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NITRIFICATION AND ORGANIC REMOVAL IN AERATED CARBON CONTACTORS

by

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CERTIFICATE OF APPROVAL

This research report is accepted and approved in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

December 12, 1975
(date)

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LIST OF ABBREVIATIONS

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
gm	grams
Kg	kilogram
ℓ	liters
m	meter
mg/ℓ	milligrams per liter
mℓ	milliliter
mm	millimeter
N	Newton
sq	square

ABSTRACT

Aerated contactors were operated for 64 days to investigate the capability of granular activated carbon to remove dilute organic material and accomplish nitrification. A parallel sand media aerated contactor provided a basis for comparison of biological activity. A dual media filter ahead of the pilot plant was used to remove excess solids from the Bethlehem, Pennsylvania high rate trickling filter recirculation flow used in the research.

In 64 days of operation, the apparent capacity was 0.430 gm COD/gm carbon. The influent COD of 77.1 mg/ℓ was reduced to 19.1 mg/ℓ at 61 ℓ/min/sq m with 25 minutes of detention.

1. INTRODUCTION

In spite of the high potential for environmental damage, typical municipal wastewaters have low concentrations of organic material. Organic material in untreated wastewater is in the order of 10^{-5} molar, and after conventional secondary treatment (85-95% efficiency) the organic concentration would be an order of magnitude lower.

The effluent from conventional secondary processes is not considered amenable to treatment by existing biological systems, due either to the refractory nature of the residual materials or simply due to the dilute nature of the organic pollutants. One concept of solving this problem is to concentrate the residual organic materials by adsorption onto granular media so that in the micro-environment of the adsorbed material, the substrate concentration would appear to be very high for microorganisms living in this space. If true, this concept would allow further biological degradation of the adsorbed organic material.

2. BACKGROUND

Laboratory and limited pilot plant studies were conducted by Johnson (1) to evaluate use of adsorption to concentrate the dilute organic materials for further biological degradation. The laboratory units which were developed were called PAB for pulsed adsorption beds. The process employed aerated contactors filled with fine granular media. The wastewater and air flowed cocurrently upward through the contactor. The air supplied oxygen for biological metabolism and provided agitation of the media to prevent clogging. The coalescence of initially small air bubbles into larger ones caused a pulsing motion of the media and gave the system its name.

The early studies used a synthetic sewage based on Metrecal[a], which was diluted to a COD value of 50 mg/ℓ for the influent. It was assumed that the rate of biological utilization would be greater for this synthetic wastewater than for the organic compounds found in treatment plant final effluents. Consequently, the organic loading and cocurrent air supply were relatively high in this initial work. The laboratory studies achieved significant removal of organic material, and it was concluded (2) that a full scale plant using aerated contactors could remove at least 70-90 percent of the organic material remaining in secondary effluent. No nitrification, however, was observed in the laboratory studies.

Concurrently with the laboratory work of Johnson, Sedgwick (3) conducted pilot plant studies using the final effluent from a conventional trickling filter treatment plant as the influent to

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[a] Mead, Johnson and Company, Evansville, Indiana

aerated contactors using sand media. Sedgwick observed considerable removal of organic material, but the degree of nitrification was quite variable.

Pilot plant studies using aerated contactors followed by dual media filters were conducted by Wall (4). The same trickling filter plant effluent was used as the influent to the contactors. The new dual media filters following the contactors were in accordance with a process concept suggested by Johnson and Baumann (2). Wall observed organic removal and filtration effects in removal of BOD and suspended solids. The aerated contactors alone achieved an average BOD removal of 47 percent. With the dual media filters following the aerated sand contactors, the overall removal increased to 76 percent. These results should be interpreted in light of treating secondary effluent of a nature that is supposedly relatively untreatable.

Additional work using aerated sand contactors was undertaken by Doutlik (5) at Lehigh University in 1971. Both coarse and fine sand media were used in the pilot plant installation at the Bethlehem, Pennsylvania high rate trickling filter plant. Recirculation flow from the high rate trickling filters was used as influent to the pilot plant. The main purpose of that research was to investigate the nitrification in the aerated contactors. However, subsequent analysis indicated that the high organic and hydraulic loadings used, as well as high air supply rates precluded obtaining significant nitrification in that particular pilot plant study.

In general, all of the studies cited observed significant removal of organic material using the aerated contactors. By experimenting with variable rates of air supply, hydraulic and organic loading, extensive knowledge was gained. No study, however, obtained results which demonstrated the capability to nitrify ammonia to nitrite and nitrate. This was one reason for another attempt to obtain nitrification using aerated contactors with lower hydraulic and organic loadings in accordance with the results of Wall and as suggested by the results of Doutlik.

A second reason for this study was to re-evaluate the use of active carbon media. In the early laboratory studies, Johnson (1) observed that sand was as effective as active carbon in this biological process, and all of the subsequent investigators used sand or other inert media with low adsorption capacity. Ongoing research at Lehigh University into biological regeneration of granular active carbon (6) indicated that the effectiveness of aerated active carbon contactors should be studied again. A comparison of the media aspect was incorporated into the research by using parallel sand and active carbon aerated contactors.

3. PILOT PLANT DESCRIPTION

The pilot plant was installed at the high rate trickling filter treatment plant serving Bethlehem, Pennsylvania. A schematic flow diagram of the pilot plant installation is shown in Fig. 1.

The treated wastewater for the pilot plant was taken from the recirculation flow to the high rate trickling filters. The draw-off in the final clarifier is intermediate and provides only partially clarified treated wastewater in the recirculation line which was the source of "treated" wastewater for this research project. The treated wastewater was pumped to the equipment room, where the pilot plant was located. The flow then passed through the dual media filter for removal of excess solids, since this recirculation flow did carry a high solids concentration. The filtered wastewater discharged into a constant head reservoir, and overflow from the reservoir returned to the treatment plant wet well.

A small centrifugal pump supplied the aerated contactors from the constant head reservoir. A small compressor-tank set provided process air to the contactors. The contactor effluents discharged into individual constant head reservoirs, where composite samples were taken.

3.1 Dual Media Filter

The dual media filter shown in Fig. 2 was fabricated from 250 mm steel pipe with blind flanges and tapped for 20 mm PVC pipe. The filter was equipped with backwash lines, pressure gauges and a

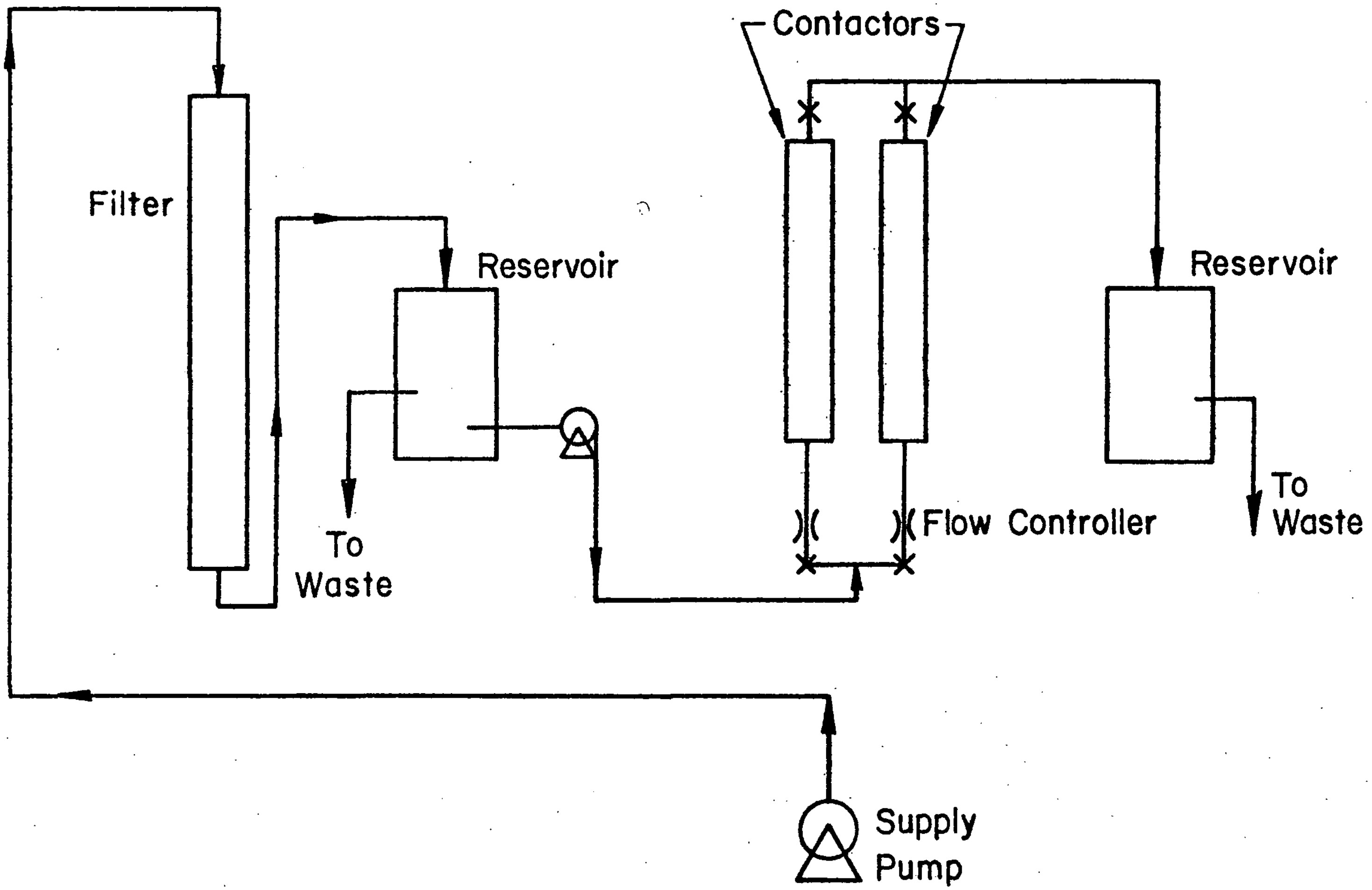

Fig. 1 Schematic Flow Diagram

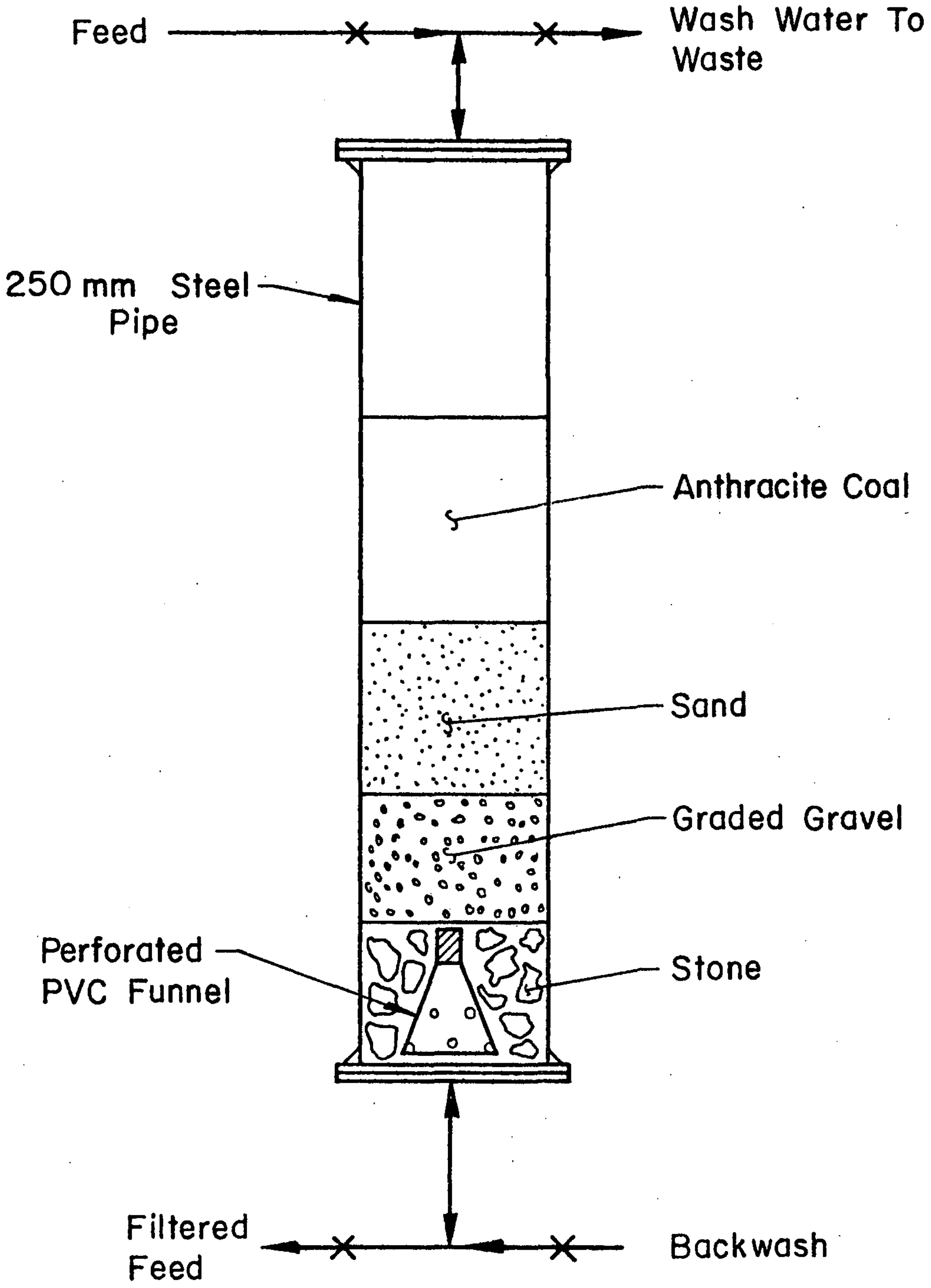

Fig. 2 Dual Media Filter

clear sight-glass to monitor the efficiency of the backwash procedure. The filter media was installed over an inlet section which was fabricated from a perforated PVC funnel to distribute the backwash water. The underdrain media was 20x12 mm gravel up to the top of the inlet funnel. Additional layers, each 75 mm deep, 6x12, 3x6, and 1.5x3 mm made up the balance of the underdrain gravel.

The upper filter media was 0.50 m of anthracite coal with an effective size of 1.84 mm and a uniformity coefficient of 1.20. All fines from the coal were washed out prior to placing in the filter. The 0.30 m layer of sand below the anthracite coal had an 0.5 mm effective size and a uniformity coefficient of 1.30.

3.2 Aerated Contactors

The aerated contactors, Fig. 3, were constructed of 250 mm (249.8 mm ID) PVC sewer pipe three meters long. Each unit was mounted vertically on an 0.3 m long 250 mm steel pipe base and inlet section. The PVC and steel pipe sections were connected using 0.4 m square flanges. A rubber gasket between the flanges compressed by C-clamps provided a pressure tight connection.

Influent to the contactors was distributed through an inverted 20 mm PVC funnel which was perforated with two rows of 6 mm holes. The base section was filled with 3x6 mm gravel up to the flange connection level. A second pipe inlet to the base section was for the air supply which flowed upward cocurrently with the wastewater.

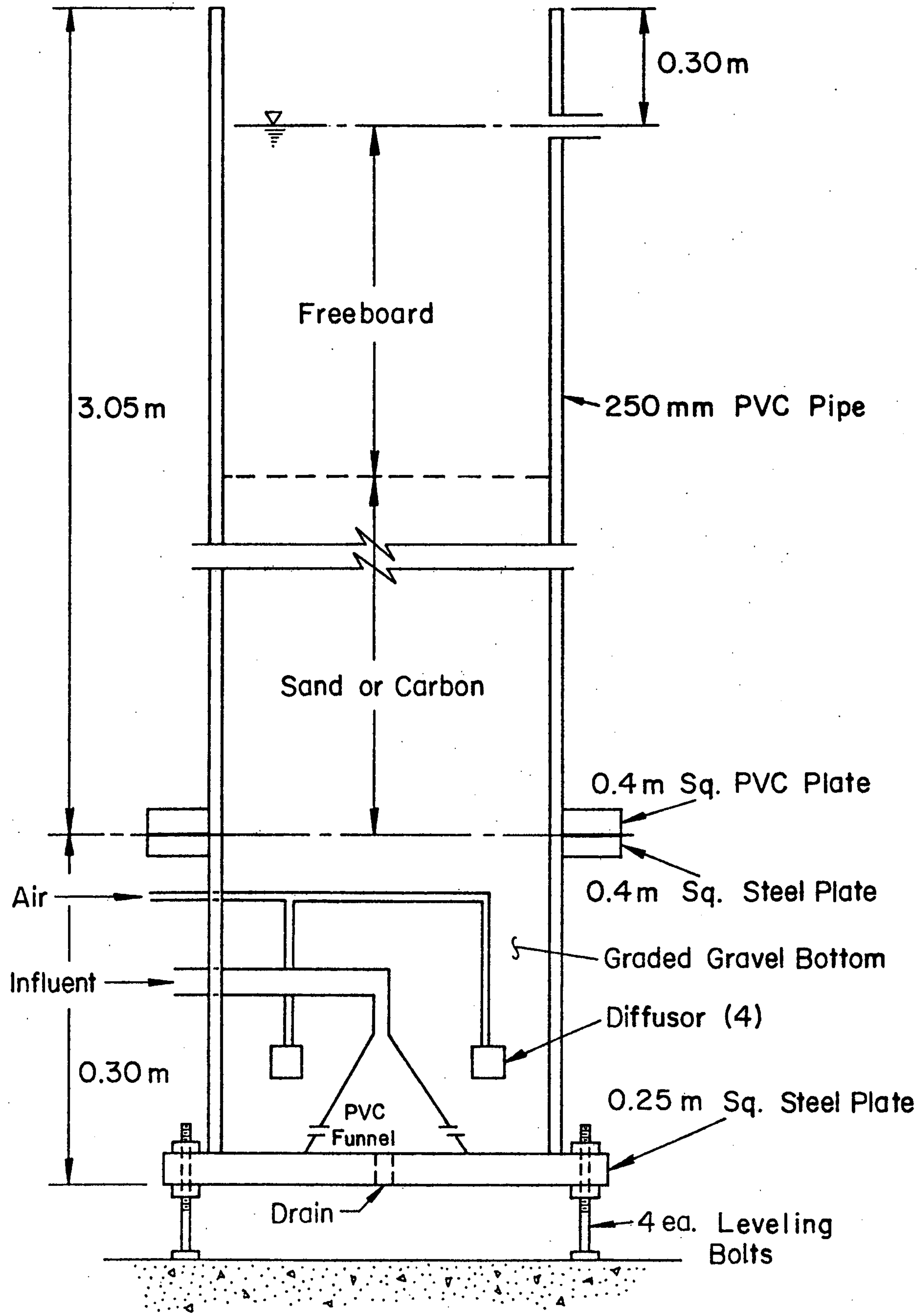

Fig. 3 Aerated Contactor

The air was diffused through four laboratory type carborundum diffusor stones.

Both aerated contactors had 1.52 m of media above the base section, one filled with sand, 0.5 mm effective size and uniformity coefficient of 1.30. The second unit used granular activated carbon, Filtrasorb 300,[a] 8x30 mesh size (2.38x0.59 mm).

3.3 Air Supply

A conventional compressor-receiver tank set provided the compressed air for the aerated contactors. The air pressure was reduced and the flow rate controlled by needle valves on the outlet of rotameters as shown in Fig. 4.

3.4 Automatic Sampling Equipment

A unique timer actuated guillotine sampler developed by Sturgis (6) was used to collect composite samples for analysis. The sampler, shown in Fig. 5, consisted of a solenoid actuated scissors mechanism which pinched off rubber sample lines which were connected to each of the influent and effluent constant head reservoirs. The scissors were counterweighted, so that the sampler would be closed in the event of power or equipment failures. A timer mechanism activated the sampler solenoid so that a sample was taken every 20 minutes and discharged into a receiving bottle to make up the composite sample.

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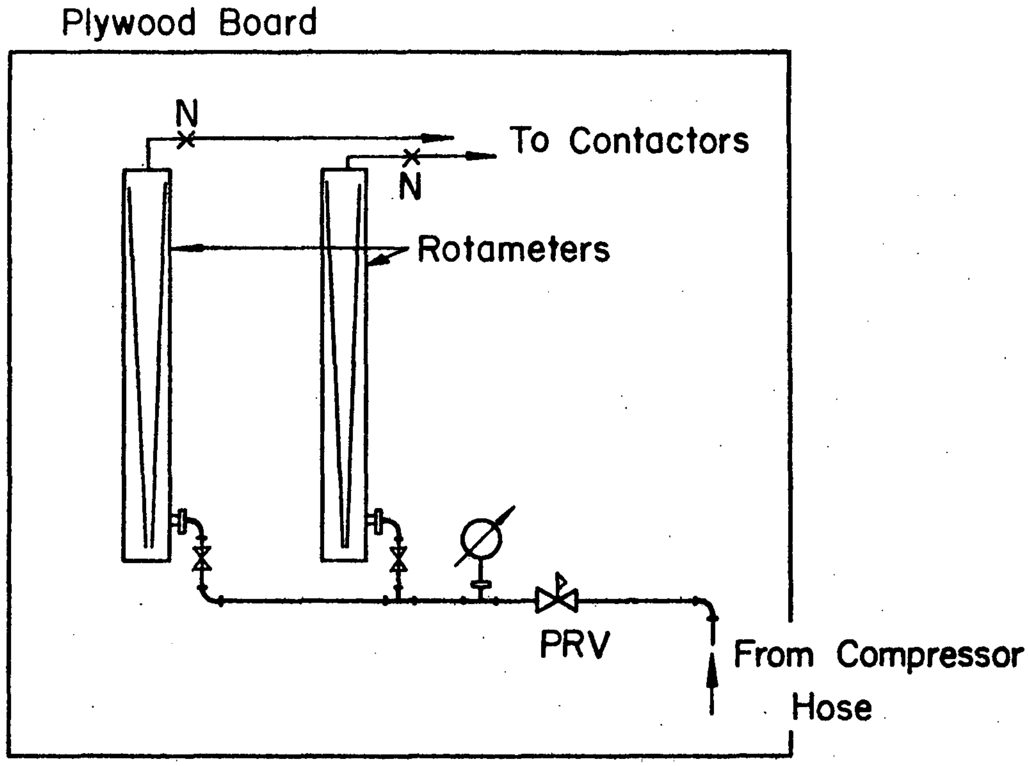
[a] Calgon Corporation



N	Needle Valve
PRV	Pressure Regulating Valve

Fig. 4 Air Supply Detail

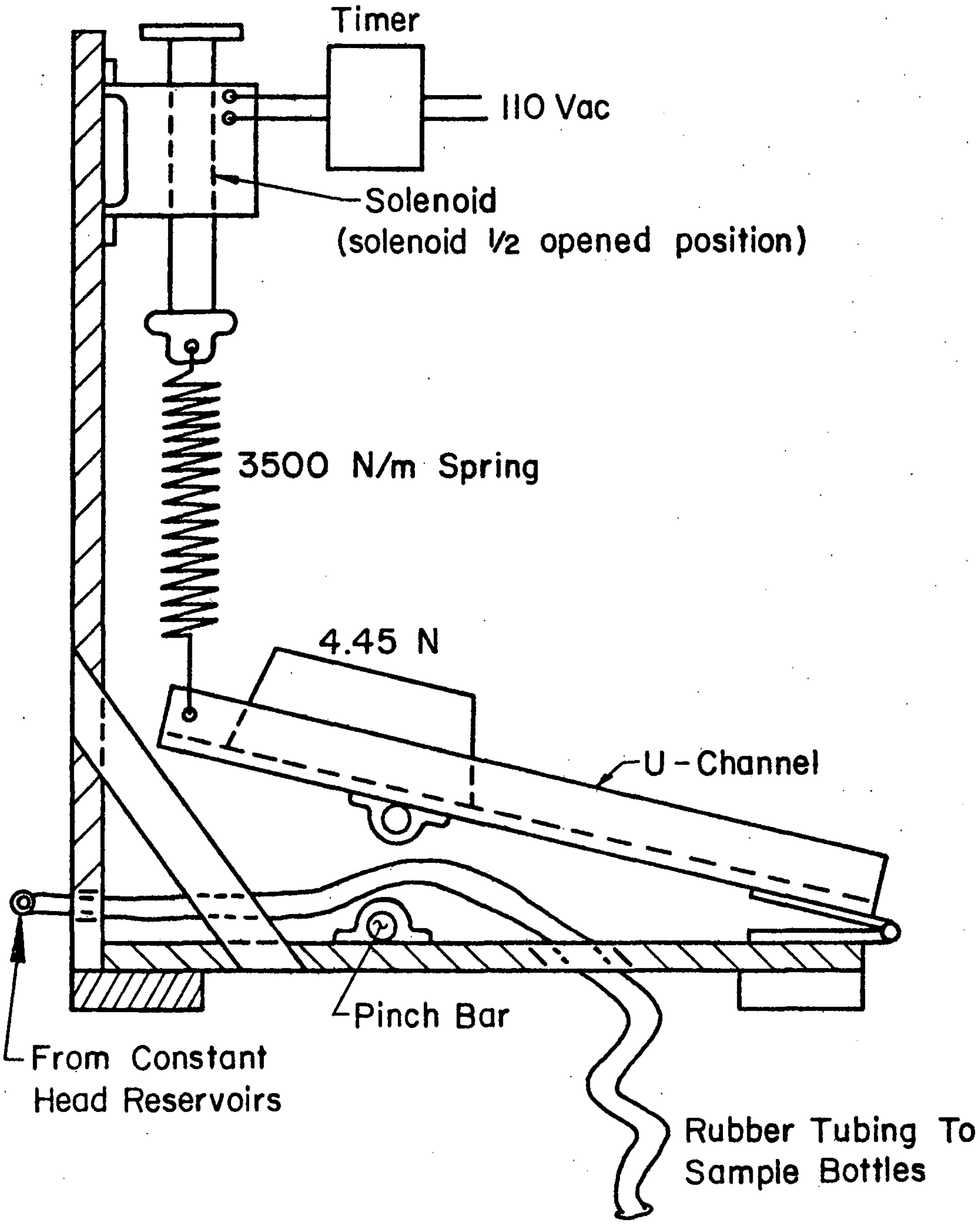


Fig. 5 Guillotine Sampler

4. OPERATION OF PILOT PLANT

The pilot plant operation was reasonably simple and trouble-free. Regular maintenance helped to eliminate potential problems. The dual media filter was backwashed every day. The sight glass previously mentioned allowed visual determination of the proper filter backwash completion. A 15 minute backwash duration proved sufficient in most instances.

The influent constant head reservoirs were flushed with clean water while the dual media filter was being backwashed. Approximately twice each week, the pump supplying the aerated contactors was disconnected, and the columns were allowed to drain slightly. This action reversed the direction of flow through the flow controllers and helped to prevent them from becoming clogged. This simple, routine procedure allowed operation of the pilot plant almost continuously for several months during 1973.

The purpose of the dual media filter ahead of the aerated contactors was simply to reduce the concentration of both solids and organic material to the aerated contactors. This filter was necessary because the "treated" wastewater supply to the pilot plant was considerably stronger than the 50 to 70 mg/ℓ COD typical of secondary effluents. The effectiveness of the preliminary filter was not measured, but rather the filter effluent was treated as if it were a typical secondary effluent.

The flow rates through the contactors varied during a 24-hour period due to some clogging that would occur in the influent rate controllers. Consequently, the flow rates were measured daily to aid in subsequent determination of total loading and removal efficiencies.

5. SAMPLING PROCEDURES AND ANALYTICAL METHODS

The clock timer and guillotine sampling device previously described released samples every twenty minutes. These small quantities were collected in 4ℓ bottles yielding a 24-hour composite sample and were analyzed each day. When nitrogen analyses were to be performed, samples were cooled by placing the collection bottles in ice filled styrofoam chests. The total daily volume of composite sample collected at each location was variable, but typically about 100 mℓ of composite sample was collected from each point. All samples were immediately returned to the laboratory for analysis.

Samples were collected five days a week for COD and pH determinations, while BOD and nitrogen forms were tested at least two days a week. Daily observations of flow rate, temperature and air supply rates were made.

5.1 Analytical Methods

The Chemical Oxygen Demand (COD) method for dilute samples as outlined in Standard Methods (7) was used. Since this method is sensitive to the environmental conditions in the laboratory, extreme care, particularly with cleaning glassware, is necessary to obtain consistent results.

Biochemical Oxygen Demand (BOD) tests were performed as described in Standard Methods (7) using the azide modification for the dissolved oxygen analyses. Dilution water was seeded using fresh domestic sewage from a residential section of the city.

Ammonia nitrogen was determined by the direct nesslerization procedures of Standard Methods (7). Nitrate nitrogen concentrations were determined using the cadmium reduction procedure (7) combined with the napthylamine-sulfanilic acid test for the resulting nitrite form. The latter test procedure was also used for determining nitrite nitrogen concentrations. In both determinations, prepared powder regents[a] were used.

The pH was measured on the composite samples using the glass electrode method of Standard Methods (7).

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[a] Nitriver III and Nitraver IV, Hach Chemical Company, Ames, Iowa.

6. RESULTS AND ANALYSIS

6.1 Organic Removal

As previously noted, one of the reasons for this research was an extension of on-going studies into biological regeneration of activated carbon. The aerated upflow contactors provided an opportunity to study the potential of continuous in-situ regeneration of the surface of the granular activated carbon. The parallel sand contactor provided an inert surface granular media to allow comparison of the vast surface area and activity of the carbon in contrast to the inert sand media. The sand contactor would permit or encourage biological activity but the sand would certainly not function in the role of an adsorbent except for the small physical adsorption which would occur.

The contactors were operated at approximately 61 ℓ/min/sq m providing a contact time of 25 minutes based on empty bed volume. The freeboard above the 1.52 m of media provided another 20 minutes of detention in the aerated contactors. The contactors were aerated to encourage aerobic biological activity, since anaerobic conditions are known to encourage growth of sulfate reducing bacteria and cause odor problems from the H_2S generated. The air supply was maintained at 61 ℓ/min/sq m and the effluent dissolved oxygen concentration was above 4.0 mg/ℓ at all times.

The influent and effluent COD for the aerated contactor operation is shown in Fig. 6. The superiority of the carbon over inert sand media is well demonstrated in contrast to previous results.

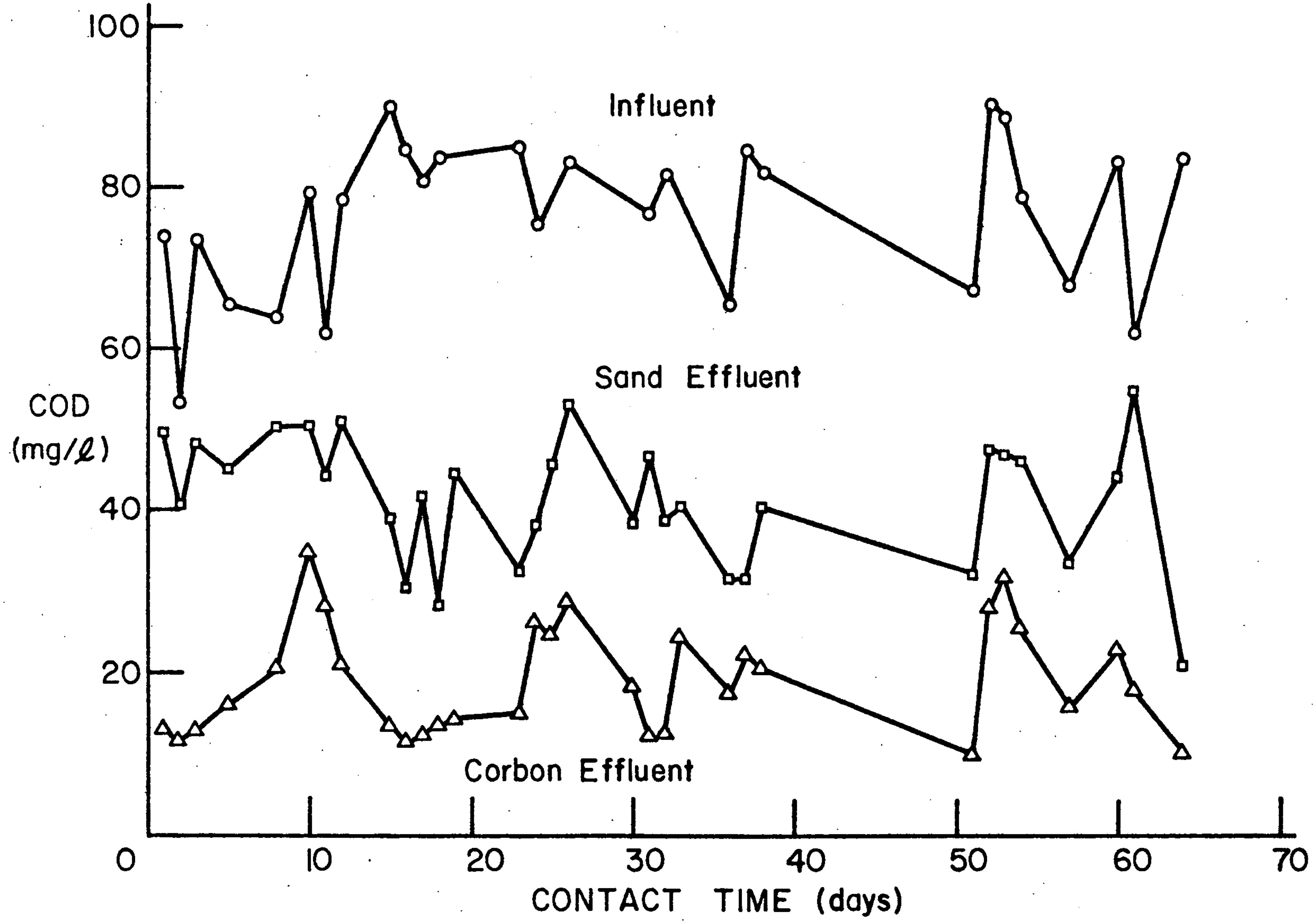

Fig. 6 COD Removal versus Contact Time

The effectiveness of the aerated mode of operation is shown even better in Fig. 7. The apparent carbon capacity in the aerated contactor for 64 days of operation was 0.43 gm COD/gm carbon. Figure 7 indicates there is no apparent reduction in the rate of COD removal in the carbon contactor, even after the 64 day period.

Based on the total mass of COD applied to each aerated contactor during the 64 day operating period, the carbon media removal efficiency was 74 percent and the sand media had 45 percent removal.

The mass loading of the contactors may be expressed in kilograms COD per cubic meter of media per day ($Kg/m^3/day$). The applied loading for the sand contactor was 3.85 $Kg/m^3/day$ while the carbon contactor was loaded at 3.71 $Kg/m^3/day$, the difference reflecting the day to day differences in hydraulic rate of wastewater applied to the aerated contactors. COD removal, on this basis of comparison, was 2.80 $Kg/m^3/day$ for the carbon media and 1.80 $Kg/m^3/day$ for the sand media.

BOD analyses are shown in Table 1. Although the data is more limited than that for COD, the results follow the same trend as that of COD. BOD removal for the carbon and sand contactors was 76 percent and 47 percent, respectively.

6.2 Nitrification

The biological oxidation of ammonia is a stepwise process and may be described by the following equations.

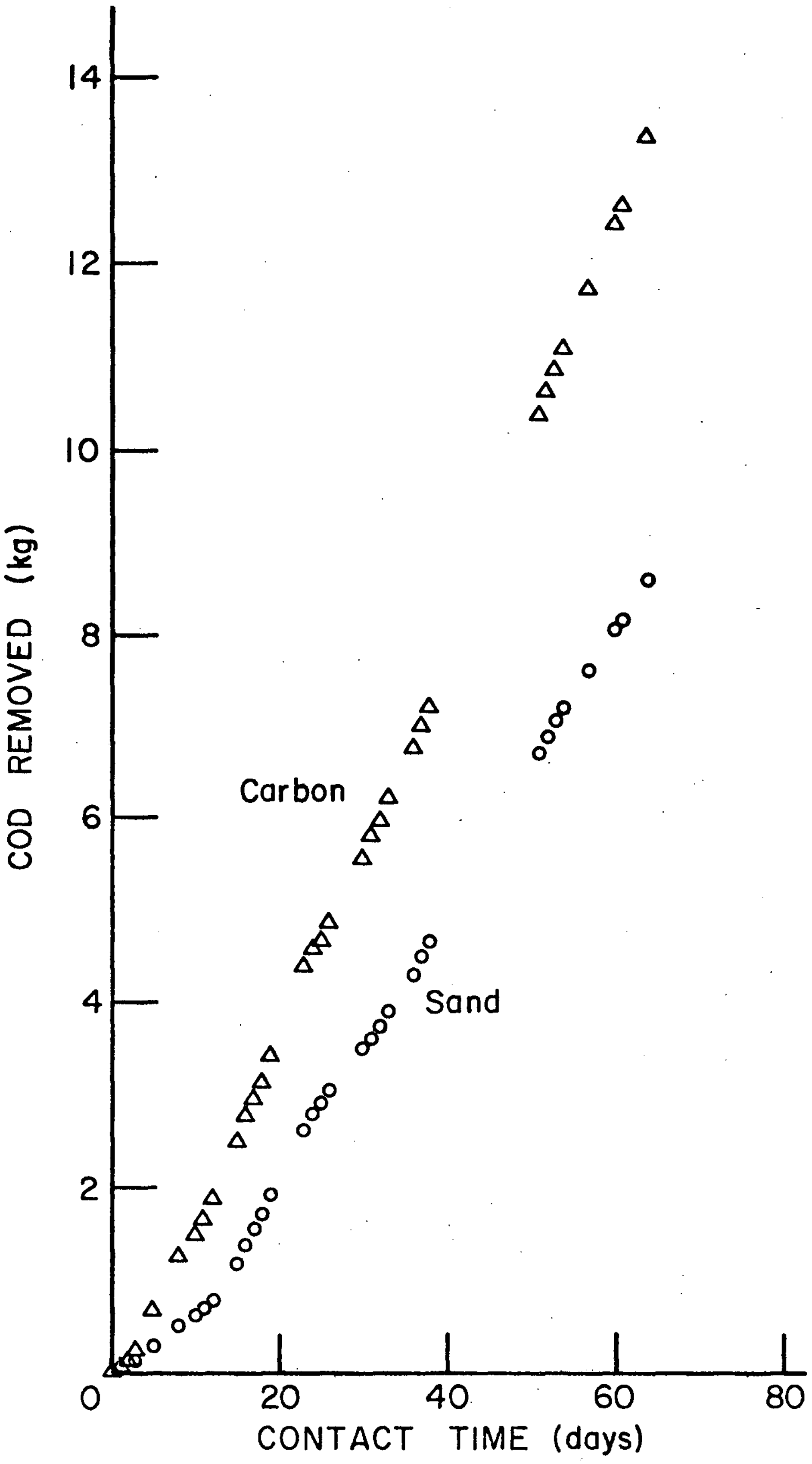

Fig. 7 Cumulative COD Removal

Table 1 BOD Results

		BOD Concentration, mg/ℓ		
			Effluent	
Date	Operational Day	Influent	Sand	Carbon
7-25-73	3	85.7	34.8	25.0
8-1-73	10	32.0	27.0	25.0
8-3-73	12	23.0	13.0	1.5
8-8-73	17	29.4	83.3	3.2
8-15-73	24	19.6	59.4	15.5
8-17-73	26	31.8	37.4	27.4
8-22-73	31	15.5	2.8	4.5
8-27-73	36	13.7	--	2.9
8-29-73	38	22.2	11.8	17.3

$$\begin{aligned} 2NH_3 + 3O_2 &\xrightarrow{\text{Nitrosomonas}} 2NO_2^- + 2H^+ + 2H_2O \\ 2NO_2^- + O_2 &\xrightarrow{\text{Nitrobacter}} 2NO_3^- \end{aligned} \tag{1}$$

Biological nitrification is enhanced by six factors (5):

1. Low concentration of carbonaceous matter
2. Absence of toxic compounds such as cyanides, phenols or heavy metals
3. Temperature range of 20-30°C
4. Basic pH, preferably about 7.8
5. Aerobic conditions
6. Biological solids residence time longer than the growth rate of nitrifying bacteria.

For the most part, conditions which existed during the period of investigation were favorable, and nitrification was achieved. The filtered recirculation wastewater was comparable to a secondary effluent with low concentrations of organic material. The Bethlehem sewage treatment plant does occasionally receive shock loadings of toxic materials, but during this experiment these were not a problem. Temperatures were almost always within the prescribed range. The pH was always basic, although it was seldom within the optimum range of values.

Initially, samples were preserved with acid, but this technique produced erratic results. Later, when samples were packed in ice, the results became somewhat more consistent. Results of analyses of acid-preserved samples are shown in Appendix B, and results of analyses of ice-packed samples are shown in Table 2. The results indicate that considerable nitrification of the wastewater was accomplished.

Table 2 Nitrogen Results - Ice-Packed Samples

Date	Operational Day	Nitrogen Concentration, mg/ℓ as N			
			Effluent		
		Influent	Sand	Carbon	
7-23-73	1	11.7	8.1	12.1	NH_3 - N
		0.05	0.02	0.04	NO_2^- - N
		0.06	1.72	4.46	NO_3^- - N
7-24-73	2	10.4	2.9	4.9	
		0.58	0.04	0.75	
		0.06	12.8	9.25	
7-25-73	3	18.9	2.9	0.20	
		0.06	0.75	0.75	
		0.79	11.8	8.60	
8-8-73	17	23.5	10.7	1.7	
		--	--	--	
		0.65	13.8	22.0	
8-15-73	24	11.3	0	13.5	
		0.05	0.42	0.33	
		0.65	26.8	10.2	
8-17-73	26	20.4	15.1	10.7	
		0.06	0.11	0.39	
		0.67	5.64	6.22	
8-22-73	31	20.4	9.3	4.0	
		0.05	0.21	0.39	
		0.52	18.0	11.5	

7. DISCUSSION

The aerated contactor units demonstrated the capability to biologically remove organic material from dilute solutions such as secondary effluents. While the mechanism of removal is not precisely known, observed results suggest that the adsorption capacity of the carbon serves to concentrate organic substrate and promote biological activity.

The removal efficiency of the active carbon was superior to that of the sand. Compared to an active carbon granule of equal diameter, a grain of sand has a very small surface area, and almost no adsorption capacity. For this reason, any removal of organic material by the sand media is essentially biological. The adsorption capacity of active carbon gives this media the capability to remove organic material in two ways. The material can be removed by adsorption, and it can be removed by microorganisms. Sand does not possess the strong adsorption capability, and it cannot perform as well as the active carbon.

The active carbon and sand media achieved approximately the same degree of nitrification. Unlike the process of organic material removal, the adsorption capability of carbon is less effective in enhancing nitrification. Ammonia in solution is not particularly adsorbed by active carbon and thus it cannot be concentrated at the media surface. Because neither media can adsorb the essential substrate, ammonia, the biological nitrification activity by active carbon and sand units should be nearly equal, which is what was observed.

There are several possible mechanisms of organic material removal which merit consideration:

1. Organisms may become concentrated on adsorption surfaces, thus occupying secure sites for capture of substrate passing by.
2. Substrate itself may be adsorbed by the media. As substrate concentration increases, it becomes more available to microorganisms in the micro-environment.
3. Adsorption of both substrate and microorganisms is another possibility. In this situation, the two would be in close proximity, and substantial growth and substrate utilization could be expected.

Examination of both COD and ammonia removal by both types of media lends support to the second possibility listed above. Adsorption of organic substrate would favor active carbon in COD removal. The failure of either media to adsorb ammonia would yield equal performance in nitrification. Adsorption of biological growth should give an advantage to nitrifying bacteria which could occupy more secure sites on the active carbon surfaces. In view of the results actually measured, the first and third possibilities listed above do not appear valid.

While adsorption is the key to the organic removal efficiency of the active carbon, the biological activity within the unit is also important. Adsorption alone would not have produced the same removal for so long a period. The carbon adsorption capacity would have become exhausted, and removal rates would have declined. The uniform removal can be explained by biological activity. Given proper loading and other environmental conditions, microorganisms could utilize adsorbed organic material at a rate which would constantly maintain exposed adsorption sites. This optimum condition could result in a continuous in-situ biological regeneration process.

The economic benefits of biological regeneration are obvious. Elimination of expensive thermal regeneration, coupled with a reduced active carbon inventory requirement, would represent a major advance in the economics of activated carbon systems.

Operational aspects of the aerated contactor system are also attractive. Aeration produces aerobic conditions and eliminates odor problems caused by H_2S production by anaerobic bacteria.

As shown in Fig. 7, the sand contactor removed 60 percent as much COD as did the active carbon contactor. In the future, it may prove feasible to combine this relatively inexpensive inert media contactor with an activated carbon unit to produce a highly treated wastewater at a lower cost than that of other process combinations. Finally, the possibility of obtaining a degree of nitrification gives the system a versatility not found in many other processes.

8. CONCLUSIONS

1. The apparent carbon capacity after 64 days of operation was 0.430 gm COD/gm carbon, with an average influent COD of 77.1 mg/ℓ and an effluent COD of 19.1 mg/ℓ.
2. The mass rate of COD removal in the aerated sand contactor was 1.80 Kg COD/day/m^3 of media when loaded in excess of 3.85 Kg COD/day/m^3 of media.
3. Appreciable nitrification was observed in the aerated contactors.
4. Use of the aerated contactor mode of operation could substantially reduce the active carbon operating costs for physical-chemical treatment plants.
5. Further study is needed to investigate the mechanism of organic material removal. Research is also needed to establish more definitely the capability of this system to accomplish nitrification.

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10. APPENDIX A: COD AND BOD DATA

Date	Operational Day	COD, mg/ℓ			BOD, mg/ℓ		
			Effluent			Effluent	
		Influent	Carbon	Sand	Influent	Carbon	Sand
7-23-73	1	74.4	13.0	49.8			
7-24-73	2	53.1	11.5	40.5			
7-25-73	3	73.8	12.9	48.4	85.7	34.8	25.0
7-27-73	5	65.5	16.1	45.0			
7-30-73	8	63.6	20.5	50.6			
8-1-73	10	79.8	35.1	50.6	32.0	27.0	25.0
8-2-73	11	61.6	28.3	44.2			
8-3-73	12	78.6	21.1	51.1	23.0	13.0	1.5
8-6-73	15	90.7	13.5	39.0			
8-7-73	16	84.0	11.5	30.5			
8-8-73	17	80.7	12.4	41.8	29.4	83.3	3.2
8-9-73	18	84.0	13.7	28.3			
8-10-73	19	84.6	14.5	44.5			
8-14-73	23	85.4	15.2	32.6			
8-15-73	24	75.1	26.4	38.3	19.6	59.4	15.5
8-16-73	25	77.9	24.8	45.7			
8-17-73	26	83.5	28.9	53.3	31.8	37.5	27.4
8-21-73	30	78.0	18.4	38.4			
8-22-73	31	76.7	12.3	46.8	15.5	2.8	4.5
8-23-73	32	82.0	12.5	38.8			
8-24-73	33	79.1	24.4	40.6			
8-27-73	36	64.9	17.6	31.6	13.7	--	2.9
8-28-73	37	85.0	22.4	31.8			
8-29-73	38	81.9	20.8	40.5	22.2	11.8	17.3
9-11-73	51	67.1	10.0	32.2			
9-12-73	52	90.9	28.2	47.7			
9-13-73	53	89.0	32.0	46.9			
9-14-73	54	78.4	25.6	46.1			
9-17-73	57	67.8	15.9	33.7			
9-20-73	60	83.9	23.0	44.3			
9-21-73	61	61.9	17.9	55.0			
9-24-73	64	84.1	10.2	21.0			

11. APPENDIX B: NITROGEN DATA

		Nitrogen Concentrations, mg/ℓ as N								
		Influent			Sand Effluent			Carbon Effluent		
Date	Operational Day	NH_3	NO_2^-	NO_3^-	NH_3	NO_2^-	NO_3^-	NH_3	NO_2^-	NO_3^-
7-23-73	1	11.7	0.52	0.06	8.1	0.02	1.78	12.1	0.44	4.46
7-24-73	2	10.4	0.58	0.06	2.9	12.8	0.40	4.9	9.25	0.75
7-25-73	3	18.9	0.60	0.79	2.9	0.25	11.8	0.2	0.75	8.60
7-27-73	5	4.6	--	0.43	5.3	--	13.2	0.1	--	12.8
7-30-73	8	3.7	--	0.51	0.2	--	17.0	0.1	--	9.62
8-1-73	10	4.3	0.40	0.56	2.4	0.25	6.9	6.4	0.56	11.7
8-2-73	11	9.4	--	0.62	16.1	--	8.63	20.7	--	14.7
8-7-73	16	--	0.11	--	11.8	--	11.8	--	--	7.8
8-8-73	17	23.5	--	0.65	10.7	--	22.0	1.7	--	13.8
8-9-73	18	20.1	--	0.68	2.6	--	37.4	0.7	--	14.2
8-10-73	19	9.8	0.32	0.53	3.7	1.51	46.2	--	--	28.0
8-14-73	23	15.6	--	--	--	--	--	0.5	--	--
8-15-73	24	11.3	0.50	0.56	--	0.42	26.8	13.5	0.33	10.2
8-16-73	25	20.4	--	--	8.2	--	--	9.4	--	--
8-17-73	26	--	0.60	0.67	15.1	0.11	5.64	10.7	0.03	6.22
8-20-73	29	22.9	--	--	5.9	--	--	18.9	--	--
8-21-73	30	20.4	--	--	15.1	--	--	10.7	--	--
8-22-73	31	2.4	0.50	0.52	9.3	0.21	18.0	4.0	0.39	11.5
8-24-73	33	20.8	0.48	0.45	12.2	0.44	37.0	14.6	0.04	16.4
8-29-73	38	13.1	0.63	0.60	7.3	0.82	48.8	9.8	0.05	9.20

12. APPENDIX C: RATE, pH AND TEMPERATURE DATA

		Sand Contactor			Carbon Contactor		
Date	Operational Day	Flow Rate (ℓ/min)	pH	T(°C)	Flow Rate (ℓ/min)	pH	T(°C)
7-23-73	1	1.97	8.00	23	1.51	7.35	23
7-24-73	2	1.97	7.20	26	1.48	7.30	24
7-25-73	3	1.89	7.55	23	1.70	7.70	23
7-27-73	5	2.57	7.45	26	2.38	7.60	26
7-30-73	8	2.76	7.15	26	2.88	7.45	26
8-1-73	10	1.82	7.60	25	1.85	7.65	23
8-2-73	11	2.91	7.80	25	3.22	7.80	25
8-3-73	12	2.12	8.10	--	3.10	8.10	--
8-6-73	15	2.27	7.65	26	2.12	7.60	26
8-7-73	16	2.80	7.95	28	2.57	7.80	27
8-8-73	17	2.42	7.50	27	1.82	7.65	26
8-9-73	18	2.31	7.90	28	1.82	7.40	28
8-10-73	19	3.06	7.60	28	2.84	7.85	26
8-14-73	23	2.61	7.40	24	2.35	7.70	25
8-15-73	24	2.42	7.40	24	2.35	7.60	24
8-16-73	25	2.80	7.90	24	1.63	7.65	24
8-17-73	26	2.61	7.40	26	2.50	7.35	21
8-21-73	30	2.42	7.50	24	2.08	7.45	24
8-22-73	31	2.61	7.80	16	1.70	7.45	16
8-23-73	32	2.61	7.85	24	1.63	7.70	24
8-24-73	33	2.57	7.80	17	2.80	7.45	16
8-27-73	36	2.61	--	--	2.54	--	--
8-28-73	37	2.80	7.45	26	2.80	7.05	26
8-29-73	38	2.57	7.80	18	2.42	7.15	12

13. VITA

Marion Michael Hunter was born in Bakersfield, California, on February 20, 1942. He attended the public schools there and completed high school in 1959.

He received a Bachelor of Science degree from the U.S. Military Academy in 1966. After graduation, he served as an Army officer at various installations in the United States, Western Europe and the Far East.

He received a Master of Science degree from Lehigh University in January, 1976. He is a registered professional engineer and is currently employed in the Water and Waste Treatment Division of Drew Chemical Corporation.