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Engineering Bulletin
Rotating Biological Contactors

Purpose

Section 121(b) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) mandates the Environmental Protection Agency (EPA) to select remedies that "utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable" and to prefer remedial actions in which treatment "permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances, pollutants, and contaminants as a principal element." The Engineering Bulletins are a series of documents that summarize the latest information available on selected treatment and site remediation technologies and related issues. They provide summaries of and references for the latest information to help remedial project managers, on-scene coordinators, contractors, and other site cleanup managers understand the type of data and site characteristics needed to evaluate a technology for potential applicability to their Superfund or other hazardous waste site. Those documents that describe individual treatment technologies focus on remedial investigation scoping needs. Addenda will be issued periodically to update the original bulletins.

Abstract

Rotating biological contactors (RBCs) employ aerobic fixed-film treatment to degrade either organic and/or nitrogenous (ammonia-nitrogen) constituents present in aqueous waste streams. Treatment is achieved as the waste passes by the media, enabling fixed-film systems to acclimate biomass capable of degrading organic waste [1, p. 91]*. Fixed-film RBC reactors provide a surface to which soil organisms can adhere; many indigenous soil organisms are effective degraders of hazardous wastes.

An RBC consists of a series of corrugated plastic discs mounted on a horizontal shaft. As the discs rotate through the aqueous waste stream, a microbial slime layer forms on the surface of the discs. The microorganisms in this slime layer degrade the waste's organic and nitrogenous constituents. Approximately 40 percent of the RBC's surface area is immersed in the waste stream as the RBC rotates through the liquid. The remainder of the surface area is exposed to the atmosphere, which provides oxygen to the attached microorganisms and facilitates oxidation of the organic and nitrogenous contaminants [2, p. 6]. In general, the large microbial population growing on the discs provides a high degree of waste treatment in a relatively short time. Although RBC systems are capable of performing organic removal and nitrification concurrently, they may be designed to primarly provide either organic removal or nitrification singly [3, p. 1-2].

RBCs were first developed in Europe in the 1950s [1, p. 6]. Commercial applications in the United States did not occur until the late 1960s. Since then, RBCs have been used in the United States to treat municipal and industrial wastewaters. Because biological treatment converts organics to innocuous products such as CO_2, investigators have begun to evaluate whether biological treatment systems like RBCs can effectively treat liquid waste streams from Superfund sites. Treatability studies have been performed at at least three Superfund sites to evaluate the effectiveness of this technology at removing organic and nitrogenous constituents from hazardous waste leachate. A full-scale RBC treatment system is presently operating in at least one Superfund site in the United States.

Technology Applicability

Research demonstrates that RBCs can potentially treat aqueous organic waste streams from some Superfund sites. During the treatability studies for the Stringfellow, New Lyme, and Moyer Superfund sites, RBC systems efficiently removed the major organic and nitrogenous constituents in the leachates. Because waste stream composition varies from site to site, treatability testing to determine the degree of contaminant removal is an essential element of the remedial action plan. Although recent Superfund applications have been limited to the treatment of landfill leachates, this technology may be applied to groundwater treatment [4].

In general, biological systems can degrade only the soluble fraction of the organic contamination. Thus the applicability of RBC treatment is ultimately dependent upon the solubility of the contaminant. RBCs are generally applicable to influents containing organic concentrations of up to 1 percent organics, or between 40 and 10,000 mg/l of SBOD. (Note: Soluble biochemical oxygen demand, or SBOD, measures the soluble fraction of the biodegradable organic content in terms of oxygen demand.) RBCs can be designed to reduce influent biochemical oxygen demand (BOD) concentrations below 5 mg/l SBOD and ammo-

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*[reference number, page number]

Table 1
Effectiveness of RBCs on General Contaminant Groups for Liquid Waste Streams

	Contaminant Groups	*Effectiveness*
Organic	Halogenated volatiles	■
	Halogenated semivolatiles	■
	Nonhalogenated volatiles	■
	Nonhalogenated semivolatiles	■
	PCBs	▼
	Pesticides	▼
	Dioxins/Furans	❑
	Organic cyanides	▼
	Organic corrosives	▼
Inorganic	Volatile metals	❑
	Nonvolatile metals	❑
	Asbestos	❑
	Radioactive materials	❑
	Inorganic corrosives	❑
	Inorganic cyanides	▼
Reactive	Oxidizers	❑
	Reducers	❑

■ Demonstrated Effectiveness: Successful treatability test at some scale completed.
▼ Potential Effectiveness: Expert opinion that technology will work.
❑ No Expected Effectiveness: Expert opinion that technology will not work.

nia-nitrogen (NH_3-N) levels below 1.0 mg/l [5, p. 2] [6, p. 60]. RBCs are effective for treating solvents, halogenated organics, acetone, alcohols, phenols, phthalates, cyanides, ammonia, and petroleum products [7, p. 6] [8, p. 69]. RBCs have fully nitrified leachates containing ammonia-nitrogen concentrations up to 700 mg/l [6, p. 61].

The effectiveness of RBC treatment systems on general contaminant groups is shown in Table 1. Examples of constituents within contaminant groups are provided in "Technology Screening Guide for Treatment of CERCLA Soils and Sludges" [9]. Table 1 is based on the current available information or professional judgment where no information was available. The proven effectiveness of the technology for a particular site or waste does not ensure that it will be effective at all sites or that the treatment efficiencies achieved will be acceptable at other sites. For the ratings used for this table, demonstrated effectiveness means that, at some scale, treatability was tested to show the technology was effective for that particular contaminant group. The ratings of potential effectiveness or no expected effectiveness are based upon expert judgment. Where potential effectiveness is indicated, the technology is believed capable of successfully treating the contaminant group in a particular medium. When the technology is not applicable or will probably not work for a particular combination of contaminant group and medium, a no expected effectiveness rating is given.

Limitations

Although RBCs have proven effective in treating waste streams containing ammonia-nitrogen and organics, they are not effective at removing most inorganics or non-biodegradable organics. Wastes containing high concentrations of heavy metals and certain pesticides, herbicides, or highly chlorinated organics can resist RBC treatment by inhibiting microbial activity. Waste streams containing toxic concentrations of these compounds may require pretreatment to remove these materials prior to RBC treatment [10, p. 3].

RBCs are susceptible to excessive biomass growth, particularly when organic loadings are elevated. If the biomass fails to slough off and a blanket of biomass forms which is thicker than 90 to 125 mils, the resulting weight may damage the shaft and discs. When necessary, excess biofilm may be reduced by either adjusting the operational characteristics of the RBC unit (e.g., the rotational speed or direction) or by employing air or water to shear off the excess biomass [11, p. 2].

In general, care must be taken to ensure that organic pollutants do not volatilize into the atmosphere. To control their release, gaseous emissions may require offgas treatment [12, p. 31].

All biological systems, including RBCs, are sensitive to temperature changes and experience drops in biological activity at temperatures lower than 55°F. Covers should be employed to protect the units from colder climates and extraordinary weather conditions. Covers should also be used to protect the plastic discs from degradation by ultraviolet light, to inhibit algal growth, and to control the release of volatiles [13]. In general, organic degradation is optimum at a pH between 6 and 8.5. Nitrification requires the pH be greater than 6 [6, p. 61].

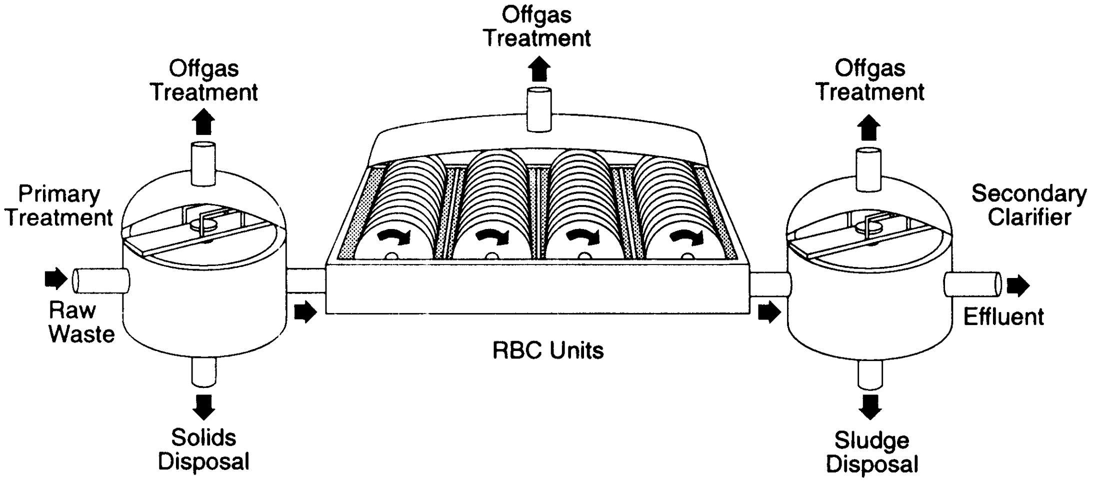
Additionally, nutrient and oxygen deficiencies can reduce microbial activity, causing significant decreases in biodegradation rates [14, p. 39]. Extremes in pH can limit the diversity of the microbial population and may suppress specific microbes capable of degrading the contaminants of interest. Fortunately, these variables can be controlled by modifying the system design.

Technology Description

A typical RBC unit consists of 12-foot-diameter plastic discs mounted along a 25-foot horizontal shaft. The total disc surface area is normally 100,000 square feet for a standard unit and 150,000 square feet for a high density unit. Figure 1 is a diagram of a typical RBC system.

As the RBC slowly rotates through the groundwater or leachate at 1.5 rpm, a microbial slime forms on the discs. These microorganisms degrade the organic and nitrogenous contaminants present in the waste stream. During rotation, approximately 40 percent of the discs' surface area is in contact with the aqueous waste while the remaining surface area is exposed to the atmosphere. The rotation of the media through the atmosphere causes the oxygenation of the attached organisms. When

Figure 1
Typical RBC Plant Schematic (12)



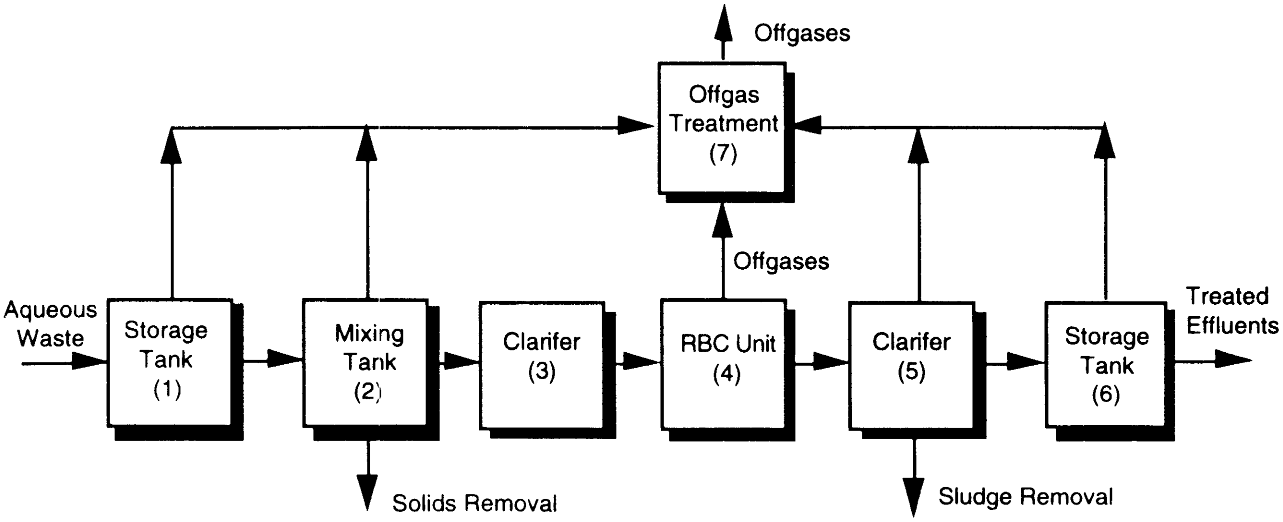
operated properly, the shearing motion of the discs through the aqueous waste causes excess biomass to shear off at a steady rate. Suspended biological solids are carried through the successive stages before entering the secondary clarifier [2, p. 13.101].

Primary treatment (e.g., clarifiers or screens), to remove materials that could settle in the RBC tank or plug the discs, is often essential for good operation. Influents containing high concentrations of floatables (e.g., grease, etc.) will require treatment using either a primary clarifier or an alternate removal system [11, p. 2].

The RBC treatment process may involve a variety of steps, as indicated by the block diagram in Figure 2. Typically, aqueous waste is transferred from a storage or equalization tank (1) to a mixing tank (2) where chemicals may be added for metals precipitation, nutrient adjustment, and pH control. The waste stream then enters a clarifier (3) where the solids are separated from the liquid. The effluent from the clarifier enters the RBC (4) where the organics and/or ammonia are converted to innocuous products. The treated waste is then pumped into a second clarifier (5) for removal of the biological solids. After secondary clarification the effluent enters a storage tank (6) where, depending upon the contamination remaining in the effluent, the waste may be stored pending additional treatment or discharged to a sewer system or surface stream. Throughout this treatment process the offgases from the various stages should be collected for treatment (7). The actual treatment train will, of course, depend upon the nature of the waste and will be selected after the treatability study is conducted.

Staging, which employs a number of RBCs in series, enhances the biochemical kinetics and establishes selective biological cultures acclimated to successively decreasing organic load-

Figure 2
Block Diagram of the RBC Treatment Process



ings. As the waste stream passes from stage to stage, progressively increasing levels of treatment occur [2, p. 13.105].

In addition to maximizing the system's efficiency, staging can improve the system's ability to handle shock loads by absorbing the impact of a shock load in the initial stages, thereby enabling subsequent stages to operate until the affected stages recover [15, p. 10.200].

Factors effecting the removal efficiency of RBC systems include the type and concentration of organics present, hydraulic residence time, rotational speed, media surface area exposed and submerged, and pre- and post-treatment activities. Design parameters for RBC treatment systems include the organic and hydraulic load rates, design of the disc train(s), rotational velocity, tank volume, media area submerged and exposed, retention time, primary treatment and secondary clarifier capacity, and sludge production [8, p. 69].

Process Residuals

During primary clarification, debris, grit, grease, metals, and suspended solids (SS) are separated from the raw influent. The solids and sludges resulting from primary clarification may contain metallic and organic contaminants and may require additional treatment. Primary clarification residuals must be disposed of in an appropriate manner (e.g., land disposal, incineration, solidification, etc.).

Following RBC treatment, the effluent undergoes secondary clarification to separate the suspended biomass solids from the treated effluent. Refractory organics may contaminate both the clarified effluent and residuals. Additional treatment of the solids, sludges, and clarified effluent may be required. Clarified secondary effluents which meet the treatment standards are generally discharged to a surface stream, while residual solids and sludges must be disposed of in an appropriate manner, as outlined above for primary clarification residuals [2, p. 13.120].

Volatile organic compound (VOC)-bearing gases are often liberated as a byproduct of RBC treatment. Care must be taken to ensure that offgases do not contaminate the work space or the atmosphere. Various techniques may be employed to control these emissions, including collecting the gases for treatment [13].

Site Requirements

RBCs vary in size depending upon the surface area needed to treat the hazardous waste stream. A single full size unit with a walkway for access on either side of the unit takes up approximately 550 square feet [16]. The total area required for an RBC system is site-specific and depends on the number, size, and configuration of RBC units installed.

Contaminated groundwater, leachates, or waste materials are often hazardous. Handling and treatment of these materials requires that a site safety plan be developed to provide for personnel protection and special handling measures. Storage should be provided to hold the process product streams until they have been tested to determine their acceptability for disposal, reuse, or release. Depending on the site, a method to store waste that has been prepared for treatment may be necessary. Storage capacity will depend on waste volume.

Onsite analytical equipment capable of determining site-specific organic compounds for performance assessment make the operation more efficient and provide better information for process control.

Performance Data

Limited information is available on the effectiveness of RBCs in treating waste from Superfund sites. Most of the data came from studies done on leachate from the New Lyme, Ohio; Stringfellow, California; and Moyer, Pennsylvania Superfund sites. The results of these studies are summarized below.

In order to compensate for the lack of Superfund performance data, non-Superfund applications are also discussed. The majority of the performance data for non-Superfund applications were obtained from industrial RBC operations. Theoretically this information has a high degree of application to Superfund leachate and groundwater treatment.

The quality of the information present in this section has not been determined. The data are included as a general guidance, and may not be directly transferrable to a specific Superfund site. Good characterization and treatability studies are essential in further refining and screening of RBC technology.

New Lyme Treatability Study

The EPA performed a remedy selection study on the leachate from the New Lyme Superfund site located in New Lyme Township, Ashtabula County, Ohio, to help determine the applicability of an RBC to treat hazardous waste from a Superfund site. Samples of leachate collected from various seeps surrounding the landfill showed that the leachate was highly concentrated. Results indicated that the leachate contained up to 2,000 mg/l dissolved organic carbon (DOC), 2,700 mg/l SBOD, and 5,200 mg/l soluble chemical oxygen demand (SCOD) [17, p. 12]. (Note: SCOD measures the soluble fraction of the organics amenable to chemical oxidation, as well as certain inorganics such as sulfides, sulfites, ferrous iron, chlorides, and nitrites.)

Leachate from the New Lyme site was transported from New Lyme to a demonstration-scale RBC located at the EPA's Testing and Evaluation Facility in Cincinnati, Ohio. After an adequate biomass was developed on the RBC discs using a primary effluent supplied by Mill Creek Treatment Facility (a local industrial wastewater treatment facility), the units were gradually acclimated to an influent consisting of 100 percent leachate. Results indicated that within 20 hours the RBC removed 97 percent of the gross organics, as represented by DOC, from the leachate (see Figure 3 and Table 2) [18, p. 7]. Priority pollutants were either converted and/or stripped from the leachate during treatment. After normal clarification, the effluent from the RBC was eligible for disposal into the sewer system leading to the Mill Creek facility.

Stringfellow Treatability Study

A remedy selection study using an RBC was conducted on leachate from the Stringfellow Superfund site located in Glen Avon, California. After the leachate from this site received lime treatment to remove metal contamination, the leachate was transported to the EPA's Testing and Evaluation Facility in Cincinnati for testing similar to the New Lyme study. The objective of this study was to determine whether the leachate from Stringfellow could be treated economically with an RBC system.

The leachate from this site was generated at a daily rate of 2,500 gallons. Compared to the New Lyme leachate, it contained moderate concentrations of gross organics with DOC values of 300 mg/l, SBOD values of 420 mg/l, and SCOD values of 800 mg/l [4, p. 44].

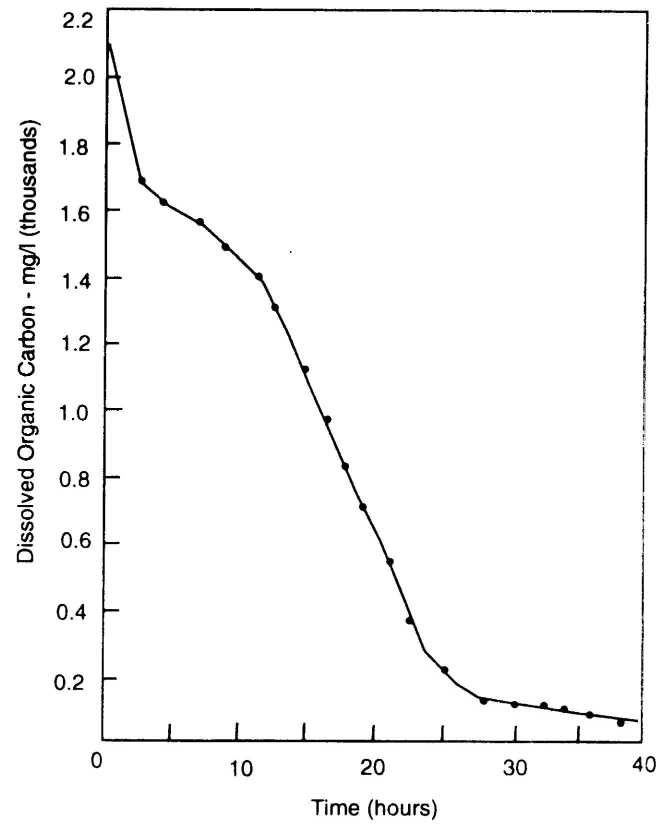
Results indicated that greater than 99 percent of SBOD was removed, 65 percent of DOC was removed, and 54 percent SCOD was removed within four days using the RBC laboratory-scale treatment system [4, p. 44]. Table 3 presents pertinent information on the treatment of 100 percent leachate. Since the DOC and SCOD conversion rates were low, a significant fraction of the refractory organics remained following treatment. Activated carbon was used to reduce the DOC to limits acceptable to the Mill Creek Treatment Facility.

Table 2
Removal of Pollutants from New Lyme Leachate (17, p. 17)
Experiment 5

	Influent (mg/l)	*Effluent (mg/l)*
SBOD	2700	4
BOD_T	3000	6.6
DOC	2000	17
TOC	2100	19
SCOD	5200	33
NO_3^-N	<1	60
SS	1400	6600
VSS	240	2600
Volatile PP		
Benzene	0.28	<0.002
Toluene	4.9	<0.002
Additional Volatiles		
Cis 1,2-Dichloroethene	0.94	ND
Xylenes	2.8	ND
Acetone	140	ND
Methyl Ethyl Ketone	470	ND
Total Organic Halides	-	1.2
Total Toxic Organics	<0.250	<0.010

BOD_T = Total Biochemical Oxygen Demand
NO_3-N = Nitrogen as Nitrate
VSS = Volatile Suspended Soilds

Figure 3
Disappearance of DOC with Time (17, p. 14)
Experiment 5*



* The influent for Experiment 5 consisted of 100 percent leachate and the biomass on the RBCs was acclimated. Nutrient addition was also employed (at a ratio of 160/5/2 for C/N/P).

Moyer Treatability Study

During a recent remedy selection study, three treatability-scale RBCs were used to degrade a low-BOD (26 mg/l), high ammonia (154 mg/l) leachate from the Moyer Landfill Superfund site in Lower Providence Township near Philadelphia, Pennsylvania [19, p. 971]. The leachate has low organic strength (e.g., 26 mg/l BOD, 358 mg/l COD, and 68 mg/l TOC) which is typical of an older landfill and it also contains mainly non-biodegradable organic compounds [19, p. 972]. (Note: Total organic carbon, or TOC, is a measure of all organic carbon expressed as carbon.) The abundance of ammonia found in the leachate prompted investigators to attempt ammonia oxidation with an RBC system. Relatively low substrate loading rates were employed during the study (0.2, 0.4, and 0.6 gpd/square foot of disc surface area per stage). Ammonia oxidation was essentially complete (98 percent) and a maximum of 80 percent of the BOD and 38 percent of the COD in the leachate was oxidized [19, p. 980]. Runs performed using lower loading rates experienced the largest removals. A limited denitrification study was also performed using an anoxic RBC to treat an RBC effluent generated during the aerobic segment of the treatability investigation. This study demonstrated the feasibility of using denitrification to treat the nitrate produced by aerobic ammonia oxidation [19, p. 980].

Non-Superfund Applications

The Homestake Mine in Lead, South Dakota has operated an RBC wastewater treatment plant since 1984. Forty-eight RBCs treat up to 5.5 million gallons per day (MGD) (21,000 m^3) of discharge water per day. The system was designed to degrade thiocyanate, free cyanide, and metal-complexed cyanides, to reduce heavy metal concentrations, and to remove ammonia, which is a byproduct of cyanide degradation [20, p. 2]. Eight parallel treatment trains, utilizing five RBCs in series, were employed to degrade and nitrify the metallurgical process waters (see Table 4 for a characterization of the influent). The first two RBCs in each train were used to degrade the cyanides and remove heavy toxic metals and particulate solids through biological adsorption. The last three RBCs employed nitrification to convert the ammonia to nitrate. Table 5 provides an average performance breakdown for the system. During its operation, overall performance improved significantly, as demonstrated by an 86 percent increase in the systems ability to reduce total effluent cyanide concentrations (e.g., from 0.45 to 0.06 mg/l). Concurrently, the cost per kg to treat cyanide dropped from $11.79 to $3.10, while the cost per m^3 to treat effluent decreased by 50 percent [21, p. 9]. In general, the system has responded well to any upsets or disturbances. Diesel fuels, lubricants, degreasers, biocides, dispersants, and flocculants have been periodically found in the influent wastewater but normally only create minor upsets in the performance of the plant. During the life of the system, the number of upsets and the biomass's ability to recuperate have both improved [21, p. 6].

A significant difference between the Homestake system and the other RBC systems described within this report is that instead of removing the metals contaminating the wastewater in the pretreatment stage, metal reduction is accomplished through bioadsorption during the treatment phase. Bioadsorption of metals by biological cells is not unlike the use of activated carbon, however the number and complexity of binding sites on the cell wall are enormous in comparison [20, p. 2].

In a study by Israel's Institute of Technology, a laboratory-scale RBC was used to treat an oil refinery wastewater. The wastewater had been pretreated using oil-water separation and dissolved air flotation. As summarized in Table 6, 91 percent of the hydrocarbon and 97 percent of the phenol were removed, as well as 96 percent of the ammonia-nitrogen [22, p. 4]. By gradually increasing the concentration of phenols present in the influent (e.g., over a 5 day period) from 5 mg/l to 30 mg/l, the system demonstrated that it was capable of quickly adapting to influent changes and higher phenolic loads [22, p. 6]. During this period, the RBC was able to maintain effluent COD concentrations at levels comparable to previous loadings. The system's resiliency was further demonstrated by its ability to recover from a major disturbance (e.g., such that effluent COD removal was interrupted) within 4 days [22, p. 7].

Table 3
Treatment of 100% Stringfellow Leachate (4, p. 44)

	Leachate (mg/l)	*RBC Effluent (mg/l)*	*Use APC plus Effluent (mg/l)*
SBOD	420	<3.0	0.9
BOD	440		22
DOC	300	110	20
TOC	310		22
SCOD	800	360	79
COD	840		95
SS	43		23
VSS	31		14
NH_3-N	3.4		6.3
NO_3-N	44		34

APC = Activated Powered Carbon
COD = Chemical Oxygen Demand

Table 4
Homestake Mine Wastewater Matrix *

	Decant Water (mg/l)	*Mine Water (mg/l)*	*Influent Blend (mg/l)*
Thiocyanate	110-350	1-33	35-110
Total Cyanide	5.5-65.0	0.30-2.50	0.50-11.50
WAD Cyanide	3.10-38.75	0.50-1.10	0.50-7.15
Copper	0.5-3.1	0.10-2.65	0.15-2.95
Ammonia-N	5-10	5.00-19.00	6-12
Phosphorus-P	0.10-0.20	0.10-0.15	0.10-0.15
Alkalinity	50-200	150-250	125-225
pH	7-9	7-9	7.5-8.5
Hardness	400-500	650-1400	500-850
Temperature°C	1.0-27.2	24-33	5-25

WAD = Weak Acid Dissociable
*Adapted from reference [20, p. 8]

Table 5
Influent, Effluent and Permit Concentrations at the Homestake Mines (20, p. 8)

	Influent (mg/l)	*Effluent (mg/l)*	*Permit (mg/l)*
Thiocyanate	62.0	<0.5	-
Total Cyanides	4.1	0.06	1.00
WAD Cyanide	2.3	<0.02	0.10
Total Copper	0.56	0.07	0.13
Total Suspended Soils	-	6.0	10.0
Ammonia-Nitrogen	5.60*	<0.50	1.0-3.9

*Ammonia peaks at 25 mg/l within the plant as a cyanide degradation byproduct

Technology Status

RBCs have been used commercially in the United States since

Table 6
Refinery Wastewater Quality Before and After RBC Treatment (22, p. 4)

Constituent		Influent (mg/l)	Effluent (mg/l)
COD	Total	715	197
	Soluble	685	186
BOD	Total	140	8
	Soluble	128	6
Phenols		7.5	0.22
Suspended Solids			
	Total	32	7
	Volatile	29	6
NH_3-N		12.8	0.48

the late 1960s to treat municipal and industrial wastes. In the past decade, studies have been performed to evaluate the effectiveness of RBCs in treating leachate from hazardous waste sites.

Treatability studies have been performed on leachate from the Stringfellow, New Lyme, and Moyer Superfund sites. Results of these studies indicate that RBCs are effective in removing organic and nitrogenous constituents from hazardous waste leachate. Additional research is needed to define the effectiveness of an RBC in treating leachates and contaminated groundwater and to determine the degree of organic stripping that occurs during the treatment process. RBCs are being used to treat leachate from the New Lyme Superfund site.

RBCs require a minimal amount of equipment, manpower, and space to operate. Staging of RBCs will vary from site to site depending on the waste stream. The cost to install a single RBC unit with a protective cover and a surface area of 100,000 to 150,000 square feet ranges from $80,000 to $85,000 [16] [23].

During the Stringfellow treatability study researchers determined that by augmenting the existing carbon treatment system with RBCs, reductions in carbon costs would pay for the RBC plant within 3.3 years [4, p. 44]. The RBC plant model used to formulate this estimate was a scaled-up version of the pilot unit used during the treatability study.

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