX C:

RECENT RBC TECHNOLOGY*

III.5.4 ROTATING BIOLOGICAL CONTACTORS [1]

III.5.4.1 Function

Rotating biological contactors (RBC) are used to remove dissolved and colloidal biodegradable organics.

III.5.4.2 Description

The process utilizes a fixed-film biological reactor consisting of plastic media mounted on a horizontal shaft and placed in a tank. Common media forms are a disc-type made of styrofoam and a denser lattice-type made of polyethylene. While wastewater flows through the tank, the media are slowly rotated, about 40 percent immersed, for contact with the wastewater to remove organic matter by the biological film that develops on the media. Rotation results in exposure of the film to the atmosphere as a means of aeration. Excess biomass on the media is stripped off by rotational shear forces, and the stripped solids are maintained in suspension by the mixing action of the rotating media. Multiple staging of RBCs increases treatment efficiency and could help achieve nitrification year round. A complete system could consist of two or more parallel trains, each consisting of multiple stages in series.

III.5.4.3 Common Modifications

Common modifications of RBCs include the following: multiple staging; use of dense media for latter stages in train; use of molded covers for housing of units; various methods of pre- and post-treatment of wastewater; use in combination with trickling filter or activated sludge processes; use of air driven system with tapered gas flow in lieu of mechanically driven system; addition of air to the tanks; addition of chemicals for pH control; and sludge recycling to enhance nitrification.

III.5.4.4 Technology Status

The process has been used in the United States since 1969 and is not yet in widespread use. Use of the process is growing, however, because of its characteristic modular construction, low hydraulic head loss, and shallow excavation, which make it adaptable to new or existing treatment facilities.

* From R. A. Sullivan, et al., Upgrading Existing Waste Treatment Facilities Utilizing the BIO-SURF Process, paper presented at the First National Symposium on RBC Technology, Pittsburgh, PA (February 1980), Vol 1 -- PB81-124539, Vol 2 -- PB81-124547.

III.5.4.5 Applications

Applicable to treatment of domestic and compatible industrial wastewater; amenable to aerobic biological treatment in conjunction with suitable pretreatment and post-treatment; can be used for nitrification, roughing secondary treatment, and polishing.

III.5.4.6 Limitations

Can be vulnerable to climatic changes and low temperatures if not housed or covered; performance may diminish significantly below 55°F; enclosed units can result in considerable wintertime condensation if heat is not added to enclosure; high organic loadings can result in first-stage septicity and supplemental aeration may be required; use of dense media for early stages can result in media clogging; alkalinity deficit can result from nitrification; supplemental alkalinity source may be required.

III.5.4.7 Residuals Generated

Sludge in secondary clarifier; 3,000 to 4,000 gal sludge/Mgal wastewater; 500 to 700 lb dry solids/Mgal wastewater. These data are based on municipal wastewater.

III.5.4.8 Reliability

Moderately reliable in the absence of high organic loading and temperatures below 55°F; mechanical reliability is generally high if first stage of system is designed to hold large biomass; dense media in first stage can result in clogging and structural failure.

III.5.4.9 Environmental Impact

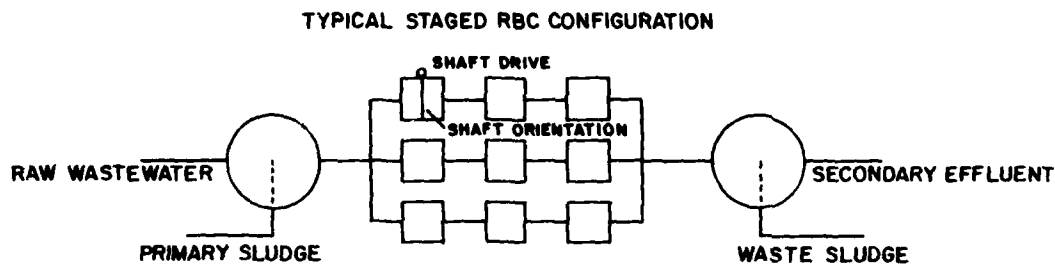
Negative impacts have not been documented; presumably, odor can be a problem if septic conditions develop in first stage.

III.5.4.10 Design Criteria

Criteria	Units	Range/value
Organic loading	lb BOD ₅ 1,000 ft ³ of media	Without nitrification: 30 - 60 With nitrification: 15 - 20
Hydraulic loading	gpd/ft ² of media	Without nitrification: 0.75 - 1.5 With nitrification: 0.3 - 0.6
Stages/train	-	At least 4

Parallel trains	-	At least 2
Rotational velocity	ft/min (peripheral)	60
Media surface area	ft ² /ft ³	Disc type: 20 - 25 Lattice type: 30 - 35
Media submerged	percent	40
Tank volume	gal/ft ³ of disc area	0.12
Detention time	min (based on 0.12 gal/ft ²)	Without nitrification: 40 - 90 With nitrification: 90 - 230
Secondary clarifier overflow	gpd/ft ²	500 - 700
Power	horse-power/25 ft shaft	7.5

III.5.4.11 Flow Diagram



ALTERNATE SHAFT ORIENTATION IS PARALLEL TO
DIRECTION OF FLOW WITH A COMMON DRIVE FOR ALL
THE STAGES IN A SINGLE TRAIN.

III.5.4.13 References

1. Innovative and Alternative Technology Assessment Manual.
EPA-430/9-78-009 (draft), U.S. Environmental Protection Agency, Cincinnati, Ohio,
1978. 252 pp.

CONTROL TECHNOLOGY SUMMARY FOR ROTATING BIOLOGICAL CONTACTORS

Pollutant	Number of data points	Effluent concentration, mg/L			Removal efficiency, %		
		Minimum	Maximum	Mean	Minimum	Maximum	Mean
Conventional pollutants:							
BOD ₅	4	18	71	31	69	82	74
COD	4	340	1,000	710	28	54	40.5
TSS	8	23	68	54	0 ^a	35	0 ^a
Oil and grease	5	13	47	27.8	0 ^a	21	6
Phosphorous	5	3.0	5	3.4	0 ^a	21	11
TKN	5	6	38	17.4	5	57	33

^aActual data indicate negative removal.

APPENDIX D:

EXCERPTS FROM CHAPTER 7, VOLUME 1, OF OPERATION OF WASTEWATER
TREATMENT PLANTS -- A FIELD STUDY TRAINING PROGRAM

(2nd edition, published by U.S. Environmental Protection Agency,
Office of Water Program Operations, Municipal Permits and
Operations Division, 1980)

GLOSSARY

Chapter 7. ROTATING BIOLOGICAL CONTACTORS

BIODEGRADABLE

Organic matter that can be broken down by bacteria to more stable forms which will not create a nuisance or give off foul odors

BIODEGRADABLE

COMPOSITE (PROPORTIONAL) SAMPLE

A composite sample is a collection of individual samples obtained at regular intervals, usually every one or two hours during a 24-hour time span. Each individual sample is combined with the others in proportion to the flow when the sample was collected. The resulting mixture (composite sample) forms a representative sample and is analyzed to determine the average conditions during the sampling period.

COMPOSITE (PROPORTIONAL) SAMPLE

GRAP SAMPLE

A single sample of wastewater taken at neither a set time nor flow.

GRAB SAMPLE

INHIBITORY SUBSTANCES

Materials that kill or restrict the ability of organisms to treat wastes.

INHIBITORY SUBSTANCES

MPN

MPN is the Most Probable Number of coliform-group organisms per unit volume. Expressed as a density or population of organisms per 100 ml.

MPN

NEUTRALIZATION

Addition of an acid or alkali (base) to a liquid to cause the pH of the liquid to move towards a neutral pH of 7.0.

NEUTRALIZATION

NITRIFICATION

A process in which bacteria change the ammonia and organic nitrogen in wastewater into oxidized nitrogen (usually nitrate). The second-stage BOD is sometimes referred to as the "nitrification stage" (first-stage BOD is called the "carbonaceous stage").

NITRIFICATION

PYROMETER

An apparatus used to measure high temperatures.

PYROMETER

SOLUBLE BOD

Soluble BOD is the BOD of water that has been filtered in the standard suspended solids test.

SOLUBLE BOD

SUPERNATANT

Liquid removed from settled sludge. Supernatant commonly refers to the liquid between the sludge on the bottom and the scum on the surface of an anaerobic digester. This liquid is usually returned to the influent wet well or to the primary clarifier.

SUPERNATANT

CHAPTER 7. ROTATING BIOLOGICAL CONTACTORS

7.0 DESCRIPTION OF ROTATING BIOLOGICAL CONTACTORS

Rotating biological contactors (RBC) are a secondary biological treatment process (Figure 7.1)* for domestic and *BIODEGRADABLE*¹ industrial wastes. Biological contactors have a rotating "shaft" surrounded by plastic discs called the "media." The shaft and media are called the "drum" (Figures 7.2 and 7.3). A biological slime grows on the media when conditions are suitable. This process is very similar to a trickling filter where the biological slime grows on rock or other media and settled wastewater (primary clarifier effluent) is applied over the media. With rotating biological contactors, the biological slime grows on the surface of the plastic-disc media. The slime is rotated into the settled wastewater and then into the atmosphere to provide oxygen for the organisms (Fig. 7.2). The wastewater being treated usually flows parallel to the rotating shaft, but may flow perpendicular to the shaft as it flows from stage-to-stage or tank-to-tank.

The plastic-disc media are made of high-density plastic circular sheets usually 12 feet (3.6 m) in diameter. These sheets are bonded and assembled onto horizontal shafts up to 25 feet (7.5 m) in length. Spacing between the sheets provides the hollow (void) space for distribution of wastewater and air (Figures 7.3 and 7.4).

The rotating biological contactor process uses several plastic media drums. Concrete or coated steel tanks usually hold the wastewater being treated. The media rotate while approximately 40 percent of the media surface is immersed in the wastewater (Fig. 7.4). As the drum rotates, the media pick up a thin layer of wastewater which flows over the biological slimes on the discs. Organisms living in the slimes use organic matter from the wastewater for food and dissolved oxygen from the air, thus removing wastes from the water being treated. As the attached slimes pass through the wastewater, some of the slimes are sloughed from the media as the media rotates downward into the wastewater being treated. The effluent with the sloughed slimes flows to the secondary clarifier where the slimes are removed from the effluent by settling. Figure 7.5 shows the location of a rotating biological contactor process in a wastewater treatment plant. The process is located in the same position as the trickling filter or activated sludge aeration basin. Usually the process operates on a "once-through" scheme, with no recycling of effluent or sludge, which makes it

a simple process to operate.

The major parts of the process are listed in Table 7.1 along with their purposes. The concrete or steel tanks are commonly shaped to conform to the general shape of the media. This shape eliminates dead spots where solids could settle out and cause odors and septic conditions. These tanks may be divided into four bays (stages) with either concrete walls or removable baffles, depending on the design.

The rotating biological contactor process is usually divided into four different stages (Fig. 7.6). Each stage is separated by a removable baffle, concrete wall or cross-tank bulkhead. Wastewater flow commonly is parallel to the shaft. Each bulkhead or baffle has an underwater orifice or hole to permit flow from one stage to the next. Each section of media between bulkheads acts as a separate stage of treatment.

Staging is used in order to maximize the effectiveness of a given amount of media surface area. Organisms on the first-stage media are exposed to high levels of BOD and reduce the BOD at a high rate. As the BOD levels decrease from stage to stage, the rate at which the organisms can remove BOD decreases.

Treatment plants requiring four or more shafts of media usually are arranged so that each shaft serves as an individual stage of treatment. The shafts are arranged so the flow is perpendicular to the shafts (Fig. 7.6, Layout No. 3). Plants with fewer than four shafts are usually arranged with the flow parallel to the shaft (Fig. 7.6, Layout No. 1).

Rotating biological contactors are covered for several reasons which depend on climatic conditions:

1. Protect biological slime growths from freezing;
2. Prevent intense rains from washing off some of the slime growths;
3. Stop exposure of media to direct sunlight to prevent growth of algae;
4. Avoid exposure of media to sunlight which may cause the media to become brittle; and
5. Provide protection for operators from sun, rain or wind while maintaining equipment.

¹ Biodegradable (BUY-o-dee-GRAD-able) Organic matter that can be broken down by bacteria to more stable forms which will not create a nuisance or give off foul odors

* Note: The figures contained in the original publication have been deleted from these excerpts.

TABLE 7.1 PURPOSE OF PARTS OF A ROTATING BIOLOGICAL CONTACTOR

Part	Purpose
1. Concrete or Steel Tank Divided into Bays (Sections) by Baffles (Bulkheads)	Tank. Holds the wastewater being treated and allows the wastewater to come in contact with the organisms on the discs. Bays and baffles. Prevent short-circuiting of wastewater.
2. Orifice or Weir Located in Baffle	Controls flow from one stage to the next stage or from one bay to the next bay.
3. Rotating Media	Provide support for organisms. Rotation provides food (from wastewater being treated) and air for organisms.
4. Cover over Contactor	Protects organisms from severe fluctuations in the weather, especially freezing. Also contains odors.
5. Drive Assembly	Rotates the media.
6. Influent Lines with Valves	Influent lines. Transport wastewater to be treated to the rotating biological contactor. Influent valves. Regulate influent to contactor and also to isolate contactor for maintenance.
7. Effluent Lines with Valves	Effluent lines. Convey treated wastewater from the contactor to the secondary clarifier. Effluent valves. Regulate effluent from the contactor and also isolate contactor for maintenance.
8. Underdrains	Allow for removal of solids which may settle out in tank.

Fiber glass covers in the shape of the media are easily removed for maintenance. In some areas, the rotating biological contactors are covered by a building. In other areas only a roof is placed over the media for protection against sunlight. The type of cover depends on climatic conditions.

Two types of drive assemblies are used to rotate the shafts supporting the media:

1. Motor with chain drive (Fig. 7.7). and
2. Air drive (Fig. 7.8).

The first type of drive assembly consists of a motor, belt drive, gear or speed reducer, and chain drive. The other drive unit consists of plastic cups attached to the outside of the media (Fig. 7.8). A small air header below the edge of the media releases air into the cups. The air in the cups creates a buoyant force which then makes the shaft turn. With either type of drive assembly, the main shaft is supported by two main bearings.

Individual units are usually provided with influent and effluent line valving to allow isolation for maintenance reasons. Usually the units are not shut down during the low flow conditions because power consumption is minimal and as the flows decrease, the percent of BOD removal increases.

7.1 PROCESS OPERATION

Performance by rotating biological contactors is affected by hydraulic loadings and temperatures below 55°F (13°C). Plants have been designed to treat flows ranging from 18,000 gpd to 50 MGD. Typical operating and performance characteristics are as follows:

Characteristic	Range
HYDRAULIC LOADING²	
BOD Removal	1.5 to 6 gpd/sq ft
Nitrogen Removal	1.5 to 1.8 gpd/sq ft
ORGANIC LOADING²	
SOLUBLE BOD³	3 to 5 lbs BOD/day/1000 sq ft
BOD Removal	80 to 95 percent
Effluent Total BOD	15 to 30mg/L
Effluent Soluble BOD	7 to 15 mg/L
Effluent NH ₃ -N	1 to 10 mg/L
Effluent NO ₃ -N	2 to 7 mg/L

See Section 7.5, "Loading Calculations," for procedures showing how to calculate the hydraulic and organic loadings on rotating biological contactors.

Advantages of rotating biological contactors over trickling filters include the elimination of the rotating distributor with its problems, the elimination of the problems caused by ponding on the media, and filter flies. More efficient use of the media is achieved due to the even or uniform rotation of the media into the wastewater being treated. A limitation of the process, as compared with trickling filters, is the lack of flexibility due to the absence of provisions for recirculation; however, in most installations recirculation is not needed.

7.10 Pretreatment Requirements

Rotating biological contactors are usually preceded by pretreatment consisting of screening, grit removal, and primary settling. Grit and large organic matter, if not removed, can settle beneath the drums and form sludge deposits which reduce the effective tank volume, produce septic conditions, scrape the slimes from the media, and possibly stall the unit.

Some rotating biological contactor plants have aerated flow equalization tanks instead of primary clarifiers ahead of the contactors. Flow equalization tanks may be installed to equalize or balance highly fluctuating flows and to allow for the dilution of strong wastes and neutralization of highly acidic or alkaline wastes. These equalization tanks are capable of reducing or eliminating shock loads.

7.11 Start-Up

Prior to plant start-up, become familiar with and understand the contents of the plant O & M manual. If you have any questions, be sure to ask the design engineer or the manufacturer's representative. Both of these persons should instruct the operator on the proper operation of the plant and maintenance of the equipment.

7.110 Pre-Start Checks for New Equipment

Before starting any equipment or allowing any wastewater to enter the treatment process, check the following items:

1. TIGHTNESS

Inspect the following for tightness in accordance with manufacturer's recommendations.

- a. Anchor bolts
- b. Mounting studs
- c. Bearing caps
 - Check any torque limitations
- d. Locking collars
- e. Jacking screws

² Hydraulic and organic loadings depend on influent flow, influent soluble BOD, effluent BOD, temperature and surface area of plastic media. Manufacturers provide charts converting flow to hydraulic and organic loadings for their media.

³ Soluble BOD Soluble BOD is the BOD of water that has been filtered in the standard suspended solids test.

- f. Roller chain
Be sure chain is properly aligned
- g. Media
Unbalanced media may cause slippage.
- h. Belts
Use matched sets on multiple-belt drives.

2 LUBRICATION

Be sure the following have been properly lubricated with proper lubricants in accordance with manufacturer's recommendations.

- a. Mainshaft bearings
- b. Roller chain
- c. Speed reducer

3 CLEARANCES

- a. Between media and tank wall.
- b. Between media and baffles or cover support beams.
- c. Between chain casing and media.
- d. Between roller chain, sprockets and chain casing.

4 SAFETY

Be sure safety guards are properly installed over chains and other moving parts.

7.111 Procedure for Starting Unit

Actual start-up procedures for a new unit should be in your plant O & M manual and provided by the manufacturer. A typical starting procedure is outlined below.

1. Switch on power, allow shaft to rotate one turn, turn off the power, lock out and tag switch. Inspect and correct if necessary during this revolution:
 - a. Movement of chain casing.
 - b. Unusual noises.
 - c. Direction of media rotation.
Where wastewater flow is parallel to the rotating media shaft, the direction of rotation is not critical. If the wastewater flow is perpendicular to the rotating media shaft, the media should be moving through the wastewater against the direction of flow (see Figure 7.6, p. 209).
2. Switch on power and allow shaft to rotate for 15 minutes. Inspect the following:
 - a. Chain-drive sprocket alignment.
 - b. Noises in bearings, chain drives and drive package.
 - c. Motor amperage. Compare with nameplate value.
 - d. Temperature of mainshaft bearing (by hand) and drive-package pillow block. If too hot for the hand, use a *PYROMETER*⁴ or thermometer. Temperature should not exceed 200°F (93°C).
 - e. Tightness of shaft bearing-cap bolts. Tighten to manufacturer's recommended torque.
 - f. Determine number of revolutions per minute for drum and record for future reference.
3. Open inlet valve and allow wastewater to fill the tank (all four stages if in one tank). Open the outlet valve to allow water to flow through the tank. Turn on power and make inspections listed in steps 1 and 2 again while drum is rotating. Shut off power, lock out and tag switch to make any corrections.
4. Check the relationship between the clarifier inlet and the rotating biological contactor outlet for hydraulic balance.

This means that you want to be sure that the tank containing the biological contactor will not overflow and cause stripping of the biomass

5. See Section 7.20 for break-in maintenance instructions which start after eight hours of operation

Development of biological slimes can be encouraged by regulating the flow rate and strength of the wastewater applied to nearly constant levels by the use of recirculation if available. Maintaining building temperatures at 65°F (18°C) or higher will help. The best rotating speed is one which will shear off growth at a rate which will provide a constant "hungry and reproductive" film of microorganisms exposed to the wastewater being treated.

Allow one to two weeks for an even growth of biological slimes (biomass) to develop on the surface of the media with normal strength wastewater. After start-up, a slimy growth (biomass) will appear. During the first week, excessive sloughing will occur naturally. This sloughing is normal and the sloughed material is soon replaced with a fairly uniform, shaggy brown-to-gray appearing biomass with very few or no bare spots.

Follow the same start-up procedures whether a plant is starting at less than design flow or at full-design flow. Start-up during cold weather takes longer because the organisms in the slime growth (biomass) are not as active and require more time to grow and reproduce.

7.12 Operation

Rotating biological contactor treatment plants are not difficult to operate and produce a good effluent provided the operator properly and regularly performs the duties of inspecting the equipment, testing the influent and effluent, observing the media, maintaining the equipment and taking corrective action when necessary.

7.120 Inspecting Equipment

This treatment process has relatively few moving parts. There is a drive train to rotate the shaft and there are bearings upon which the shaft rotates. Neither the media nor the shaft require maintenance. Check the following items when inspecting equipment:

1. Feel outer housing of shaft bearing to see if it is running hot. Use a pyrometer or thermometer if temperature is too hot for your hand. If temperature exceeds 200°F (93°C) the bearings may need to be replaced. Also check for proper lubrication and be sure the shaft is properly aligned. The longer the shaft, the more critical the alignment.
2. Listen for unusual noises in motor bearings. Locate cause of unusual noises and correct.
3. Feel motors to determine if they are running hot. If hot, determine cause and correct.
4. Look around drive train and shaft bearing for oil spills. If oil is visible, check oil levels in the speed reducers and chain drive system. Also look for damaged or worn-out gaskets or seals.
5. Inspect chain drive for alignment and tightness.
6. Inspect belts for proper tension.
7. Be sure all guards over moving parts and equipment are in place and properly installed.
8. Clean up any spills, messes or debris.

⁴ *Pyrometer* (pie-ROM-uh-ter). An apparatus used to measure high temperatures.

7.121 Testing Influent and Effluent

Wastewater analysis is required to monitor overall plant and process performance. Because there are few process control functions to be performed, only a minimal analysis is required to monitor and report daily performance. To determine if the rotating biological contactors are operating properly, you should measure (1) BOD, (2) suspended solids, (3) pH and (4) dissolved oxygen (DO). Performance is best monitored by analysis of a 24-hour **COMPOSITE SAMPLE**⁵ for BOD and suspended solids on a daily basis. DO and pH should be measured using **GRAB SAMPLES**⁶ at specific times. Actual frequency of tests may depend on how often you need the results for plant control and also how often your NPDES permit requires you to sample and analyze the plant effluent.

DISSOLVED OXYGEN

The DO in the wastewater being treated beneath the rotating media will vary from stage to stage. A plant designed to treat primary effluent for BOD- and suspended-solids removal will usually have 0.5 to 1.0 mg/L DO in the first stage. The DO level will increase to 1 to 3 mg/L in the fourth stage. A plant designed for **NITRIFICATION**⁷ to convert ammonia and organic nitrogen compounds to nitrate will have four stages also. The difference between a RBC unit designed for BOD removal and one designed for nitrification is the design flow applied per square foot of media surface area. DO in the first stage of nitrification unit will be more than 1 mg/L DO and often as high as 2 to 3 mg/L. The DO in the fourth stage of a nitrification unit may be as high as 4 to 8 mg/L.

EFFLUENT VALUES

Typical BOD, suspended solids, and ammonia and nitrate effluent values for rotating biological contactors depend on NPDES permit requirements and design effluent values. As flows increase, effluent values increase because a greater flow is applied to each square foot of media while the time the wastewater is in contact with the slime growths is reduced. Also, the greater the levels of BOD, suspended solids and nitrogen in the influent, the greater the levels in the plant effluent. Figure 7.9 shows influent and effluent values for a rotating biological contactor. The influent and effluent data plotted are seven-day moving averages which smooth out daily fluctuations and reveal trends. Procedures for calculating moving averages are explained in Chapter 18, "Analysis and Presentation of Data."

If analysis of samples reveals a decrease in process efficiency, look for three possible causes.

1. Reduced wastewater temperatures.
2. Unusual variations in flow and/or organic loadings, and
3. High or low pH values (less than 6.5 or greater than 8.5).

Once the cause of the problem has been identified, possible solutions can be considered and the problem corrected.

TEMPERATURE

Wastewater temperatures below 55°F (13°C) will result in a reduction of biological activity and in a decrease in BOD or

organic material removal. The contactors can be heated by the operator increasing wastewater temperatures by no more than 10°F. Under severe conditions, special steps can be made to heat the building, the air inside the RBC, and cover of the RBC, and influent.

Solar heat can be used effectively to maintain temperature in buildings and enclosures without drying out the biological slime growths. Ceilings should be kept low to effectively use available heat. If existing buildings have high ceilings, large vane fans can be mounted on the ceilings to direct heat downward.

INFLUENT VARIATIONS

When large daily influent flow and/or organic (BOD) variations occur, a reduction in process efficiency is likely to result. Before corrective steps are taken, the exact extent of the problem and resulting change in process efficiency must be determined. In most cases, when the influent flow and/or organic peak loads are less than three times the daily average values during a 24-hour period, little decrease in process efficiency will result.

In treatment plants where the influent flow and/or organic loads exceed design values for a sustained period, the effluent BOD and suspended solids must be measured to determine if corrective action is required.

During periods of severe organic overload, the bulkhead or baffle between stages one and two may be removed. This procedure provides a larger amount of media surface area for the first stage of treatment. If the plant is continuously overloaded and the effluent violates the NPDES permit requirements, additional treatment units should be installed. A possible short-term solution to an overload problem might be the installation of facilities to recycle effluent; however, this would cause a greater increase of any hydraulic overload.

pH

Every wastewater has an optimum pH level for best treatability. Domestic wastewater pH varies between 6.5 and 8.5 and will have little effect on organic removal efficiency. If this range is exceeded at any time (due to industrial waste discharges for example), however, a decrease in efficiency is likely.

To adjust the pH towards 7.0, either pre-aerate the influent or add chemicals. If the pH is too low, add sodium bicarbonate or lime. If the pH is too high, add acetic acid. The amount of chemicals to be added depends on the characteristics of the water and can best be determined by adding chemicals to samples in the lab and measuring the change in pH.

When dealing with nitrification, pH and alkalinity are very critical. The pH should be kept as close as possible to a value of 8.4 when nitrifying. The alkalinity level in the raw wastewater should be maintained at a level at least 7.1 times the influent ammonia concentration to allow the reaction to go to completion without adversely affecting the microorganisms. Sodium bicarbonate can be used to increase both the alkalinity and pH.

Another item under pH variations could be the adding of

⁵ **Composite (Proportional) Sample (com-POZ-it)** A composite sample is a collection of individual samples obtained at regular intervals, usually every one or two hours during a 24-hour time span. Each individual sample is combined with the others in proportion to the flow when the sample was collected. The resulting mixture (composite sample) forms a representative sample and is analyzed to determine the average conditions during the sampling period.

⁶ **Grab Sample** A single sample of wastewater taken at neither a set time nor flow.

⁷ **Nitrification (NYE-tri-fi-KAY-shun)** A process in which bacteria change the ammonia and organic nitrogen in wastewater into oxidized nitrogen (usually nitrate). The second-stage BOD is sometimes referred to as the "nitrification stage" (first-stage BOD is called the "carbonaceous stage").

SUPERNATANT⁸ from a digester. The supernatant should be tested for pH and suspended solids. Without testing the supernatant, you will not know what kind of load you're placing on the rest of the plant. Sometimes it's best to drain supernatant at low flows to the plant. Caution should be taken to avoid overloading the process. If the supernatant pH is too low, supernatant could be drawn off during high flows when these flows can be used for dilution and **NEUTRALIZATION**.⁹

7.122 Observing the Media

Rotating biological contactors use bacteria and other living organisms growing on the media to treat wastes. Because of this, you can use your sight and smell to identify problems. The slime growth or biomass should have a brown-to-gray color, no algae present, a shaggy appearance with a fairly uniform coverage, and very few or no bare spots. The odor should not be offensive, and certainly there should be no sulfide (rotten egg) smells.

BLACK APPEARANCE

If the appearance becomes black and odors which are not normal do occur, this could be an indication of solids or BOD overloading. These conditions would probably be accompanied by low DO in the plant effluent. Compare previous influent suspended solids and BOD values with current test results to determine if there is an increase. To solve this problem, place another rotating biological contactor unit in service, if possible, or try to pre-aerate the influent to the RBC unit. Also review the operation of the primary clarifiers and sludge digesters to be sure they are not the source of the overload.

WHITE APPEARANCE

A white appearance on the disc surface also might be present during high loading conditions. This might be due to a type of bacteria which feeds on sulfur compounds. The overloading could result from industrial discharges containing sulfur compounds upon which certain sulfur-loving bacteria thrive and produce a white slime biomass. Corrective action consists of placing another RBC unit in service or trying to pre-aerate the influent to the unit. During periods of severe organic or sulfur overloading, remove the bulkhead or baffle between stages one and two.

Another cause of overloading may be sludge deposits which have been allowed to accumulate in the bottom of the bays. To

remove these deposits, drain the bays, wash the sludge deposits out and return unit to service. Be sure the orifices in the baffles between the bays are clear.

SLOUGHING

If severe sloughing or loss of biomass occurs after the start-up period and process difficulty arises, the causes may be due to the influent wastewater containing toxic or **INHIBITORY SUBSTANCES**¹⁰ that kill the organisms in the biomass or restrict their ability to treat wastes. To solve this problem, steps must be taken to eliminate the toxic substance even though this may be very difficult and costly. Biological processes will never operate properly as long as they attempt to treat toxic wastes. Until the toxic substance can be located and eliminated, loading peaks should be dampened (reduced) and a diluted uniform concentration of the toxic substance allowed to reach the media in order to minimize harm to the biological culture. While the corrections are made at the plant, dampening may be accomplished by regulating inflow to the plant. Be careful not to flood any homes or overflow any low manholes. Toxic wastes may be diluted using plant effluent (until it contains toxic material) or any other source of water supply.

Another problem which could cause loss of biomass is an unusual variation in flow and/or organic loading. In small communities one cause may be high flow during the day and near zero flow at night. During the day the biomass is receiving food and oxygen and starts growing; then the night flow reduces to near zero — available food is reduced and nearly stops. The biomass starts sloughing off again due to lack of food.

Possible solutions to sloughing of the biomass due to excessive variations in plant flow and/or organic loading include throttling peak conditions and recycling from the secondary clarifier or RBC effluent during low flows. Be very careful when throttling plant inflows that low elevation homes are not flooded or that manholes do not overflow. Usually RBC units do not have provisions for any recycling from the secondary clarifier. If low flows at night are creating operation problems due to lack of organic matter, a possible solution is the installation of a pump to recirculate water from the secondary clarifier. If recirculation is provided, try to maintain a hydraulic loading rate of greater than 1.0 to 1.5 gpd/sq ft. A flow equalization tank can be used to provide fairly continuous or even flows.

Possible rotating biological contactor process operational problems, causes and solutions are summarized in Table 7.2.

⁸ Supernatant (sue-per-NAY-ent). Liquid removed from settled sludge. Supernatant commonly refers to the liquid between the sludge on the bottom and the scum on the surface of an anaerobic digester. This liquid is usually returned to the influent wet well or to the primary clarifier.

⁹ Neutralization (new-trail-ZAY-shun). Addition of an acid or alkali (base) to a liquid to cause the pH of the liquid to move towards a neutral pH of 7.0.

¹⁰ Inhibitory Substances. Materials that kill or restrict the ability of organisms to treat wastes.

TABLE 7.2 POSSIBLE RBC OPERATIONAL PROBLEMS, CAUSES AND SOLUTIONS

Problem	Cause	Solution
1. Slime on media appears shaggy with a brown-to-gray color	PROPER OPERATION	NO PROBLEM NORMAL CONDITION
2. Black slime	Solids and/or BOD overloading	- Place another RBC unit in service if available. - Pre-aerate RBC influent. - For severe organic overloads, remove bulkhead or baffle between stages 1 and 2.
3. Rotten egg or other obnoxious odors	Solids and/or BOD overloading	See problem 2, solutions a, b and c above.
4. White slime	Bacteria which feed on sulfur compounds. Also, industrial discharges containing sulfur compounds may cause an overload.	See problem 2, solutions a, b and c above.
5. Sloughing or loss of slime (biomass)	- Toxic or inhibitory substances in influent. - Variation in flow and/or organic loading.	- Eliminate source of toxic or inhibitory substances. - Reduce peaks of toxic or inhibitory substances by carefully regulating inflow to plant. - Dilute influent using plant effluent or any other source of water.
6. Decrease in process efficiency	- Reduced wastewater temperature. - Unusual variations in flow and/or organic loading. - Sustained flows or loads above design levels. - High or low pH values. - Improper rotation of media.	- Heat air inside RBC unit cover or building. - Heat influent to unit. See problem 5, cause (2), solutions a, b and c above. Install additional treatment units. - If the pH is too low, add an alkali (base) such as lime. - If the pH is too high, add an acid such as acetic acid. - Inspect belt tension and adjust. - Check air pressure and adjust.

7.13 Abnormal Operation

Abnormal operating conditions may develop under the following circumstances:

1. High or low flows,
2. High or low solids loading, and
3. Power outages.

When your plant must treat high or low flows or solids (organic) loads, abnormal conditions develop as the treatment efficiency drops. For solutions to these problems, refer to Section 7.12, "Operation," and Table 7.2. One advantage of RBC units is the fact that high flows usually do not wash the slime growths off the media; consequently the organisms are present and treating the wastewater during and after the high flows.

A power outage requires the operator to take certain precautions to protect the equipment and the slime growths while no power is available. If the power is off for less than four hours, nothing needs to be done. If the power outage lasts longer than four hours, the RBC shaft needs to be turned about one-quarter of a turn twice a day. Turning prevents all the slime growth from accumulating on the bottom portion of the plastic disc media. Before attempting to turn the shaft, lock out and tag the power in case the outage ends abruptly. To turn the shaft, **REMOVE THE BELT GUARD USING EXTREME CARE.** Turn the shaft by using the belts. **BE CAREFUL YOU DON'T CUT OFF YOUR FINGERS.** Place a wedge-shaped block between the belts and belt sprocket to hold the shaft and media in the desired location. Actually, the shaft is very delicately balanced and easy to rotate. Do not try to weld handles or brackets to the shaft to facilitate turning because this will throw the shaft off balance.

WARNING. If the shaft starts to roll back to its original position before you get the block properly inserted, do not try to stop the shaft. Let it roll back and stop. If you try to stop the shaft from rolling back, you could injure yourself and also damage the belts and sprockets.

Gently spray water on the slime growth that is not submerged frequently enough to keep the biomass moist whenever the drum is not rotating.

If the power outage lasts longer than 12 hours, more than normal sloughing will occur from the media when the unit is placed back in service. When the sloughing becomes excessive, increase the sludge-pumping rate from the secondary clarifier.

7.14 Shutdown and Restart

The rotating biological contactor may be stopped by turning off the power to the drive package. If the process is to be stopped for longer than four hours, follow the precautions listed in Section 7.13, "Abnormal Operation," when a power outage occurs. Do not allow one portion of the media to be submerged in the wastewater being treated for more than four hours. Occasionally spray the media not submerged to prevent the slime growth from drying out whenever the drum is not rotating.

If the tank holding the wastewater being treated must be drained, a portable sump pump may be used. A sump is usually located at the end of the unit by the motor. Pump the water either to the primary clarifier or to the inlet end of a RBC unit in operation. A trough running the full length of the tank allows the

solids to be pumped out. While the tank is empty, inspect for cracks and any other damage and make necessary repairs.

Try to keep the slime growths moist to minimize sloughing and a reduction in organism activity when the process starts again. A loss in process efficiency can result if the slimes are washed off the media. **DO NOT WASH THE SLIME GROWTH OFF THE MEDIA** because you will be washing away the organisms that treat the wastewater. If the unit is to be out of service for longer than one day, the slimes may be washed off the media to prevent the development of odor problems.

Restart rotation by applying power to the drive unit. Before applying power, inspect the shaft and drive unit for possible interference from such items as tools or bulkheads. If slippage occurs from an unbalanced media, inspect and adjust alignment and tension.

7.2 MAINTENANCE

Rotating biological contactors have few moving parts and require minor amounts of preventive maintenance. Chain drives, belt drives, sprockets, rotating shafts and any other moving parts should be inspected and maintained in accordance with manufacturers' instructions or your plant's O & M manual. All exposed parts, bearing housing shaft ends and bolts should be painted or covered with a layer of grease to prevent rust damage. Motors, speed reducers and all other metal parts should be painted for protection.

Maintenance also includes the repair or replacement of broken parts. A preventive maintenance program that keeps equipment properly lubricated and adjusted to help reduce wear and breakage requires less time and money than a program that waits for breakdowns to occur before taking any action. The frequency of inspection and lubrication is usually provided by manufacturer's instructions and also may be found in the plant O & M manual. The following sections indicate a typical maintenance program for a rotating biological contactor treatment process. More detail can be found in a plant O & M manual.

7.20 Break-In Maintenance

AFTER 8 HOURS OF OPERATION

1. Recheck tightening torque of capscrews in all split-tapered bushings in the drive package.
2. Visually inspect hubs and capscrews for general condition and possibility of rubbing against an obstruction.
3. Inspect belt drive (drive package).

AFTER 24 HOURS OF OPERATION

1. Inspect all chain drives.

AFTER 40 HOURS OF OPERATION

1. Inspect all belt drives in drive packages.

AFTER 100 HOURS OF OPERATION

1. Change oil in speed reducer. Use manufacturer's recommended lubricants.

2. Clean magnetic drain plug in speed reducer.
3. Check all capscrews in split-tapered bushings and setscrews in drive package output sprocket and bearing for tightness.
4. Inspect belt drive of drive package.

AFTER 3 WEEKS OF OPERATION

1. Change oil in chain casing. Be sure oil level is at or above the mark on the dipstick. Use manufacturer's recommended lubricants.

7.21 Preventive Maintenance Program

Interval	Procedure
Daily	1. Check for hot shaft and bearings. Replace bearings if temperature exceeds 200°F (93°C).
Daily	2. Listen for unusual noises in shaft and bearing. Identify cause of noise and correct if necessary.
Weekly	3. Grease the mainshaft bearings and drive bearings. Use manufacturer's recommended lubricants. Add grease slowly while shaft rotates. When grease begins to ooze from the housing, the bearings contain the correct amount of grease. Add six full strokes where bearings cannot be seen.
4 wk.	4. Inspect all chain drives.
4 wk.	5. Inspect mainshaft bearings and drive bearings.
4 wk.	6. Apply a generous coating of general purpose grease to mainshaft stub ends, mainshaft bearings and end collars.
3 mo.	7. Change oil in chain casing. Use manufacturer's recommended lubricants. Be sure oil level is at or above the mark on the dipstick.

- | | |
|--------|---|
| 3 mo. | 8. Inspect belt drive. |
| 6 mo. | 9. Change oil in speed reducer. Use manufacturer's recommended lubricants. |
| 6 mo. | 10. Clean magnetic drain plug in speed reducer. |
| 6 mo. | 11. Purge the grease in the double-sealed shaft seals of the speed reducer by removing the plug located 180 degrees from the grease fitting on both the input and output seal cages. Pump grease into the seal cages and then replace the plug. Use manufacturer's recommended grease. |
| 12 mo. | 12. Grease motor bearings. Use manufacturer's recommended grease. To grease motor bearings, stop motor and remove drain plugs. Inject new grease with pressure gun until all old grease has been forced out of the bearing through the grease drain. Run motor until all excess grease has been expelled. This may require up to several hours running time for some motors. Replace drain plugs. |

7.22 Housekeeping

Properly designed systems have sufficient turbulence so solids or sloughed slime growths should not settle out on the bottom of the bays. If grease balls appear on the water surface in the bays, they should be removed with a dip net or screen device.

If media comes apart, squeeze the two unbonded sections together with a pair of pliers. Take another pair of pliers and force a heated nail through the media. The heat from the nail will melt the plastic and make a plastic weld between the two sections of media.

7.23 Troubleshooting Guide

7.230 Roller Chain Drive

Trouble	Probable Cause	Corrective Action
1. Noisy Drive	1. Moving parts rub stationary parts. 2. Chain does not fit sprockets. 3. Loose chain. 4. Faulty lubrication. 5. Misalignment or improper assembly. 6. Worn parts.	1. Tighten and align casing and chain. Remove dirt or other interfering matter. 2. Replace with correct parts. 3. Maintain a taut chain at all times. 4. Lubricate properly. 5. Correct alignment and assembly of the drive. 6. Replace worn chain or bearings. Reverse worn sprockets before replacing.
2. Rapid Wear	1. Faulty lubrication. 2. Loose or misaligned parts.	1. Lubricate properly. 2. Align and tighten entire drive.
3. Chain Climbs Sprockets	1. Chain does not fit sprockets. 2. Worn-out chain or worn sprockets.	1. Replace chain or sprockets. 2. Replace chain. Reverse or replace sprockets.
4. Stiff Chain	3. Loose chain. 1. Faulty lubrication. 2. Rust or corrosion. 3. Misalignment or improper assembly. 4. Worn-out chain or worn sprockets.	3. Tighten. 1. Lubricate properly 2. Clean and lubricate 3. Correct alignment and assembly of the drive. 4. Replace chain. Reverse or replace sprockets.
5. Broken Chain or Sprockets	1. Shock or overload. 2. Wrong size chain, or chain that does not fit sprockets. 3. Rust or corrosion. 4. Misalignment. 5. Interferences.	1. Avoid shock and overload or isolate through couplings. 2. Replace chain. Reverse or replace sprockets. 3. Replace parts. Correct corrosive conditions. 4. Correct alignment. 5. Make sure no solids interfere between chain and sprocket teeth. Loosen chain if necessary for proper clearance over sprocket teeth.

7.231 Belt Drive

Trouble	Probable Cause	Corrective Action
1 Excessive edge wear	1. Misalignment or non-rigid centers.	1. Check alignment and/or reinforcement mounting.
	2. Bent flange.	2. Straighten flange.
2 Jacket wear on pressure-face side of belt tooth.*	Excessive overload and/or excessive belt tightness.	Reduce installation tension and/or increase drive load-carrying capacity.
3 Excessive jacket wear between belt teeth (exposed tension members)*	Excessive installation tension.	Reduce installation tension.
4 Cracks in Neoprene backing	Exposure to excessively low temp. (below -30°F or -35°C).	Eliminate low temperature condition or consult factory for proper belt construction.
5 Softening of Neoprene backing	Exposure to excessive heat (+200°F or 93°C) and/or oil.	Eliminate high temperature and oil condition or consult factory for proper belt construction.
6 Tensile or tooth shear failure.*	1. Small or sub-minimum diameter pulley.	1. Increase pulley diameter.
	2. Belt too narrow.	2. Increase belt width.
7 Excessive pulley tooth wear (on pressure-face and/or OD)*	1. Excessive overload and/or excessive belt tightness.	1. Reduce installation tension and/or increase drive load-carrying capacity.
	2. Insufficient hardness of pulley material.	2. Surface-harden pulley or use harder material.
8 Unmounting of flange	1. Incorrect flange installation.	1. Reinstall flange correctly.
	2. Misalignment.	2. Correct alignment.
9 Excessive drive noise	1. Misalignment.	1. Correct alignment.
	2. Excessive installation tension.	2. Reduce tension.
	3. Sub-minimum pulley diameter.	3. Increase pulley diameters.
10 Tooth shear*	1. Less than 6 teeth in mesh (TIM).	1. Increase TIM or use next smaller pitch.
	2. Excessive load.	2. Increase drive load-carrying capacity.
11 Apparent belt stretch	Reduction of center distance or non-rigid mounting.	Re-tension drive and/or reinforce mounting.
12 Cracks or premature wear at belt tooth root.*	Improper pulley groove top radius.	Regroove or install new pulley.
13 Tensile break	1. Excessive load.	1. Increase load-carrying capacity of drive.
	2. Sub-minimum pulley diameter.	2. Increase pulley diameters.

* Pertains to a timing belt system only.
Recent systems use a V-belt drive.

7.3 SAFETY

Any equipment with moving parts or electrical components should be considered a potential safety hazard. **ALWAYS SHUT OFF THE POWER TO UNIT, TAG THE SWITCH AND LOCK THE POWER SWITCH IN THE "OFF" POSITION BEFORE WORKING ON A UNIT.**

7.30 Slow-Moving Equipment

Slow-moving equipment does not appear dangerous. Unfortunately, moving parts such as the chain sprockets, chain, belt sprockets and belts can cause serious injury by tearing and/or crushing your hands or legs.

7.31 Wiring and Connections

Wiring and connections should be inspected regularly for potential hazards such as loose connections and bare wires. Again, always shut off, tag, and lock out the power switch before working on a unit.

7.32 Slippery Surfaces

Caution must be taken on slippery surfaces. Falls can result in serious injuries. Any spilled oil or grease must be cleaned up immediately. If covers over the media allow sufficient space for walkways, condensed moisture on surfaces will create slippery places. If the temperature of the air within the enclosure can be kept several degrees above the temperature of the wastewater, condensation is significantly reduced. This condensation

cannot be avoided completely so walk carefully at all times.

7.33 Infections and Diseases

Precautions must be taken to prevent infections in cuts or open wounds and illnesses from waterborne diseases. After working on a unit, always wash your hands before smoking or eating. **GOOD PERSONAL HYGIENE MUST BE PRACTICED BY ALL OPERATORS AT ALL TIMES.**

7.4 REVIEW OF PLANS AND SPECIFICATIONS

When reviewing plans and specifications, be sure the following items are included in the design of rotating biological contactors.

1. Enclosure to protect biomass from freezing temperature. Enclosure constructed of suitable corrosion-resistant materials and has windows or louvered structures in sides for ventilation. Forced ventilation is not necessary.
2. Heating. A source of heat is helpful during winter operation to minimize the corrosion caused by condensation and to improve operator comfort. If the temperature of the air within the enclosure is kept several degrees above the temperature of the wastewater, condensation is significantly reduced. Ceilings should be kept low to effectively use available heat.

METRIC CONVERSION FACTORS

1 in. = 25.4 mm
1 ft = .3048 m
1 sq ft = .0929 m²
1 cu ft = .0283 m³
1 gal = 3.785 L
1 mgd = 3785.0 KL/day
°C = 5/9 (°F-32)
1 kW = 14.34 kg-cal/min
1 kWh = 3.6 MJ

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ATTN: Chief, NPSEN-PL-ER
Walla Walla
ATTN: Chief, Engr Div
Alaska
ATTN: Chief, NPASA-R

US Army Engineer Division
New England
ATTN: Chief, NEDED-E
North Atlantic
ATTN: Chief, NADEN-T
Middle East (Rear)
ATTN: Chief, MEDED-T
South Atlantic
ATTN: Chief, SADEN-TE
Huntsville
ATTN: Chief, HNOED-GS
ATTN: Chief, HNOED-ME
ATTN: Chief, HNOED-SR
Lower Mississippi Valley
ATTN: Chief, PD-R
Ohio River
ATTN: Chief, Engr Div
North Central
ATTN: Chief, Engr Planning Br
Missouri River
ATTN: Chief, MRDED-T
Southwestern
ATTN: Chief, SWDED-TH

US Army Engineer Division
South Pacific
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ATTN: Laboratory
Pacific Ocean
ATTN: Chief, Engr Div
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ATTN: Chief, PODED-P
North Pacific
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WASH DC 20330

2854 ABG/DEEE
Tinker AFB, OK 73145

2852 APG/DE
McClellan AFB, CA 95652

Patrick AFB, FL 32925
ATTN: XRQ

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Tyndall AFB, FL 32403

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Smith, Edgar D.

Upgrading DA trickling filter sewage treatment plants / by E. D. Smith, C. P. Poon, R. D. Miller. -- Champaign, IL : Construction Engineering Research Laboratory ; available from NTIS, 1981.

117 p. (Technical Report ; N-102)

1. Sewage disposal plants. 2. Sewage - purification - rotating disc process. I. Poon, C. P. C. II. Miller, Roy D. III. Title. IV. Series: U. S. Army Construction Engineering Research Laboratory. Technical report ; N-102.

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