RECONSIDERING ROTATING BIOLOGICAL CONTACTORS AS AN OPTION FOR MUNICIPAL WASTEWATER TREATMENT

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OVERVIEW

There are many domestic wastewater treatment processes in use today. Generally, they are all biological systems and they may be broadly categorized as either fixed film processes or suspended growth processes. During the 1970s and early 1980s, the rotating biological contactor process (RBC), a particularly efficient fixed film process, became popular. However, the primary manufacturer of RBCs in the United States manufactured some defective equipment in that time period, which led to mechanical failures and tainted the market for this process. This has caused most consulting engineers to dismiss this option from consideration.

We were recently asked to revisit this process by one of our clients and the information that we uncovered in this investigation we felt was worth sharing.

A brief overview of what we found was that RBCs may be the best process choice for some wastewater treatment plants because of their proven simplicity, reliable performance, and low energy usage (particularly important when considering LEED qualification). RBC manufacturers made several important improvements to this, over forty year old, technology to increase process performance and provide an even more robust mechanical design. For these reasons, we believe that the RBC process deserves greater consideration during process selection process than is common.

This paper presents the information found in our investigation in a FAQ format. It presents answers to twelve of the most frequently asked questions regarding the use of RBCs for wastewater treatment. Before presenting those questions and answers, the following statements by RBC operators provide a "front row" evaluation of RBCs.

> *"VRI Environmental Services, Inc. currently operates over 80 water and wastewater treatment facilities in the United States. ... In my experience RBC's provide a very economical and robust solution to wastewater treatment. ... The RBC is very easy to operate."* **Kenneth G. Scherrieble, Principal/President, VRI Environmental Services, Inc., Millbrook, New York** (Ken's complete email from which these quotes were taken is attached)

> *"Our RBC system, with 10 shafts, has been running for over 20 years and has proven to be a good, simple, low energy usage system, requiring low operational attention. It has reliably met our effluent limits."* **Joe Keefe, Superintendent, Grosse Ile Wastewater Treatment Plant, Grosse Ile Township, Michigan**

"For ease of maintenance and operation, of all of the ten plants that we operate, the RBC is the better way to go. The plant does not create any unpleasant odors." **Steve Hughes, Plant Supervisor, Handy Township Wastewater Treatment Plant, Fowlerville, Michigan**

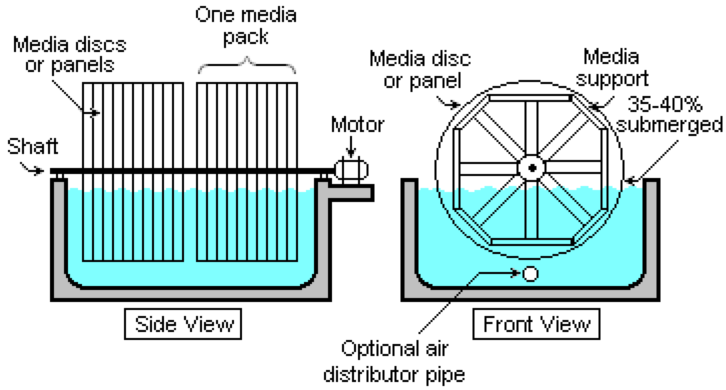
"Our first RBC's were commissioned in 1980. It's a great process. They flat-out work. There is not a lot of operator intervention required. The RBC's are energy efficient and easy to maintain. Our plant is located in the downtown area and we have not had any complaints about plant odor in all that time. I would highly recommend the use of RBC technology for municipal wastewater treatment." **Mr. Timothy Stallcup, Director of Wastewater Operations, Holly, Michigan**

"The use of RBC technology with air drive … has been an incredibly successful process for us. The plant has been in operation since 1981 and has proven to be easy to operate, routine maintenance is simple with very limited requirements, we have low power usage, and the RBC and overall process provides a high level of water quality performance. I would highly recommend the use of RBC technology ….", **Michael Barricklow, Assistant Superintendent, Allendale Charter Township, Michigan**

ROTATING BIOLOGICAL CONTACTORS (RBC)
FREQUENTLY ASKED QUESTIONS

1. How does the rotating biological contactor system work?

RBCs are a fixed film, aerobic, biological wastewater treatment system. Physically, they consist of parallel, deformed discs mounted perpendicularly on a shaft that is slowly rotated in a tank through which the wastewater to be treated is passed. The shaft is mounted above the water level in the tank. A schematic drawing follows.



Simplified Schematic of Rotating Biological Contactor

During the treatment process, microbes that remove the organic material in the wastewater (by using the organic material as a food source) attach themselves to the disc surfaces. They grow in a thin biofilm, whose thickness is controlled by the shearing force of the discs being rotated through the water. By rotating out of the water into the atmosphere, the microorganisms, growing on the disc, are provided oxygen. The surplus microorganisms that are sheared off the discs are carried with the wastewater to clarifiers where they are separated from the treated wastewater by settling out. The settled solids are then pumped from the bottom of the clarifier for further processing, most commonly, for use as fertilizer or soil amendment.

2. Why are fixed film systems, such as RBCs, becoming more popular?

Fixed film processes have several advantages over the activated sludge process, which is the most common suspended growth process. Also, advances in design have been made, eliminating fixed film processes previous disadvantages. Therefore, there is increasing interest in fixed film processes in the wastewater treatment industry. In recognition of the increasing interest in fixed film processes, the Water Environment Federation recently published "Biofilm Reactors – Manual of Practice 35" in September 2010. The advantages of fixed film systems are as follows:

- **Low Energy Usage** – RBCs uses approximately one half the amount of energy used by the activated sludge process. (See "**5. Can the energy savings of RBCs be quantified?"** below.)
- **Process Stability with Load Variations** – Since the microorganisms in a fixed film system are attached to a media, they cannot wash out with increased flows. Also fixed film systems generally have a greater mass of microorganisms, making them better able

to handle organic load increases. The activated sludge process, on the other hand, is more susceptible to performance deterioration due to hydraulic and organic load variations. Rapid flow increases tend to wash microorganisms out of the aeration tank at precisely the time that a high concentration is needed. Sometimes the microorganisms are even washed out of the system with the clarifier effluent. Rapid changes in organic loads can result in significantly reduced performance as a result of too few microorganisms in the system relative to the organic load.

- **Low Solids Generation** – Fixed film systems generate fewer, more concentrated solids than activated sludge. This results in smaller clarifiers and reduces the size of solids handling systems. The literature reports that the mass of solids produced by typical fixed film systems is 10% to 20% less than for activated sludge, due to the longer solids retention time.

- **More Reliable Liquid/Solids Separation** – The technical literature regarding activated sludge is filled with advice on how to avoid filamentous growth, foaming, dispersed growth, and other situations that lead to poor liquid/solids separation and poor effluent quality. Fixed film systems seldom experience such problems since the surplus bacteria generated slough off the media in relatively large, easily settled floc.

- **Easy to Operate** – Fixed film systems operate with little operator intervention and monitoring and generally use simple, low maintenance equipment. With activated sludge, the operator must constantly be aware of conditions that could lead to poorly settling sludge or inadequate BOD removal. This requires continual monitoring of the wastewater quality, the type of microorganisms in the aeration basin, the amount of dissolved oxygen in the aeration basin, the rate at which the biological solids settle and how well they compact, and other conditions. To address system changes, the operator must adjust the amount of biological solids in the system, the amount of oxygen provided, the rate of return of biological solids from the clarifier to the aeration basin, and may have to make other process adjustments. All of these require operator attention and time. Further, activated sludge plants occasionally experience periods of poor performance due to poorly settling solids. During these times, the operator must take steps to respond that often involve even more intensely monitoring plant conditions. Also, activated sludge systems often use high speed rotating equipment and aeration devices that require frequent maintenance.

- **No Sludge Return** – In order to maintain a large mass of microorganisms in the system, activated sludge plants need to return activated sludge that settles in the secondary clarifiers back to the aeration tank. This requires pumping and operational control. This requires energy, pump maintenance, and close process monitoring. Since the required mass of microorganisms in the RBC system is attached to the media surface, no sludge return pumping is required.

- **Less Land Required** – Fixed film processes can achieve more treatment on less land than conventional activated sludge systems. ("Water Environment Federation – Manual of Practice 8", p. 12-5) (See "**7. How much less land is used by the RBC process than the activated sludge process?"** below**)**

3. Can RBCs produce high quality effluent?

"*Properly designed the RBC system can achieve superior performance to suspended growth biological treatment systems* as well as other fixed film systems due to lower organic loading per mass of biological solids, longer solids detention time, and better control of short circuiting." (emphasis added) United States Environmental Protection Agency (1992) *Rotating Biological Contactors*, EPA/540/S-92/007, Washington.

As an example, the RBC wastewater plant at Allendale, Michigan uses a polishing pond following secondary clarification and it regularly achieves monthly average effluent BOD5 and TSS concentrations of less than 10 mg/l.

4. Can RBCs be used for larger wastewater treatment plants?

Just like activated sludge, *RBCs are a modular process and are scalable to any plant size*.

However, in most cases, large wastewater treatment plants serve communities that began building their wastewater treatment plants before the invention of RBCs and therefore are committed to the activated sludge process. Thus, it is relatively uncommon for RBCs to be found at large plants. Not because they are not appropriate, but because the plants are already using the activated sludge process and it is natural to expand using the same process. However, there are cases where RBCs have been added to activated sludge plants to increase the level of treatment where a smaller footprint and reduced energy costs are desired.

An example of a larger wastewater treatment plant in the United States using RBCs is Asheville, North Carolina, which uses one hundred fifty two (152), 8 meter long, 3 meter diameter RBCs to treat up to 40 mgd (150,000 cubic meters per day) of domestic wastewater. An aerial photo of this plant follows.

Aerial Photo – Asheville, North Carolina (Buncombe County) WWTP

Following is a ground level view of a portion of the RBCs used for the Asheville wastewater treatment plant.

Ground Level View - RBCs – Asheville, North Carolina (Buncombe County) WWTP

Another example is at Peoria, Illinois, where eighty four (84), 8 meter long, 3 meter diameter RBCs are used to remove ammonia from a design average flow of 37 mgd (140,000 cubic meters per day). An overview and some photos of that plant follow.

The treatment plant serving the City of Peoria, shown at left, is designed to treat an average flow of 37 million gallons of wastewater every day. The plant was originally built as an activated sludge plant and eighty four (84) RBCs were added later, as a second stage, to remove ammonia, demonstrating the use of RBCs as a cost effective method of nutrient removal. An aerial view of the RBCs follows.

Birds Eye View - Eighty four (84) RBCs for Nitrification at Peoria

5. Can the energy savings of RBCs be quantified?

Energy saving is an attractive feature of RBC treatment. In order to understand the magnitude of the savings, we will assume that we are designing a plant for 30 mgd (112,500 cubic meters of wastewater per day) containing 355 mg/l of BOD. If we assume that 30% of the influent BOD is removed in primary treatment, then approximately 250 mg/l of BOD (62,000 pounds per day) will be applied to secondary treatment each day.

RBC plants employing 3 meter diameter discs (the size most frequently used for larger plants) typically use motors drawing 3 kW per 100,000 square feet of disc surface area. Commonly, an RBC plant, treating typical domestic wastewater, can remove 0.0023 lbs of BOD per square foot of disc surface area. Therefore, in our theoretical plant, we will need approximately 26,700,000 square feet of disc surface area (62,000 pounds of BOD divided by 0.0023 pounds per square foot). At 3 kW per 100,000 square feet this plant will use approximately 800 kW of power (26,700,000 square feet divided by 100,000 square feet times 3 kW).

An activated sludge plant will require approximately 1.2 pounds of oxygen per pound of BOD removed. 1 kWh of power is required to provide approximately 2 pounds of oxygen. Therefore, for our theoretical plant we will need to generate 75,000 pounds of oxygen per day (62,000 pounds of BOD times 1.2 pounds of oxygen per pound of BOD). This will require 1,500 kW of power (75,000 pounds of oxygen per day divided by 2 pounds of oxygen per kilowatt hour times 24 hours per day). In addition, the activated sludge process requires pumping of return activated sludge, which generally uses 10% of the power required for aeration, bringing the process total to over 1,650 kW of power required.

In this simplified, theoretical example, it can be seen that the RBC process uses less than half the power used by a typical activated sludge system. Energy savings are even greater when compared to an MBR activated sludge system. Energy requirements of membrane bioreactor activated sludge plants, "Historically…exceeded that of a typical activated sludge plant by a factor of 1.5 to 3." Wallis-Lage, C and Scott Levesque, "Energy Efficient MBRs", Water & Environment Technology, January 2011.

6. How do RBCs reduce the cost of other plant processes?

RBCs reduce the cost of other plant processes by the nature of the excess biosolids that are generated when compared to those created in the activated sludge process.

Activated sludge plants often generate sludge that settles poorly in secondary clarifiers, due to its finely divided nature and occasional problems with filamentous bacteria. RBCs, on the other hand, generate larger, more rapidly settling sludge particles. The wastewater industry recognizes this fact and generally allows the secondary clarifiers for RBC plants to be approximately 20% smaller than for activated sludge plants. This is one area of construction cost and land area savings. This difference in solids separation also leads to reduced operator attention, since controlling filamentous bacteria and controlling sludge recycle rate are constant concerns of activated sludge plant operators.(see above "**2. Why are fixed film systems, such as RBCs, becoming more popular?**" bullet point "Easy to Operate")

Additionally, RBC sludge is more concentrated than waste activated sludge and thickens better, reducing the volume of sludge that must be handled by approximately 25%. This, in turn reduces the size of sludge processing facilities, such as digesters by a similar percentage and can also reduce operating costs.

7. How much less land is used by the RBC process than the activated sludge process?

Going back to our theoretical plant treating 30 mgd (112,500 cubic meters per day) of wastewater, 26,700,000 square feet of RBC media are required. A 10 foot by 25 foot tank will contain 100,000 square feet of media. Therefore, 270 RBCs are needed, occupying a surface area of approximately 98,000 square feet, including three feet on all sides of the tank.

For the activated sludge plant, an aeration basin with about 8 hours of detention time is needed. Typically, these basins are approximately 12 to 15 feet deep. Assuming they are 15 feet deep, then the area required is 90,000 square feet. The blower and control building will typically occupy approximately 10,000 square feet. In addition, the final clarifiers will need to be approximately 6,000 square feet larger.

Based on this example, the RBC process will occupy slightly less area than that occupied by the activated sludge process.

8. Can RBCs provide nutrient removal similar to that provided by activated sludge systems?

RBCs can provide nutrient removal in the following ways. For ammonia conversion to nitrates (nitrification), more surface area must be provided, just as more microorganisms (higher sludge age) are required for activated sludge to nitrify (for an example of RBCs used for nitrification see "**Can RBCs be used for larger wastewater treatment plants?"** above with reference to the Peoria wastewater treatment plant). For nitrogen removal, submerged RBCs are used following nitrification.

With regard to phosphorus removal, conventional biological processes remove phosphorus with excess cell mass. If further phosphorus removal is required, the addition of iron or aluminum salts to RBCs is the way in which phosphorus levels can be reduced to less than 1 mg/l. Some variants of the activated sludge process accomplish additional phosphorus removal through biological nutrient removal.

9. Why are fixed film systems (RBCs and trickling filters) more resistant to process upsets than activated sludge?

RBCs are more resistant to process upsets for two reasons. First is that the microorganisms are attached to the media and are not washed out of the system by high flows. Also, since the microorganisms are attached to the media, recovery from toxic discharge upsets is much more rapid. Second, there are more kilograms of microorganisms in an RBC plant than an activated sludge plant. The more microorganisms in a system the better able it is to withstand increased organic loads and toxic discharges.

10. Why has the wastewater industry primarily used activated sludge treatment?

Fixed film processes, mainly rock trickling filters, predominated in the early years of biological wastewater treatment. Rock filters, however, had certain drawbacks – mainly plugging, odors and seasonally poor performance. This led to activated sludge becoming the primary biological treatment method for municipal wastewater.

However, it was recognized by wastewater experts that fixed film processes had certain advantages – low energy usage, simple operation, and resistance to shock loadings. For these reasons, engineers endeavored to determine the causes of poor performance of rock trickling filters. The general problems were found to be poor oxygen transfer, particularly during periods when the air and water temperature were nearly equal causing little or no airflow through the media, and the second problem was the lack of uniform clearance in the rock media, which allowed plugging to occur and subsequent anaerobic pockets within the media. Occasionally, low flows also inhibited removal of excess microorganisms. Synthetic media, plastic and wood, with forced draft ventilation was used to overcome these problems, along with recirculation and control of wastewater application. Dow Chemical in the United States and Munters in Sweden did much of this research. With the changes proposed by Dow and Munters, relatively tall, plastic media trickling filter facilities became possible. But at that point in time, many plants were already using activated sludge, so conversion was not considered an option.

Rotating biological contactors, which were developed as an even more energy efficient fixed film process than synthetic media trickling filters, were developed in the late 1960s and began to be commercialized in the mid-1970s. Again, most plants in the United States, by that time, employed activated sludge, so conversion to RBCs was not considered an option.

11. How much less operation and maintenance attention is required by an RBC system than an activated sludge system?

This issue was studied by the United States Environmental Protection Agency and the results were published by the Office of Research and Development in "Treatability Manual – EPA-600/8-80-042d". In this study, it was estimated that *a plant treating approximately 2.5 mgd using an RBC process would use less than one-half the labor required by a conventional activated sludge plant* using mechanical aeration and approximately one fifth for plants treating 25 mgd. We believe these labor estimates overstate the savings for RBCs, but do indicate the advantage that RBCs have in this regard.

12. How is the RBC process designed?

The RBC process is designed like any other fixed film system. The key considerations are mass transfer of oxygen and substrate to the microorganisms growing on the discs and the overall mass of microorganisms in the system in relation to the BOD, ammonia, and/or nitrogen that must be removed. In general, the first stage is limited by oxygen transfer and the organic loading must be limited to less than a certain amount of BOD per unit of surface area to prevent overgrowth and anaerobic conditions in the first stage. The overall RBC surface area is then dependent on the effluent results required. This can be determined using 2 dimensional mass transfer models, such as Biowin, GPS-X, or Pro2D. Typically, three stages are required to get a high degree of BOD removal and more may be required for nitrification (biological conversion of ammonia to nitrate). Submerged discs are used to achieve denitrification (biological nitrogen removal by converting nitrate to nitrogen gas).

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