United States
Environmental Protection
Agency

Municipal Environmental
Research Laboratory
Cincinnati OH 45268

Research and Development

EPA-600/S2-84-106 July 1984

Project Summary

Design Information on Rotating Biological Contactors

Richard C. Brenner, James A. Heidman, Edward J. Opatken, and Albert C. Petrasek, Jr.

A document summarizing design information for rotating biological contactors (RBC) was developed to provide in-depth data on the critical features of this process and the key factors affecting its operation and performance. The information provided is intended to supplement and qualify that available from RBC manufacturers and the published literature. Topics addressed include process and design considerations for carbonaceous removal, nitrification, and denitrification; equipment reliability and service life; power requirements for air driven and mechanically driven RBC units; and general system design considerations involving structural, hydraulic, and operational flexibility. Practical, usable design information was emphasized along with important theoretical concepts.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the design information document that is available in its entirety in a separate report of the same title (see Project Report ordering information at back).

Introduction

RBC's for municipal wastewater treatment have been introduced relatively rapidly to the United States. The result has been widespread application of a technology that is not familiar to many design engineers. Out of necessity, many RBC designs were initially based solely on proprietary-generated empirical design procedures. The lack of a comprehensive appraisal of modified media configurations left design engineers and equipment purchasers with an inadequate basis for comparing performance of alternative equipment designs and effectively relating anticipated performance to loading. As interest in the process has increased, more complex, deterministic design approaches have begun to appear in the technical literature.

The purpose of this project was to prepare a design information document that would supplement commonly accepted RBC design methodology (such as manufacturers' design manuals and deterministic models) by providing appropriate qualifiers and summaries of operating and performance data not readily available to the design community. Important design parameters and relationships (or lack of them) are discussed to promote a more rational RBC design approach. Many aspects of the information contained in the document are equally applicable to industrial wastewater treatment. The document is *not* intended to serve as a cookbook-style design reference or to replace any of the design guides mentioned above.

The full report considers the equipment and design practices of the five current U.S. RBC manufacturers — Autotrol (now Envirex), Clow, Crane-Cochrane, Lyco, and Walker Process.* Significant variations in shaft, media configuration, and media attachment designs are evident among the five and must be taken into account in designing an RBC system.

Information was originally presented on the equipment and design practices of a sixth U.S. RBC manufacturer. This manufacturer has recently stopped

---

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

marketing RBC units and is referred to hereinafter as Manufacturer X. Descriptions of Manufacturer X's equipment have subsequently been removed from the full report and this Project Summary, but published references to and discussions of its previous design methods have been retained where appropriate.

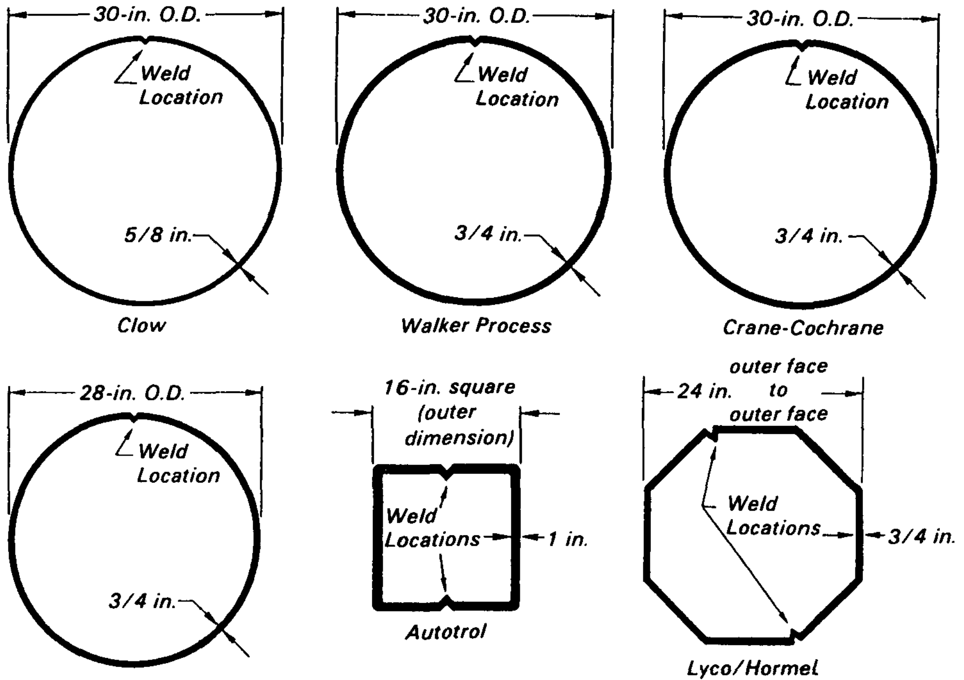
Equipment Description and Performance

The most serious equipment problem that can affect an RBC system is the structural breaking (failure) of a shaft. A shaft failure usually involves temporary loss of the affected RBC unit and perhaps its entire train, damage to a portion of the media, and replacement of the broken shaft with a new shaft along with salvaged and/or new media. Numerous failures of first-generation shafts in this country have been attributed to poor fabrication and welding practices. Improved second-generation designs have corrected most of the early manufacturing deficiencies. Shaft failures have also occurred because of fatigue resulting from overstressing of the member's load-carrying capacity.

A matrix of estimated shaft fatigue limits and shaft fatigue lives was developed for the shaft cross-sections shown in Figure 1 as a function of shaft attachment detail, shaft wall thickness, and combined media and biofilm load. Appropriate fatigue provisions of the American Welding Society (AWS) Structural Welding Code for Design of Tubular Structures (Section 10) and Design of New Bridges (Section 9) were used to determine the fatigue limit of each shaft design and the estimated shaft life when imposed loads exceed fatigue limits. A shaft member subjected to a stress range below its fatigue or endurance limit will not fail (with a high degree of confidence) as a result of structural fatigue.

Fatigue loading limits for RBC shafts can be expressed as a function of the thickness of the biofilm attached to the rotating media. Estimates of allowable biofilm thickness that keep the imposed load below the respective fatigue limits of the six shafts varied depending on shaft structural dimensions and characteristics. The ranges calculated were 75 to >150 mils (0.075 to >0.15 in.) for standard density media and 50 to 125 mils (0.05 to 0.125 in.) for high density media.

These estimates of shaft fatigue limits were made assuming that no welding deficiencies or shaft deterioration existed as a result of corrosion. The weldment provisions of the AWS Structural Welding Code should be used as an absolute minimum to ensure satisfactory weldment fabrication. Epoxy coatings are routinely used by RBC manufacturers to protect shafts from the corrosive effects of wastewater. Available information from coating manufacturers indicates that epoxy coating materials have an expected life of 5 to 10 years or more, but long-term data are limited.



Clow

Walker Process

Crane-Cochrane

Lyco

Autotrol

Lyco/Hormel

Figure 1. Cross-sections of RBC shafts.

Shaft fatigue protection may also be provided by increasing shaft section modulus (additional shaft wall thickness) to decrease the applicable cyclic stress range and compensate for possible metal loss resulting from corrosion. In selecting and specifying RBC shafts, the designer should require evidence from the shaft manufacturer that satisfactory fatigue stress protection (including protection from possible corrosive effects) has been provided to cover the design life of the RBC system under expected loading conditions, either by providing reliable protective coating material or by modifying the shaft design to increase the section modulus.

Design techniques can be used to minimize shaft overstressing from excessive biofilm growth. These techniques include (1) incoming load manipulation to bypass temporarily the organically overloaded stages (usually the first two) and/or to distribute that load to greater media surface through step feeding or removal of baffles and (2) variable speed mechanical drives to reduce biofilm thickness by means of increased shear. For some mechanically driven systems, strategic placement of supplemental air headers to increase biofilm shearing rates may also represent a cost-effective method. A secondary benefit of variable speed drives and/or supplemental air would be the ability to increase temporarily the concentration of bulk liquid dissolved oxygen (DO) in specific stages.

The plant operator must be provided with sufficient flexibility to respond to changing load and process conditions. In addition to mechanisms for manipulating load and increasing DO concentration and biofilm shearing potential, recommended operational tools include (1) shaft load cells for estimating biofilm weight (particularly in the critical lead stages), (2) DO monitoring equipment to aid in process control, (3) flow control devices to equalize hydraulic and organic loads to parallel trains, and (4) air flow measuring equipment to adjust air flow rates properly in air drive RBC installations.

High density polyethylene (HDPE) is used by all manufacturers in the fabrication of RBC media. The method of forming a media pack and attaching it to the shaft determines whether an RBC assembly must be removed from its tank for field replacement of damaged or deteriorating media. In designing an RBC system, the engineer should consider the operation and maintenance ramifications of field media replacement. If a particular design requires removal of the RBC assembly from its tank to perform this task, permanently installed shaft removal equipment may be cost effective. The alternative is to bring in an over- or off-the-road crane as needed. Present media pack attachment designs of Clow, Crane-Cochrane, and Lyco do not require removal from the tank for media replacement, but current Autotrol, Tait/Bio-Shafts, and Walker Process designs do.

A standard RBC assembly consists of media approximately 12 ft in diameter supported on or from a 27-ft-long shaft (25-ft media length). Standard density media are defined as those with a nominal surface area of 100,000 sq ft/25 ft of media length. High density media are formed by reducing the space between repeating plastic corrugations by 33 percent, thus achieving a media configuration with 50 percent more available surface area (i.e., a nominal surface area of 150,000 sq ft/25 ft of media length).

Standard density media are normally used in the front or lead stages of an RBC train where organic strength is highest and biofilm growth is thickest. High density media have been used primarily in the middle and final stages where lower organic concentrations will not promote and sustain thick biofilm growth. Excepting for second-step nitrification applications where the organic load is known to be low, use of high density media in lead RBC stages should be avoided because of potentially excessive biofilm development per unit volume of media (resulting in shaft overstressing) and the increased possibility of inducing biofilm bridging between adjacent media sheets. Recommended rules of thumb are to limit media biofilm thickness, if possible, to 75 mils (0.075 in.) for standard density media and 50 mils (0.05 in.) for high density media to provide an acceptable margin of safety against shaft overload and possible fatigue failure. These recommendations do not apply to Walker Process and Lyco because of the much higher fatigue limits of their shafts.

Early media designs were subject to degradation from the ultraviolet component of sunlight. The use of anti-oxidants in HDPE formulations and protective covers have essentially eliminated this problem. Prolonged exposure to high temperature environments and concentrated organic solvents can also lead to media degradation and/or brittleness. Cases of media rupture resulting from the poorly understood phenomenon of stress cracking have also been reported. Media can be broken while in service as a result of lateral shifting in assemblies using radial arm support systems if inadequate bracing and tightening capability are not provided. On the average, however, media failures have not been encountered as often as shaft failures.

The drive assembly has proven to be the most reliable equipment component in a mechanically driven RBC system. Occasional broken drive chains are the only problem of note. Operating experience with air driven systems is too limited to date to make definitive projections of equipment performance. The critical aspects of air driven system performance currently appear to relate more to achieving desired air distribution among multiple shafts and maintaining uniform rotational speeds of individual shafts than they do to reliability of the air delivery equipment itself.

In a few severe cases where biofilm growth on RBC media has become grossly uneven or unbalanced, lack of positive rotational control with air driven systems has brought shaft rotation to a complete halt. Providing the operator with load manipulation capability and/or equipment to achieve rapid biofilm stripping (e.g., high pressure water injection) are the most effective techniques for responding to these situations.

The full report summarizes the structural and mechanical performance of 17 RBC plants surveyed using questionnaires and onsite visits. Data are presented for the three major RBC system component units (shaft, media, and drive).

Organic Removal

Under most circumstances, mass transfer is the dominant factor affecting organic removal in an RBC system. Mass transfer resistances associated with both the liquid phase and the biofilm result in significant concentration gradients from the bulk liquid to biological reaction sites on the media, and frequently these resistances control system performance. Oxygen transfer becomes rate limiting and controls the overall reaction rate in heavily loaded systems. After all of the factors affecting substrate removal and oxygen transfer are considered, no reason exists to expect substrate removal from the RBC bulk liquid to follow any simple mathematical model.

Oxygen loading to any stage of an RBC system should not exceed values compatible with the oxygen transfer capability of the system. COD balance studies conducted on a full-diameter RBC unit have indicated a maximum oxygen transfer rate of approximately 1.5 lb O_2/day/1000 sq ft. Most oxygen transfer in an RBC takes place in the atmospheric portion of the rotational cycle.

The presence of *Beggiatoa* organisms on RBC media is associated with biofilm DO depletion and is considered an indication of organic overloading. In the absence of DO, sulfide essential for *Beggiatoa* growth is generated by means of sulfate reduction and/or anaerobic decomposition deep within the biofilm. When designing a mechanically driven RBC system, research and field observations indicate that safe, conservative first-stage loading figures to avoid organic overloading are 2.5 lb soluble BOD_5/day/sq ft or 6 lb total BOD_5/day/1000 sq ft. These figures may be increased, but the designer must recognize that this increase may lead to heavier-than-normal biofilm growth, bulk liquid DO depletion, development of sulfide oxidizing nuisance organisms, deteriorlation of overall process and/or mechanical performance, etc.

A first-stage loading exceeding the above figures may be justified depending on the degree of operational and maintenance attention the plant will receive, the structural capacity of the selected shaft, the ability to strip excess biomass from the media, the levels of sulfur compounds in the RBC system influent, the media surface area required in the remaining stages, and the ability to vary the operational mode of the plant. The loading, however, should generally not exceed 4 lb soluble BOD_5/day/1000 sq ft or 8 lb total BOD_5/day/1000 sq ft.

Mass organic removal rates in an overloaded RBC stage may exceed those of a stage operating in a proper loading range if sulfide levels are low enough to avoid extensive *Beggiatoa* growth. In many instances, however, mass removal rates in overloaded stages may actually decrease as *Beggiatoa* organisms begin to compete seriously with desirable heterotrophs for oxygen and space on RBC media. In extreme cases, the takeover of the first stage of an overloaded RBC system by *Beggiatoa* can shift the load to the next stage, leading to a progressive *Beggiatoa* takeover of the entire system and significant deterioration of effluent quality.

Present procedures for scaling up pilot test data collected on less-than-full-diameter RBC units to full-scale design are inadequate. Mass removal data generated on less-than-full-diameter units operated at equivalent fieldscale tip speeds (60 fpm ±) tend to be optimistic because of the higher rates of oxygen transfer and atmospheric surface renewal inherently achieved. The distortion is magnified as the scale decreases.

Deterministic mathematical models that attempt to incorporate all of the factors affecting the RBC process have been used in some design situations in conjunction with the results of smaller-scale RBC pilot studies carried out on the wastewater in question. Though these models provide considerable insight into the variables and ranges of variables affecting RBC performance, their successful application to design depends greatly on accurate calibration of model coefficients.

Very small-scale RBC pilot units (1.5-ft diameter or less) are more useful in determining the basic treatability of a wastewater than in establishing full-scale design parameters. If small-diameter units must be used to collect design data, however, it is important that each stage be loaded below the oxygen transfer capability of a full-scale unit to minimize scale-up considerations. Full-diameter (12 ft ±) or nearly full-diameter RBC pilot studies are recommended where feasible, since they offer the highest probability of obtaining reliable RBC design data.

Additional factors affecting organic removal in RBC's include, among others, the ratio of tank volume to media surface area (detention time), influent wastewater strength, influent flow and load variability, wastewater temperature, and staging configuration. Most RBC manufacturers have standarized ratios of tank volume-to-media surface area at 0.12 gal/sq ft, since higher ratios did not improve BOD removal at equal hydraulic loading rates. For municipal wastewaters, percentage BOD removal normally increases with increasing wastewater strength; the converse is generally true for high-strength industrial wastewaters.

Loading variations are not assumed by the manufacturers to affect process performance adversely at peak-to-average flow ratios of 2.5 or less. The Autotrol and Clow design manuals recommend using either peak flow and load conditions for design or flow equalization for ratios above 2.5.

The manufacturers universally contend that about 55°F wastewater temperature does not affect organic removal design. Below 55°F, varying degrees of decreased biological activity are predicted by the manufacturers.

The optimal number and size of stages and the overall staging configuration for a given design are frequently difficult to predict. Flexible hydraulic designs that enable the plant operator to change the size and number of stages (e.g., step feeding and stage bypass provisions, removable baffles, etc.) will enhance the potential for maximum performance from any RBC facility.

No single best design procedure or set of relationships has been found that can universally predict RBC organic removal. Empirical design approaches used by four manufacturers (Autotrol, Clow, Lyco, and Manufacturer X) exhibit considerable variation in organic loading versus predicted effluent quality (Figure 2). Except for Lyco, these empirical design techniques are based on predictions of effluent soluble BOD_5. Effluent total BOD_5 projections are then made assuming a set ratio (e.g., 0.5) of soluble-to-total BOD_5 in the effluent. This assumption ignores (1) the impact of solids settling characteristics on final clarifier performance and (2) the wide variations in effluent suspended solids and particulate BOD_5 that are possible with any given concentration of effluent soluble BOD_5. In the absence of full-diameter pilot plant data for the design in question, any RBC design guidelines should be used with discretion.

To devise an improved method for estimating organic removal, soluble organics interstage data were evaluated using second order kinetics. Interstage and final effluent soluble BOD_5 values predicted using this approach are compared in the full report with measured values obtained at nine full-scale, air driven RBC plants. The predicted and measured values are in good agreement for seven of the nine plants. The lack of close agreement at one of the other two plants could be explained by inadequate oxygen transfer in the first stage to handle the high influent organic loading. The lack of close agreement at the ninth plant could not be explained.

The second-order predicted values more closely approximated measured soluble BOD_5 concentrations than did values predicted by Autotrol's empirical organic removal design method for air driven RBC's. These results indicate that second-order kinetics may offer an improved basis for predicting interstage soluble organic removals in RBC systems that are not oxygen transfer limited; they also suggest that further evaluations be conducted for both mechanically and air driven options as additional interstage data become available. As with manufacturers' empirical techniques, the second-order kinetic approach only addresses the impact of soluble organics on effluent quality.

Nitrogen Control

Nitrification

The factors affecting nitrification in the RBC process are representative of those that affect any attached growth biological process. They include influent organic concentration, influent nitrogen concen-

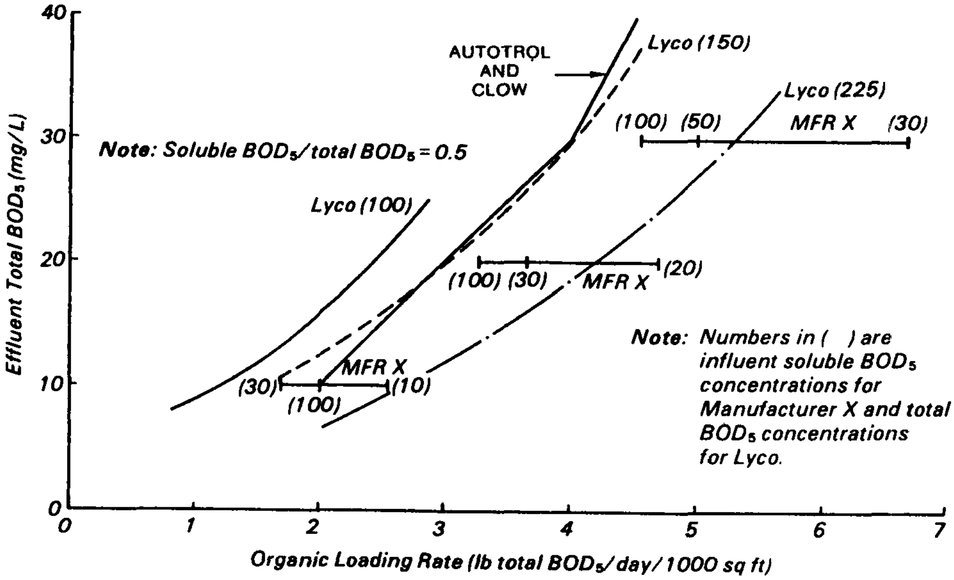


Figure 2. *Effluent BOD_5 as a function of organic loading for selected RBC manufacturers design techniques.*

tration and composition, wastewater temperature, DO concentration, pH and alkalinity, and influent flow and load variability, among each others.

Most empirical design procedures are based on the assumption that significant nitrification does not begin in an RBC system until bulk liquid soluble BOD_5 has been reduced to 15 mg/L, or total BOD_5 to 30 mg/L. In combined carbon oxidation/nitrification units, BOD_5 values of this magnitude may first be encountered in the second, third, or fourth stages, depending on influent strength, organic loading rate, and wastewater temperature. In separate-stage nitrification RBC applications, the soluble BOD_5 concentration of the wastewater entering the RBC reactor is usually well below 15 mg/L and substantial nitrification is typically evident in the first stage. Analysis of field data indicates that while incipient nitrification is generally observed in RBC stages with soluble BOD_5 concentrations of 15 mg/L ± maximum nitrification rates are not attained until bulk liquid soluble BOD_5 drops to 10 mg/L or less.

Numerous investigators have found that RBC nitrifier growth kinetics and ammonia nitrogen oxidation follow the classic Monod expression. When substrate (ammonia nitrogen) concentration is low compared with the half-velocity constant, ammonia nitrogen oxidation approaches first-order removal. Conversely, when substrate concentration is high in relation to the half-velocity constant, oxidation approaches a constant zero-order removal rate.

The zero-order ammonia nitrogen removal rate observed for RBC's and the ammonia nitrogen concentration transition point at which it begins depend on scale and wastewater temperature. Zero-order removal rates as high as 0.8 lb NH_3-N/day/1000 sq ft have been measured on small pilot units. For full-diameter RBC's, the maximum attainable zero-order removal rate is generally acknowledged to be about 0.3 lb NH_3-N/day/1000 sq ft. As with organic removal, higher inherent rates of atmospheric surface renewal and oxygen transfer are the probable reasons for the higher mass nitrification rates attainable with pilot RBC units.

Because of the varying degrees of hydrolysis that can occur in sewer lines, RBC nitrification designs should not be based on influent ammonia nitrogen concentration alone. To do so risks serious undersizing if substantial amounts of organic nitrogen are present.

Nitrification rates drop sharply at wastewater temperatures below 55°F. The manufacturers have found, however, that wastewater temperatures above 55°F do not affect RBC nitrification. Nitrification temperature correction factors recommended by four manufacturers are given in the full report.

Minimum DO levels of 3 to 4 mg/L are recommended in RBC nitrifying stages to ensure that nitrification is not limited by oxygen transfer into the biofilm. Lower DO levels are more likely to occur in the transition stage from organic removal to incipient nitrification and in the next succeeding stage than in the final stages. The beneficial effect on DO of compressed air injection in air driven RBC's is approximately offset by their lower atmospheric oxygenation (compared with mechanically driven units), which results from reduced rotational velocities (typically 65 to 75 percent of the standard mechanically driven velocity of 1.6 rpm).

The literature recommends optimal pH values for nitrification ranging from 7.0 to 9.0. If pH drops much below 7.0 in unacclimated systems, the nitrification rate will be seriously retarded, decreasing to zero somewhere between pH 6.0 and 5.0. Since nitrification reactions consume alkalinity, alkaline addition may be required for RBC nitrification systems treating wastewaters with low or highly variable alkalinity.

Nitrification rates have been enhanced through upward pH adjustment in pilot-scale RBC units, with the optimum rate occurring at pH 8.5. Similar response has not been demonstrated on full-diameter RBC's.

The impact of flow and mass loading variations is usually more severe on the nitrification efficiency of RBC's than on organic removal performance. Nitrifiers have long generation times compared with heterotrophs. Furthermore, external accumulation and/or internal storage of substrate for delayed metabolism does not take place with nitrifiers as with heterotrophs. Consequently, influent surges in flow or unoxidized nitrogen concentration (either of which increases nitrogen mass loading) will be accompanied by similar delayed (roughly equal to reactor detention time) spikes of unoxidized nitrogen in the effluent unless adequate RBC surface is provided to compensate for expected variations. In design situations that specify consistently low effluent ammonia nitrogen residuals (1 to 2 mg/L), the amount of media surface required should be estimated with and without prior flow equalization to determine which option is more cost effective.

Since the mid-1970's, Autotrol has conducted extensive testing and data evaluation to model ammonia nitrogen oxidation in RBC's. Their current empirical procedure for full-diameter RBC units operating at wastewater temperatures of 55 °F or greater is based on a Monod-type curve (Figure 3). This curve projects first-order removal (oxidation) of ammonia nitrogen at concentrations in the stage liquid below about 5 mg/L. Above 5 mg/L NH_3-N, removal is claimed to proceed at a zero-order rate of approximately 0.3 lb NH_3-N/day/1000 sq ft. This rate is consistent with the maximum potential nitrification rate (0.33 lb NH_3-N/day/1000 sq ft) that can be calculated based on an assumed peak oxygen transfer capability for 12-ft diameter media of 1.5 lb O_2/day/1000 sq ft (see the earlier section on Organic Removal).

Applied to a staged RBC reactor, the above design basis predicts that when soluble BOD_5 drops below 15 mg/L, ammonia nitrogen will be oxidized at a constant (zero-order) rate as it passes through succeeding stages down to a bulk liquid concentration of about 5 mg/L, and thereafter at an approximate first-order rate. Nitrification performance data from three full-scale RBC facilities were evaluated for wastewater temperatures of 55 ± 2°F. The resulting best fit curve of ammonia nitrogen removal rate versus ammonia nitrogen concentration closely approximates the Autotrol design curve (Figure 3).

Denitrification

Denitrification can be accomplished with RBC's using two different process configurations. In the first, representing the traditional biological denitrification approach, organic removal and nitrification occur upstream of the denitrification reactor in either a lead-stage(s) RBC unit or some other type of biological system. A supplemental carbon source (commonly methanol) must be added to the wastewater to provide the required energy for microbial denitrification in the denitrification (anoxic) stage. A short-term, final, aerated RBC stage or other polishing biological unit may also have to be added to oxidize any residual methanol not used for denitrification.

A possible alternative RBC denitrification configuration would be to place the anoxic stage before the organic removal and nitrification reactor(s). This technique is well known for activated sludge systems, but thus far it has not been used in any full-scale RBC installations. The organic carbon naturally present in the incoming wastewater provides the necessary energy for reducing nitrate nitrogen

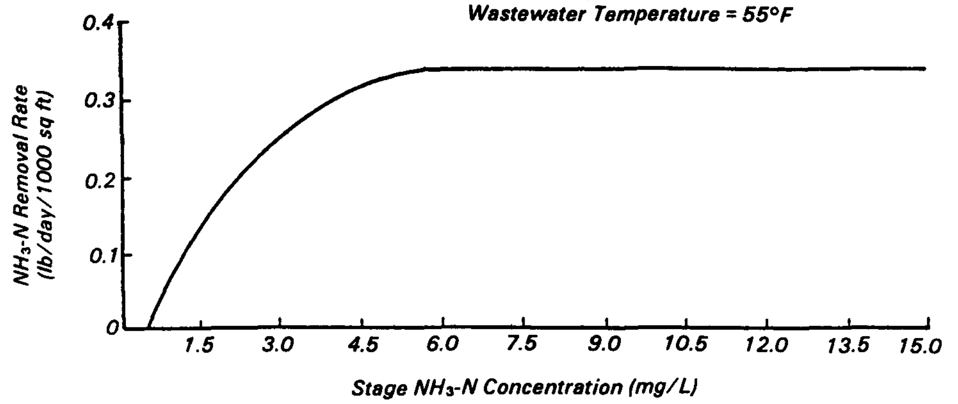


Figure 3. *Second-generation Autotrol ammonia nitrogen removal rate curve for full-scale RBC's (from: Antonie, R.L., "Nitrogen Control with Rotating Contactors," Autotrol Corporation, Undated; Reprinted with permission).*

recirculated to the anoxic stage from the downstream reactor(s). Though the maximum potential denitrification efficiency at recirculation-to-plant influent flow ratios of 1 to 3 is reportedly only about 75 percent, this method has the advantage of not requiring a supplemental carbon source.

To keep the denitrification stage anoxic, the RBC media must be completely submerged in the wastewater. Rotation is achieved with mechanical drives at an angular velocity of approximately 1.6 rpm. At this time, Autotrol (now Envirex) is the only manufacturer marketing RBC's for denitrification.

Autotrol's design procedure is based on pilot studies indicating that in the presence of an adequate carbon source the denitrification rate in RBC's is independent of bulk liquid nitrate nitrogen concentration down to 1 mg/L, with a zero-order removal rate at 55°F of approximately 0.9 lb NO_3-N/day/1000 sq ft. Other pilot plant results, however, have exhibited a first-order relationship between nitrate removal rate and bulk liquid nitrate nitrogen concentration in the 0- to 6-mg/L range.

Power Consumption

In mechanically driven RBC systems, power is used to overcome internal resistances and losses in the motors, friction losses in gear reduction and drive belts or chains, friction losses in shaft support bearings, and the drag forces resulting from rotation of the media and attached biofilm through the wastewater. The drag forces, which represent the largest power drain, are affected by the amount and shape of the media surface, rotational speed, wastewater viscosity, and the type and amount of biological growth.

In air driven systems, compressed air discharged beneath the RBC media rises and is captured by air cups mounted to the periphery of the media. The resulting buoyant forces provide the torque necessary for media rotation. Power is required to overcome (1) losses in the compressor, compressor motor, air headers, control valves, and diffusers and (2) the static head of wastewater in the RBC tank.

Power factor is an important parameter in determining the energy cost associated with operating an induction motor. Power factor is defined as actual power divided by apprarent power. Polyphase watt meters measure actual power (kW) drawn, but demand charges are based on apparent power (kVA). Most electric utilities have demand charge schedules that penalize customers with power factors of less than 0.9. The use of capacitors to increase the power factors of induction motors can significantly reduce power costs in RBC plants, particularly plants that have large numbers of mechanically driven units.

The Upper Mill Creek treatment plant in Butler County, Ohio, uses mechanically driven units equipped with power factor correction capacitors. Measurements made on seven units indicated that the capacitors were increasing power factor from an average of about 0.5 to 0.99. The resulting 2.5-kVA savings in apparent power is worth $17.30/month/shaft in lower electricity costs at an assumed demand charge of $6.92/month kVA. Based on an approximate installed capacitor cost of $200, the payout period in this case would be about 12 months.

Field measurements of the power required for mechanically driven RBC units are reported for 16 facilities (92 shafts) in the full design information document. The media surface area for the shafts monitored varied from 100,000 to 180,000 sq ft. The measured mean power requirement was 2.98 hp/shaft, with a standard deviation of 0.71 hp/shaft and recorded high and low readings of 5.10 and 1.62 hp/shaft, respectively.

Of the 92 mechanical drive units monitored, a total of 55 were equipped with media having a surface area of 100,000 to 128,250 sq ft. Media having a surface area in this range are generally regarded in the industry as representing standard density media. The media surface area of the other 37 units varied from 138,000 to 180,000 sq ft, a range characteristic of high density media. The average measured power consumption for the standard density units was 2.80 hp/shaft with a standard deviation of 0.62 hp/shaft. For the high density units, the average power requirement recorded was 3.22 hp/shaft with a standard deviation of 0.79 hp/shaft.

An earlier EPA survey indicated that manufacturers' estimated power requirements for mechanically driven RBC's range from 2.7 to 3.4 hp/shaft for standard density media and from 3.5 to 4.2 hp/shaft for high density media. The above field-measured values agree well with the manufacturers' esitmates for standard density media and are slightly lower than the estimates for high density media.

When field-measured, mechanical drive power levels exceed the means indicated above for standard and high density media by one to two standard deviations or more, the operator should investigate whether the higher power consumption is being caused by equipment problems, heavier-than-normal biofilm growth, or both. Potential equipment problem areas include improper alignment, inadequate lubrication, excessive rotational speed, excessive belt tension or belt slippage, and general wear and deterioration of the drive components.

Power consumption in air driven RBC systems is affected by motor and blower characteristics and line losses as well as rotational speed and biofilm growth. The type of blower and its proximity to the RBC trains can significantly affect overall power requirements. Information on rotational speed versus air flow relationships is thus of greater value to the design engineer than are indiscriminate, overall power measurements.

Because the type of information discussed above is essentially unavailable to the design community at large, studies were conducted at two air driven installations (Lower East Fork and Indian Creek) in the Cincinnati, Ohio, area. In general, Autotrol's design curves underestimated the actual air requirements measured at the two plants. Load cell readings at Lower East Fork did not indicate that the biofilm being carried on those units was excessive. Though data from two plants are not sufficient to describe the rotational responses that may prevail at other RBC air driven installations, they do indicate that the recommended design relationships are not always applicable.

General Plant Design Considerations

In general, housing RBC units within a building (as opposed to using individual covers for the RBC units) is undesirable because of the high humidities and the corrosive atmospheric conditions associated with H_2S release. Condensation problems have been encountered on interior building walls in cold climates, and the associated high humidities and ventilation requirements increase heating costs. If buildings are chosen to house an RBC unit, the building design must provide for removal of a shaft/media assembly should repair or replacement prove necessary. In contrast to individual fiber glass covers, full building cover normally provides more convenient access to RBC's for routine maintenance and visual observation.

In all RBC designs, access to individual shafts for repair or possible removal mus t be considered. Bearings should also be accessible for easy removal and replacement and should also be accessible for easy removal and replacement and should be equipped with oversized grease cups to minimize manpower requirements for lubrication.

Whenever multiple-process trains are employed, provision for positive and measurable flow control to individual trains is essential. Use of single, long influent channels with slide gate control for individual trains makes it difficult for the operator to locate flow maldistributions and implement appropriate corrective procedures. Splitter boxes and/or weirs are low-cost solutions to this problem. Adequate flow control equipment is especially important if individual trains are fed from a single channel, with some trains rotating with and other trains against the direction of plant flow.

Feed and discharge flexibility should be considered in RBC design. Step feed capability can relieve overloaded first stage(s) and potentially decrease or eliminate excessively thick biofilm growth. Removable baffles may also be effective in this regard. In underloaded plants, the final stages frequently must be operated to keep suspended solids in suspension rather than to provide additional treatment to meet effluent standards. Thus, the capability for temporarily bypassing these terminal units would yield savings in energy and operation and maintenance.

Load cells can provide useful operating and shaft load data, especially in the first stages. Where parallel trains are in operation, they can pinpoint overloaded or underloaded trains. Stop motion detectors, rpm indicators, and clamp-on ammeters are also potentially useful monitoring instruments.

The use of deep channels leading to and exiting from RBC tanks has resulted in solids deposition and subsequent accumulation at a number of installations. Providing for channel aeration (3.5 scfm/linear ft) or using channel configurations that promote adequate scouring velocity should overcome this problem.

Equipment warranties can be negotiated with the manufacturers, and in some cases, extended equipment warranties have been obtained. This possibility should be thoroughly considered in equipment specifications. Although RBC manufacturers continue to make improvements in their equipment, major equipment problems and failures have occurred at some installations.

How sidestreams from other unit proceses affect RBC performance must be considered. Anaerobic digesters increase ammonia nitrogen loadings, and sludge conditioning processes such as heat treatment contribute increased organic and ammonia nitrogen loadings. Whenever septic tank discharges are part of the influent wastewater or when any unit processes are employed that may produce sulfide ahead of the RBC units, the additional oxygen demand associated with sulfide must be considered in system design. Prechlorination or preaeration may represent potentially cost effective means of eliminating the oxygen demand posed by incoming sulfide. High influent grease loads require the use of primary clarifiers instead of screens.

Nitrification is slow to develop in cold temperatures, and 8 to 10 weeks may be required before an RBC nitrification system approaches equilibrium conditions. Where seasonal standards for nitrification are required, the final design must consider the transition time and temperatures needed to develop an adequate nitrifying population.

Most existing air driven installations do not have provisions for measuring and controlling air flow to individual RBC units. Furthermore, some plants cannot easily verify whether some of the air driven diffusers have plugged. Operating an air driven facility under such blind conditions makes it more difficult to respond appropriately to operational problems that may arise. The question of how much plant blower capacity should be provided is open to debate. A critical need exists for more information on the normal range of air flows that should be expected with air driven units.

*The EPA authors **Richard C. Brenner, James A. Heidman, Edward J. Opatken,** and **Albert C. Petrasek, Jr.**, are with the Municipal Environmental Research Laboratory, Cincinnati, OH 45268.*

The complete report, entitled "Design Information on Rotating Biological Contactors," (Order No. PB 84-199 561; Cost: $17.50, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA authors can be contacted at:
Municipal Environmental Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

*USGPO: 1984-759-102-10622

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

MERL0063240
LOU W TILLEY
REGION V EPA
LIBRARIAN
230 S DEARBORN ST
CHICAGO IL 60604