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Project Summary

Rotating Biological Contactors Hydraulic Versus Organic Loading

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A study was undertaken to provide plant-scale data to develop design and operating criteria for rotating biological contactor (RBC) wastewater treatment facilities. The study determined RBC effectiveness over varying flowrates and organic loads for two different flow schemes—one based on hydraulic loading rates with stages of equal media surface area, and the second based on organic loading rates with each stage receiving approximately equal mass loadings of organic matter (carbonaceous biochemical oxygen demand, or cBOD). The flowrate was varied from 50% to 200% (430 to 1720 gpm) of design flow. The hydraulic and organic bays operated in parallel at and below 125% (1075 gpm) of design flow.

After treatment by 400,000 ft^2 of surface area, the hydraulic bay had soluble cBOD concentrations that were 2 to 5 mg/L lower than those in the organic bay in the parallel flow experiments. Above 400,000 ft^2, no statistically significant difference occurred in soluble cBOD concentrations. At flows up to 125% of design flow, ammonia nitrogen concentrations in the hydraulic bay were from 0 difference to 4 mg/L lower than those in the organic bay after 400,000 ft^2 of treatment, and up to 1 mg/L lower in the hydraulic bay after 600,000 ft^2 of medium treatment. After this point, there was no statistical difference between ammonia nitrogen concentrations in the two bays. At flows greater than 125% of design, no significant nitrification occurred in either train.

This Project Summary was developed by EPA's Water Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The wastewater treatment plant at Columbus, Indiana, is a 12.4-million-gallon-per-day (mgd) facility using rotating biological contactors (RBC) for secondary treatment and nitrification. Expansion and improvement to the plant occurred in 1976 with the selection of the RBC process to provide removal of carbonaceous biochemical oxygen demand (cBOD) and conversion of ammonia-nitrogen to other nitrogen forms. The RBC portion of the plant consists of 10 treatment bays with 8 shafts each. Because the size of the Columbus installation allowed the plant to operate at near-design conditions while using only a portion of the facility, a number of RBC units were available for experimentation. Wastewater that has undergone conventional primary treatment enters the RBC train for secondary treatment. The treated wastewater is then passed on to a clarifier and a chlorination tank before being discharged to the East Fork of the White River.

The overall objective of this study was to provide plant-scale experimental data to develop appropriate design and operational criteria for RBC wastewater treatment facilities. The specific goal of this study was to determine RBC effectiveness over varying flow rates and organic loads for two different flow schemes operating side by side. The first flow scheme was operated on the basis of hydraulic loading rates with stages of equal media surface area. The second flow scheme was operated on the basis of organic loading rates with each stage receiving approximately equal mass loadings of organic matter (cBOD). Hydraulic and organic loading rates varied from 50% to 200% (430 to 1720 gpm) of design flow to determine treatment effectiveness and limitations for the two operational schemes.

Figure 1 depicts the flow schemes for the hydraulic and organic bays. A portion of the primary treated wastewater was diverted to the two experimental bays. The hydraulic bay consisted of eight shafts in conventional series configuration. In this bay, stages and shafts were synonymous. The organic bay consisted of eight shafts in a tapered configuration. The primary treated wastewater was evenly divided among four parallel shafts in stage one, followed by two shafts in stage two, and one shaft each in stages three and four. A side stream of the effluent from each bay was diverted to a pilot clarifier to characterize settled effluent quality.

Experimental Methods

The Columbus RBC Research Project consisted of two full-scale trains of eight shafts, each of which contained 100,000 ft^2 of media. One train was arranged for hydraulic loading and one for organic loading. Monitoring requirements included flow (continuous), dissolved oxygen (continuous and spot check), pH (continuous and spot check), temperature (continuous and spot check), biochemical oxygen demand (nitrification inhibited), chemical oxygen demand, total filterable residue, ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen biomass, and power (see Figure 1). All analytical tests were performed on daily composite wastewater samples in accordance with U.S. Environmental Protection Agency (EPA) approved procedures. A laboratory quality control/quality assurance program was developed, reviewed, and accepted by EPA and was rigorously adhered to throughout the study.

A typical experiment lasted 14 to 21 days, with all parameters being monitored throughout the experiment. Following each process adjustment (flow increase or decrease), a 10- to 14-day period of stabilization was included in the experimental protocol.

Selected Results

The concentration of residual soluble cBOD depended on the cumulative wastewater retention time in either the hydraulic or organic bays. In Figure 2, the soluble cBOD versus retention time data are illustrated for both bays. These data tend to overlap one another, except for retention times of less than 1 hr, when the organic bay seems to have a slightly higher remaining soluble cBOD concentration. The reason for this somewhat reduced level of treatment in the organic bay is not specifically known, but it may

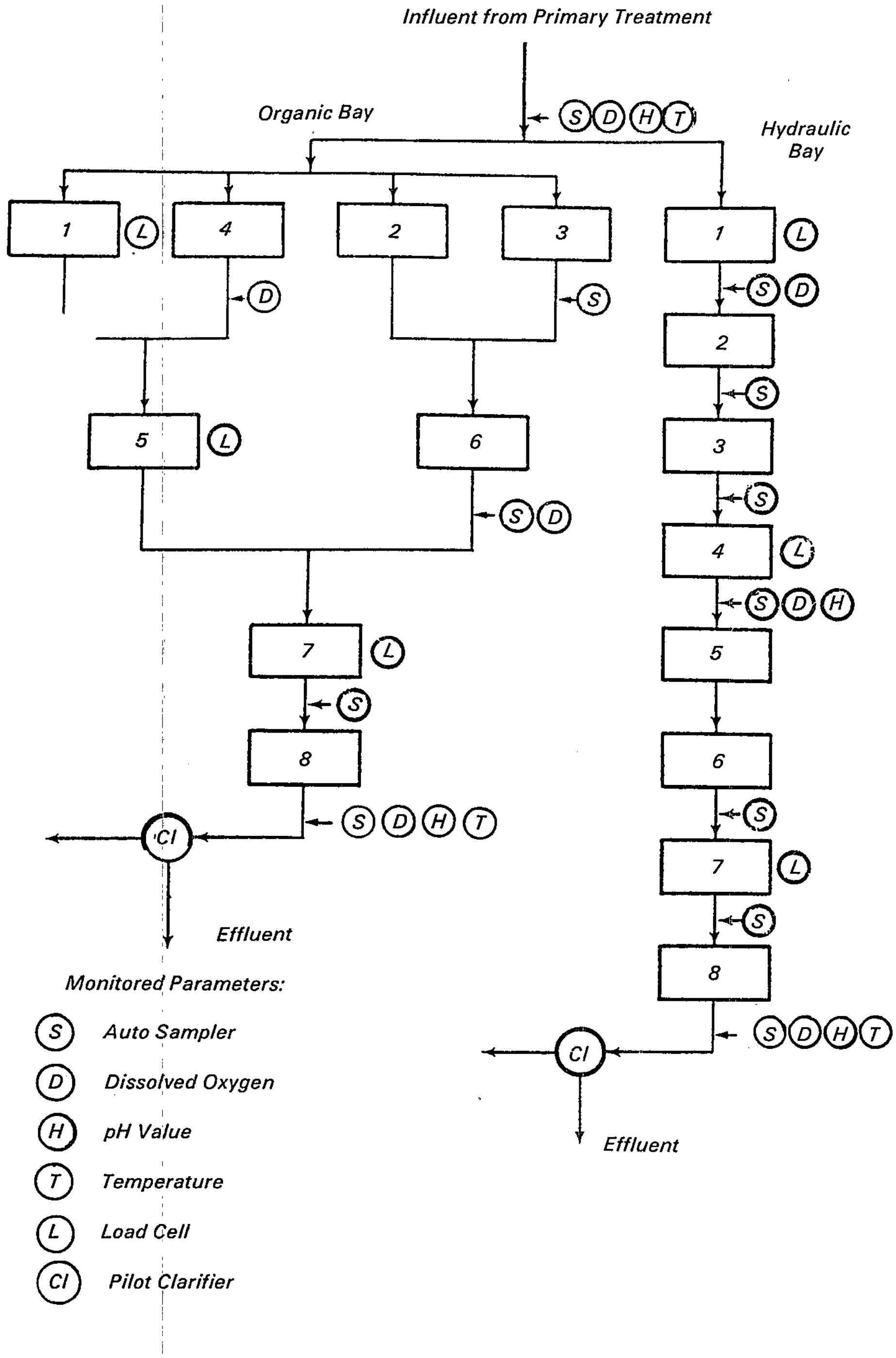

Figure 1. *Stage configuration of experimental bays.*

have resulted from the increased staging at the 1-hr retention time in the hydraulic bay compared with that in the organic bay. These observations generally reveal that RBC treatment is a high-rate process that achieves low effluent cBOD concentrations in a short wastewater retention time.

The total cBOD removal by both the hydraulic and organic bays was quite impressive throughout the study (Table 1). The increasing flowrate did not significantly influence the treatment ability of the two flow schemes, as demonstrated by the relatively stable removal efficiencies for the 50% to 175% (430 to 1510 gpm) design flow experiments. When the flow was increased to 200% (1720 gpm) of the design flow, some deterioration occurred in effluent quality, probably because of the reduced residence time in the treatment bays. The higher flowrate could also have caused increased shearing of biological slime from the media, thereby increasing the suspended solids in the effluent and reducing total cBOD removal efficiencies.

One of the major advantages of the organic bay flow scheme is its ability to lower the organic loading rate applied during early stages of treatment. At the Columbus RBC research facility, this lower rate was achieved by having 400,000 ft^2 and 200,000 ft^2 of media surface area in the first and second stages of treatment, respectively. The ability of the organic bay flow scheme to distribute the organic loading equally among stages is apparent in Figure 3, which depicts the organic loading rate versus the stage of treatment for both the hydraulic and organic treatment bays. Data from Experiment 4 (100% design flow, 860 gpm) and Experiments 8 and 11 (175% design flow, 1510 gpm) are shown in Figure 3 to illustrate how the organic loading varied under average and high flowrate conditions. Note especially the ability of the organic bay flow configuration to maintain a relatively constant organic loading rate at each stage of treatment. In addition, the loading to each stage was less than 2.5 to 4.0 lb/day per 1000 ft^2—the range of maximum first-stage loadings recommended by EPA to avoid the problems associated with organic overloading. In contrast, the organic loading in the hydraulic bay exceeded the EPA guideline in many of the earlier RBC stages. These results indicate that the organic flow scheme allows equalization of the organic load among stages, which may help to avoid many of the problems that have occurred when RBC units are organically overloaded. Such conditions include excessive biomass growth with possible structural failures, low oxygen or anoxic conditions, undesirable odors, nuisance organisms, and poor cBOD removal.

Table 1. *Comparison of Total cBOD Removals in the Hydraulic and Organic Bay Experiments*

Percent of Design Flowrate	*Percent Removal of Total cBOD*	
	Hydraulic Bay	*Organic Bay*
50*	83⁺†	79⁺
75*	83⁺†	85⁺
100*	83†	85
125	83⁺†	85⁺
150	73	82
175	83	80
200	67	72

**Side-by-side evaluation.*
⁺Average of two replicate experiments.
†Based on average of 700,000 and 800,000 ft^2 of treatment.

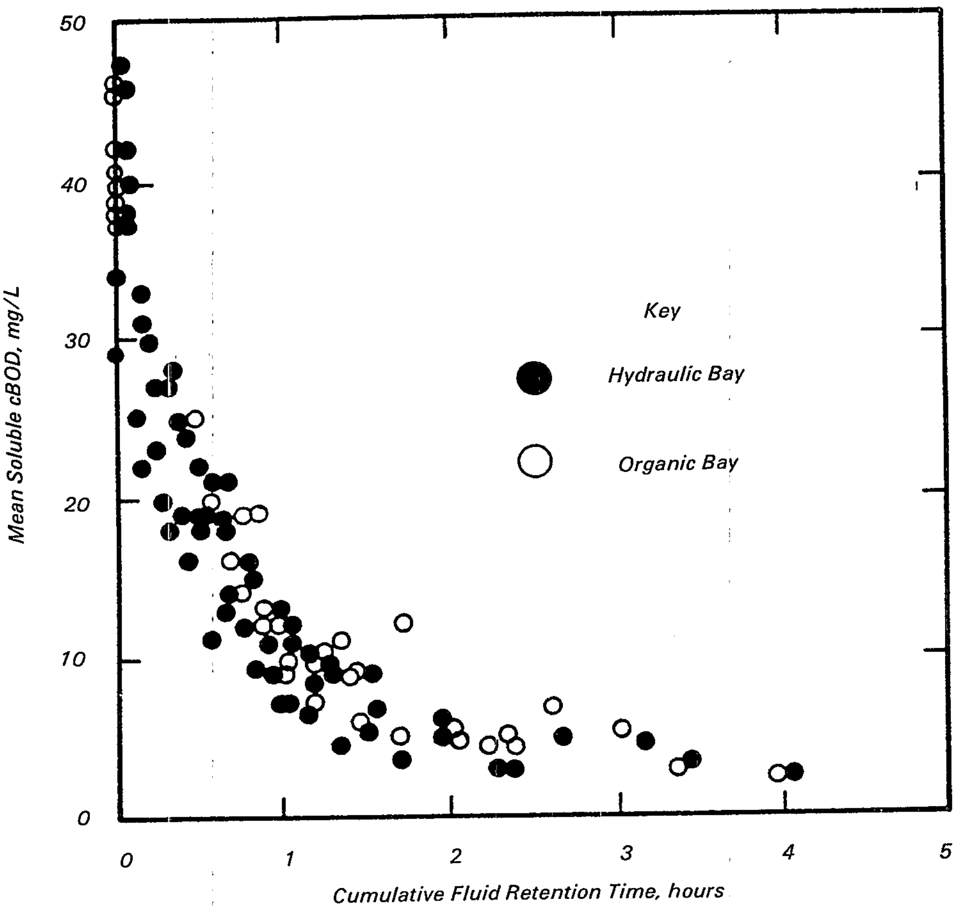

Figure 2. *Comparison of mean soluble cBOD concentration versus cumulative wastewater retention time for the hydraulic and organic bay experiments.*

Conclusions

Specific conclusions from the Columbus RBC research project are as follows:

1. The mean total cBOD concentration in the effluent for the various experiments ranged from 63 to 95 mg/L and from 72 to 95 mg/L for the hydraulic and organic bays, respectively. Total cBOD removal

efficiency in the hydraulic bay was stable at 83% for all the design flow experiments, with exceptions noted at 150% (1290 gpm) and 200% (1720 gpm) of design flow. In the organic bay, the removal efficiency measured 79% to 85% as the flow changed from 50% to 75% (430 to 650 gpm) of design flow, and it remained steady at the 85% level through the 125% (1080 gpm) design flow studies. When the flow was further increased, total cBOD removal efficiency fell to 72% at 200% (1720 gpm) of design flow in the organic bay and to 67% as the flow changed from 175% to 200% of design flow in the hydraulic bay.

2. The 4-2-1-1 shaft-staging configuration of the organic bay allowed soluble cBOD loadings to the first stage of this treatment train to be less than the range of maximum loading recommended by EPA (2.5 to 4.0 lb cBOD/day per 1000 ft^2). First-stage soluble cBOD loadings ranged from a low of 0.44 lb cBOD/day per 1000 ft^2 in the 50% (430 gpm) design flowrate experiment to a high of 2.2 lb cBOD/day per 1000 ft^2 in the 200% (1720 gpm) design flowrate experiment. In contrast to the organic bay, first-stage soluble cBOD loadings in the hydraulic bay ranged from a low of 1.8 lb cBOD/day per 1000 ft^2 in the 50% (430 gpm) design flowrate experiment to a high of 7.3 lb cBOD/day per 1000 ft^2 in the 150% (1290 gpm) design flowrate experiment. In addition, the first-stage cBOD loadings exceeded even the upper limit of EPA's guideline in all experiments where the flowrate equalled or exceeded 100% (860 gpm) of the design flowrate. The ability to achieve low effluent cBOD concentrations and comply with the EPA organic loading guideline is an advantage of the organic bay's staging configuration compared with the more commonly used flow scheme in the hydraulic bay.

3. The experimental means for soluble cBOD concentration in the influent to the experimental RBC treatment trains ranged from 29 to 47 mg/L and from 26 to 46 mg/L for the hydraulic and organic bays, respectively. Both treatment trains consistently reduced the influent soluble cBOD to less than 10 mg/L under flowrate variations between 50% and 200% (430 and 1720 gpm) of the design flowrate. Mean effluent soluble cBOD levels as low as 2 to 4 mg/L were achieved in both treatment configurations at rates lower than 100% (860 gpm) of the design flow. Effluent levels of soluble cBOD were slightly higher when the experimental flow exceeded 75% (650 gpm) of the design flow. The highest mean effluent soluble cBOD level for the organic bay was 8.3 mg/L at 200% (1720 gpm) of design flowrate (Experiment 12). Similarly, the highest effluent soluble cBOD concentration in the hydraulic bay was 9.2 mg/L, again at 200% (1720 gpm) of the design condition (Experiment 9). Removals of mean soluble cBOD exceeded 80% for all experiments except those in the hydraulic bay at 200% of the design flow where a 73% removal was

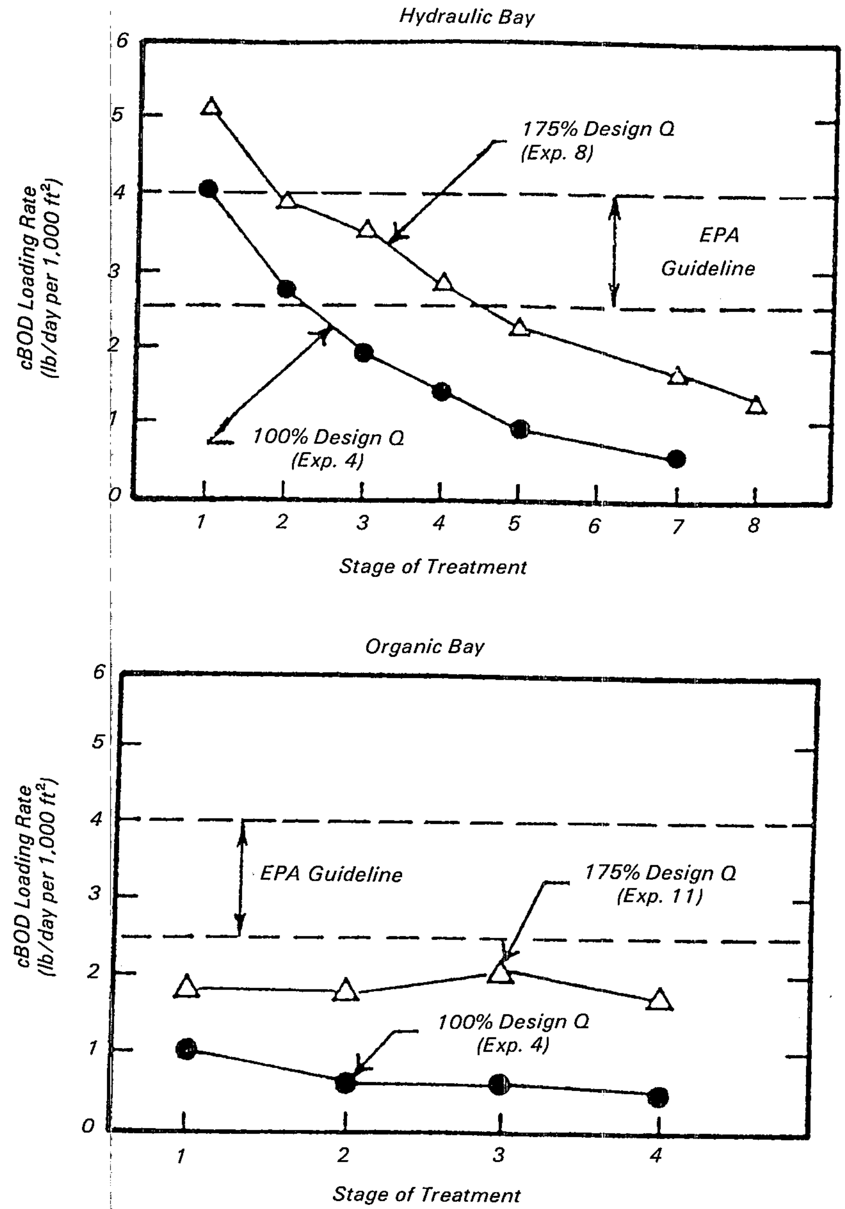

Figure 3. *Comparison of mean soluble cBOD loading rates for selected experiments in the hydraulic and organic bays.*

recorded. Soluble cBOD removals between 87% and 94% were evident for both the hydraulic and organic bays at flowrates at or below 100% (860 gpm) of the design flowrate.

4. The removal of soluble chemical oxygen demand (COD) followed a pattern similar to that of soluble cBOD. Mean soluble COD concentrations in the effluent from the hydraulic and organic bays were always below 60 mg/L. Effluent COD levels of 30 to 40 mg/L were achieved in both treatment trains at flowrates equal to or less than 100% (860 gpm) of the design flowrate—except for hydraulic bay Experiment 3 (75% of design flow, 650 gpm), in which an uncommonly high mean effluent COD value of 52 mg/L was recorded. Cumulative removals of COD ranged from 49% to 74% and from 59% to 72% in the hydraulic and organic bays, respectively. As expected, COD removals increased when the experimental flowrate was decreased.

5. The hydraulic treatment bay achieved slightly lower soluble cBOD concentrations after the 400,000 ft^2 surface area treatment than did the organic bay. This observation was based on the comparison of daily soluble cBOD concentrations for those experiments during which the hydraulic and organic bays were compared on a true side-by-side basis. The greater soluble cBOD removal in the hydraulic bay at 400,000 ft^2 of treatment was confirmed from statistical analysis with a 90% confidence level. Again, when comparing data from parallel flow experiments, the concentrations of soluble cBOD in the hydraulic and organic bays were not statistically different after treatment by 600,000 ft^2 (or more) of media surface area.

6. In both the organic and hydraulic treatment bays, the concentration of soluble cBOD and COD at each stage of treatment appeared to be related to the cumulative fluid retention time. A majority of the observed removals occurred within the first 2 hr of treatment, after which the removal rates of both cBOD and COD became extremely slow. For practical purposes, the ultimate removal achieved was nearly complete after 2 hr of retention time. This observation confirms that RBC treatment, regardless of the flow configuration, is a high-rate process in which low effluent cBOD and COD concentrations may be obtained with a short wastewater retention time. For example, the relationship of soluble cBOD remaining versus wastewater retention time (which was developed from the hydraulic bay experiments) would predict an effluent soluble cBOD concentration of 10 mg/L after 1 hr of treatment and a concentration of 5 mg/L after 2 hr of treatment.

7. The organic bay flow configuration offers several operational advantages over the commonly used hydraulic bay configuration. The equalization of organic loading among stages that is accomplished in the organic bay flow configuration allows this treatment system to (a) meet EPA's organic loading guideline; (b) better withstand organic shock loadings; (c) control the growth of nuisance organisms, odors, and similar problems associated with organic overloading; (d) maintain acceptable dissolved oxygen values in all stages of treatment, thereby maintaining an aerobic treatment process and eliminating oxygen transfer as a rate-limiting step in the removal of organic matter; and (e) control the occurrence of excess biomass growth that can cause structural failure of RBC shafts. These operational advantages are attained in the organic bay flow configuration with no adverse impact on treatment performance. As noted previously (see Concusion 5), a slightly lower cBOD was obtained in the organic bay with 400,000 ft^2 of media area than in the hydraulic bay. The difference was small, however, and was not recorded after treatment by 600,000 ft^2 of surface area.

8. The level of ammonia-nitrogen present in the effluent from the hydraulic and organic bays varied depending on the flowrate and organic loadings. In experiments below 100% (860 gpm) of the design flowrate, both treatment bays were able to reduce the influent ammonia-nitrogen level to less than 1.0 mg/L, indicating that effective nitrification was occurring. For the 100% to 150% (860 to 1290 gpm) design flowrate experiments, some reduction in the concentration of ammonia-nitrogen was evident, although only partial nitrification of the effluent was accomplished. Very little to no change in the ammonia-nitrogen concentration was evident between stages in either the organic or hydraulic treatment bay at the 175% and 200% (1510 and 1720 gpm) design flowrate experiments. This result shows that nitrification was not significant at these high-flow conditions.

9. In the parallel flow experiments in which the hydraulic and organic bays were compared directly, the ammonia-nitrogen concentrations after 400,000 and 600,000 ft^2 of treatment were lower in the hydraulic bay. Statistical analysis supports this conclusion with a 95% confidence level. The superior performance of the hydraulic bay is thought to have resulted from the increased level of staging in this bay's flow scheme. Increased treatment performance is expected with increased staging for processes in which the kinetic order is something other than zero.

10. Nitrite- and nitrate-nitrogen production was closely associated with the removal of ammonia-nitrogen. As the flowrate was increased, the concentration of nitrite- and nitrate-nitrogen decreased and the production occurred in the later stages of treatment. At flowrates exceeding 150% (1290 gpm) of design, little to no nitrite- and nitrate-nitrogen production was evident in either the organic or the hydraulic bay. This result indicates that nitrification was not occurring at either the 175% or the 200% (1510 or 1720 gpm) flow conditions.

11. The organic bay showed an ability to resume nitrification shortly after a reduction from 200% to 75% (1720 to 650 gpm) of the design flowrate. This result suggests that nitrifying organisms were still present in the 200% (1720 gpm) flowrate experiment but that overriding factors rendered them ineffective in lowering the ammonia concentration. Conversely, increasing the flowrate from 50% to 200% (430 to 1720 gpm) of design resulted in an immediate and significant decrease in the removal of ammonia.

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The complete report, entitled "Rotating Biological Contactors—Hydraulic Versus Organic Loading," (Order No. PB 86-160 322/AS; Cost: $16.95, subject to change) will be available only from:

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