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Robert L. Johnson

# BIOLOGICAL REGENERATION OF ACTIVATED CARBON IN ADVANCED WASTEWATER TREATMENT

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## ABSTRACT

Enhancement of biological activity was used for off-line batch regeneration of exhausted carbon and in aerated contactors for in-situ regeneration. A parallel sand media aerated contactor provided a base line comparison of the 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.

After three off-line batch biological regeneration cycles, the carbon capacity exceeded 1.0 lbs COD/lb with no apparent reduction in the COD removal rate compared to virgin carbon. In 200 days of aerated contactor operation the apparent capacity was 1.87 lbs COD/lb carbon. The influent COD of 94.6 mg/ℓ was reduced to 30.4 m/ℓ at 1.5 gpm/sq ft with 25 minutes detention.

The aerated sand contactor removed over 140 lbs COD/day per 1000 cu ft (ptcfd) at 340 ptcfd loading rate.

Using existing data, carbon operating costs for small physical-chemical treatment plants could be reduced 50% by using aerated contactors. Comparable economic advantages can be achieved in tertiary treatment plants by utilizing the contactor biological activity in a positive manner.

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# I. CONCLUSIONS

1. Off-line batch biological regeneration of spent activated carbon has been shown to effectively maintain the carbon capacity near that of virgin carbon. After a total of three biological batch regeneration periods, the carbon showed a total apparent capacity in excess of 1.0 lbs COD/lb carbon.

2. Recirculating aerated water through the contactor at incipient fluidization velocities proved to be a simple effective means of regeneration. The biological mass entrapped in or on the activated carbon was sufficient to accomplish the biological regeneration and maintenance of a separate biomass was unnecessary.

3. The apparent carbon capacity after 200 days of operation in an aerated contactor was 1.87 lbs COD/lb carbon with an average influent COD of 94.6 mg/ℓ and an effluent COD of 30.4 mg/ℓ.

4. The mass rate of COD removal in the aerated sand contactor was over 140 lbs COD/day per 1000 cu ft media when loaded in excess of 340 lbs COD/day/1000 cu ft media.

5. Use of the aerated contactor mode of operation could reduce the carbon operating costs by 50 percent for small PCT plants and comparable savings can be realized for larger PCT plants.

6. Appreciable nitrification was observed in the aerated contactors.

7. Even using virgin carbon with contact times of 84 minutes, the Bethlehem wastewater could not be reduced below 15-20 mg/ℓ COD.

## II. RECOMMENDATIONS

Additional studies should be conducted to extend the results of this research into practice and try to determine mechanisms involved in some of the observed phenomena.

1. Add the simple off-line batch regeneration scheme developed to an existing tertiary treatment plant and evaluate the field performance.
2. Apply the aerated contactor mode of operation to an existing PCT plant and to an existing tertiary treatment plant for field evaluation.
3. Investigate the rate of nitrification achievable in both inert and active carbon media aerated contactors.
4. Attempt to characterize the organic constituents in the influent and effluent wastewater of aerated and anaerobic carbon contactors as part of a study to determine the mechanisms involved for the biological activity in the carbon contactors.
5. Develop process flow schemes for tertiary and PCT plants involving off-line batch regeneration and aerated contactors, both inert and active surface media, and re-evaluate the economic relationships as compared to the current design suggestions.

# III. INTRODUCTION

## ACTIVATED CARBON ADSORPTION IN WASTEWATER TREATMENT

Concern about national water pollution problems and water reuse technology for water supply augmentation has led to extensive investigation of advanced waste treatment processes (1,2) to supplement conventional treatment. The need for highly polished effluents from wastewater treatment facilities, both for more stringent surface water quality and for water reuse stimulated a great interest in carbon treatment systems for removal of dissolved organic material (3-7).

Conventional secondary biological treatment facilities with conservative design and operation can usually produce effluents with 10-20 mg/ℓ suspended solids and 50-60 mg/ℓ COD (Chemical Oxygen Demand). However, in many cases, this level of effluent quality is not sufficient to prevent degradation of receiving surface waters. In particular this level of effluent quality does not lend itself to water reuse on an extensive basis.

Activated carbon adsorption in tertiary stages for removal of residual organics from effluent streams of conventional biological treatment systems has proven successful in "polishing" operations. Granular activated carbon with a long history of industrial applications has proven to be the more practical form (5) with present application technology, although the emerging powered carbon technology (2) may add another process element to be considered.

Initial applications of granular carbon adsorption in tertiary

stages used downflow packed beds (8). The beds were regularly backwashed to remove suspended solids accumulation which caused high pressure loss across the contact units. Clogging problems, as well as the need for greater clarity of effluent, led to chemical coagulation, seminentation and filtration for solids separation ahead of the downflow carbon contact units.

Incorporation of such solids separation techniques led to the concept of physical-chemical treatment (PCT) of raw sewage as an alternative to conventional biological treatment. Physical-chemical treatment (PCT) systems use chemical coagulation, sedimentation and filtration for solids removal followed by granular activated carbon adsorption for additional removal of organic material, particularly the dissolved organics. Thus, we have a situation where the same physico-chemical processes applied to effluent streams from biological treatment systems is termed advanced wastewater treatment (AWT) and when applied to raw sewage, it is termed physical-chemical treatment (PCT).

In either application--AWT or PCT--the heart of the system for removal of the dilute dissolved organics is granular activated carbon. The economic basis for the use of the activated carbon lies in 1) having a high capacity to remove residual organics (lbs COD removed/lb carbon) and 2) the regeneration of the carbon capacity for reuse in the treatment facility.

A greater carbon capacity (lbs COD removed/lb carbon) will lead to a lower required dosage of carbon (lbs carbon/MG) for any one treatment system. Thus, the carbon inventory, regeneration capacity

and contactor size can be reduced for a given effluent quality.

## ACTIVATED CARBON REGENERATION

With high first costs ($0.35 to $0.50/lb carbon), it is essential in most applications that the carbon be regenerated and reused after exhaustion of the initial adsorption capacity in order to be economically feasible. The main system utilized thus far has been thermal regeneration in a multiple hearth furnace. Thermal regeneration consists of three steps: 1) de-watering of the activated carbon slurry, 2) baking and pyrolysis of adsorbed organics and 3) reactivation of the carbon. Multiple-hearth furnaces can restore granular activated carbon to capacities near the virgin conditions (4,6). The size of the operation is very important in the economics of regeneration (6,9,10) as shown in Table 1 since the first cost of the equipment for regeneration is appreciable.

TABLE 1

COST OF GRANULAR CARBON REGENERATION (10)

| Regeneration Capacity[a] lbs/day | Treatment Capacity MGD AWT[b] | PCT[c] | Total Regeneration Cost[d] $/lb Carbon |
|---|---|---|---|
| 2,000 | 4.0 | 0.8 | 0.236 |
| 5,000 | 10.0 | 2.0 | 0.149 |
| 10.000 | 20.0 | 4.0 | 0.115 |
| 20,000 | 40.0 | 8.0 | 0.156 |

a Based on 100% excess capacity
b Based on 250 lbs/MG carbon dosage
c Based on 1200 lbs/MG carbon dosage
d Based on 8% loss per regeneration and includes total operating costs as well as amortization

The effect of size, not only for regeneration, but from all aspects, has been well documented through all periods of development of the present technology (6, 7, 9, 10). The total cost of small to medium size tertiary treatment installations is shown in Fig. 1 using data by Cover (6,p64). Much of this cost for the small installations is due to the high cost incurred in using the granular carbon on a once-through throwaway basis.

The effect of size on regeneration costs is succinctly stated in the EPA process design manual (10, p 5-8 and 5-9):

> "So far as provision for on-site carbon regeneration is concerned, small plants can be placed into three categories according to their carbon usage:
>
> 1. For plants with carbon usage less than 200 lbs/day, carbon regeneration faciltities should not be provided. If granular carbon is to be used, it would be on a once-through throwaway basis, or the spent carbon could be transported to and from a central regeneration station if one is available. This category would include AWT plants using the tertiary sequence of treatment having a carbon usage of about 250 pounds per million gallons (lbs/MG) and smaller than 800,000 gpd capacity, and PCT plants having a carbon usage of about 1,200 lbs/MG and smaller than 170,000 gpd capacity.
>
> 2. When average carbon regeneration requirements exceed 1,500 lbs/day, there is no question but that on-site carbon regeneration facilities should be built. This category would include tertiary plants having capacities greater than 6 mgd and physical-chemical plants rated at 800,000 gpd or more.

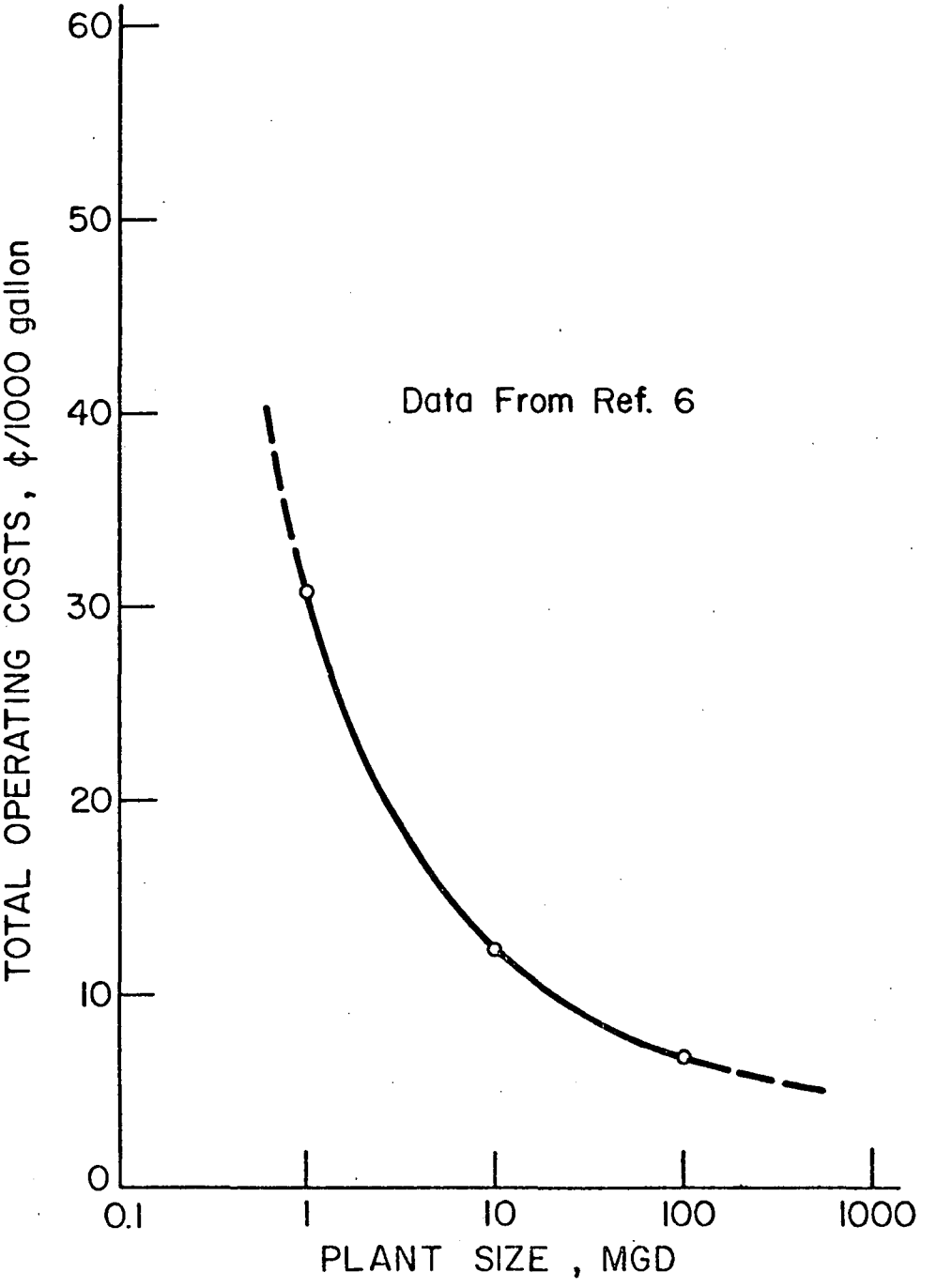


Fig. 1 Tertiary Treatment Costs with Activated Carbon

3. For carbon usages between 200 and 1,500 lbs/day, which would include tertiary plants with capacities between 0.80 and 6.0 mgd and PCT plants with capacities between 170,000 and 800,000 gpd, the cost of on-site regeneration must be compared to the costs of central regeneration and to the costs of alternate treatment methods for removing refractory organics."

One extreme, that of no regeneration has been evaluated, although indirectly. The Environmental Protection Agency has evaluated some small scale PCT systems and results of field studies have been reported (2, Session Four). For these treatment systems of less than 0.5 MGD size, the activated carbon is not regenerated. The marked reduction in cost with increased carbon capacities is shown in Fig. 2. Any increase in the carbon capacity will drastically reduce the total costs of this type of plant. Likewise, any simple inexpensive method of regenerating the exhausted carbon, preferably in-situ, would drastically reduce the costs of the small to medium sized plant.

In-place steam regeneration of the exhausted carbon has been considered (6, p 96), but since the costs appear to be comparable to the conventional thermal means, this has not been studied further.

Chemical oxidation and oxidation-reduction have been studied (11) as a potential alternative to thermal regeneration. Chemical treatment has proven to be not only unsatisfactory for effective regeneration, but also economically prohibitive.

In addition to the physical and chemical aspects of operation and regeneration, there are important biological considerations in

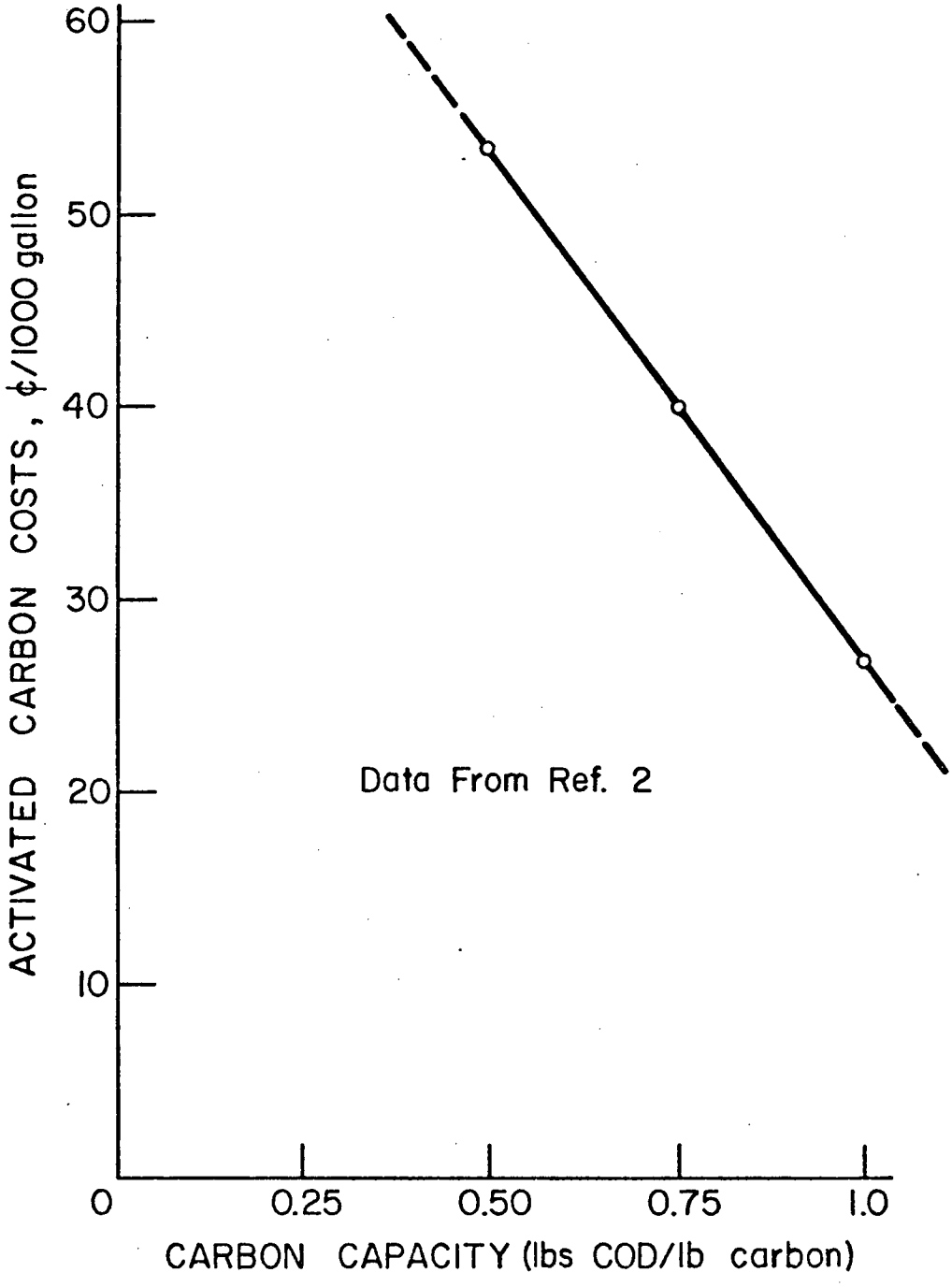


Fig. 2 Activated Carbon Costs for Small PCT Plants

the design and operation of activated carbon contactors. The effluent from conventional treatment systems is considered too dilute to support further biological treatment units. However, after carbon adsorption of the organics, biological activity flourishes within the carbon contactors.

## BIOLOGICAL ACTIVITY IN ACTIVATED CARBON ADSORPTION

The concentration effect in adsorbing the organic material creates a highly enriched substrate on a micro-environmental scale which is very conducive to active biological growth. The biological acitivity in carbon contactors has been viewed with mixed feelings. From a positive point of view, the biological activity has advantages of 1) increasing the apparent carbon capacity, and 2) removing non-adsorbable biodegradable materials.

From the negative view (5) the biological activity is considered a problem which tends to clog the pores of the carbon. Another problem that occurs in the anaerobic environment of the carbon contactors has been the growth of sulfate reducing bacteria causing $H_2S$ odor problems. Various means have been proposed to control this problem (10).

Viewed as a benefit, the biological activity has been tolerated and considered to be a safety factor in design (6, 12) due to the lack of data on the extent of the biological activity. Much of the research and operating data has been derived from downflow packed beds, where biological activity has, at best, been merely tolerated,

if not actively discouraged, primarily due to the $H_2S$ odor problems of anaerobic conditions in the contactors.

One research study has attempted to use the biological activity potential in carbon adsorption systems. In this study (13) a textile dye waste was adsorbed onto granular activated carbon. An offstream activated sludge type biological reactor provided a reservoir of organisms which were used to regenerate the spent carbon by recirculating the biological regenerating slurry through the carbon contactors. They found that bio-regeneration was possible, but that the intermittent feeding of the biological culture (10 hours without feeding and 14 hours in the regeneration cycle) presented problems of maintaining the biological culture.

Other researchers (14) have investigated aerobic and anaerobic activity in expanded bed carbon contactors in a PCT pilot plant treating a primary effluent wastewater. They found appreciable extension of the carbon service time and apparent capacity. They also speculated that the biological activity in the carbon contactor is a combination of anaerobic degradation in the micro-environment of the granular carbon supplemented with aerobic biological activity which degraded the smaller organic molecules diffusing away from the carbon. The biological activity was viewed as greatly extending the carbon capacity in a PCT facitility.

Some of the advantages of the biological activity are briefly discussed in the EPA process design manual (10, p 4-17), but on the whole, utilization of the biological activity in carbon systems is discouraged by this manual.

Adequate recognition of the benefits of biological activity in activated carbon contactors will allow a better definition of the real life design adsorption capacity of activated carbon. Either partial regeneration of the activated carbon by biological oxidation of the adsorbed organic material or extension of the carbon adsorption capacity by enhancing on-stream biological activity could provide economic savings which would enhance the utilization of activated carbon systems.

A larger maximum adsorption capacity will allow longer carbon contact periods before thermal regeneration is necessary. In some cases, such as small installations, it may be economical to completely eliminate thermal regeneration.

## RESEARCH OBJECTIVES

Utilization of the biological activity in carbon contactors in two specific modes of operation was the general aim of this project. The first operational mode investigated was the off-line biological regeneration of spent carbon in batch type reactors. Results observed will be applicable to existing facilities using carbon contactors and thermal regeneration, where modifications could be made to take advantage of the savings afforded by biological regeneration. This type of operating mode would also be applicable to existing small AWT or PCT facilities where it is uneconomical to provide thermal regeneration, particularly since the regeneration scheme developed in this research is simple and inexpensive.

A second mode investigated was operation of aerated contactors to allow in-situ pseudo-continuous regeneration of the active carbon surfaces.

A major objective of this project was more adequate definition of the increase in carbon capacity (lbs COD/lb carbon) due to biological activity to allow future design incorporation of this phenomenon on a rational basis.

## IV. DESCRIPTION OF RESEARCH SYSTEM

The experimental apparatus was installed at the Bethlehem Sewage Treatment Plant, a high-rate trickling filter of the bio-filter type which utilizes recirculation from the final clarifier to the primary clarifier. 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 treatment facility design capacity is 12.5 MGD, but the plant is overloaded and has operated at about 15 MGD for some time. This situation combined with the "partial" clarification of research treated wastewater provided some problems in simulating a typical secondary treatment effluent as the influent wastewater.

Bethlehem is a highly industrialized community with many different sources of industrial wastewaters in addition to the domestic wastewaters. In particular there are numerous metal-plating operations in addition to the several sources of wastewaters from the primary metal industry, namely the Bethlehem Steel Corporation. Some specific wastewaters entering the treatment facility are partially treated weak ammonia liquors, which includes the waste activated sludge from a phenol treatment facility. In general, the wastewater would have to be classified as difficult, both by the very nature of the waste sources and the variability of the wastewater character.

The successful utilization of the biological activity with this type of wastewater makes its applicability to other wastewater even more definite.

## RESEARCH OPERATING PHASES

The research was conducted in three phases with the equipment and apparatus modified to fit each of the new conditions imposed. Phase I involved carbon contacting with off-line batch regeneration of the spent carbon. Thus there was a contacting flow scheme and a regeneration scheme to consider.

Phase II was the continuous operation of parallel aerated contactors. One unit used granular activated carbon and the second contactor had sand as an inert type of media. The last portion of the research, Phase III, involved the combination, in series, of the aerated contactors and batch type carbon contactors with off-line regeneration.

## RESEARCH PROCESS FLOW SCHEMES

This section of the report describes the different operating schemes used in research efforts. Details of the equipment are described later.

Contacting Scheme: Phase I - The treated wastewater was taken from the recirculation pump suction line and pumped to the equipment room where the experimental apparatus was located. This influent was filtered through a dual media pressure filter to remove some of the

suspended solids and more nearly simulate a secondary treated effluent wastewater. The filter effluent discharged into a constant head reservoir which fed a variable speed pump[a] supplying the carbon contactors. Effluent from the contactors flowed into a second constant head reservoir where samples were taken and this reservoir overflow returned to the treatment plant wet well.

No attempt made to regulate the pH, temperature, or solids load of the contactor influent, except as noted previously in connection with the dual media filter. At first, hydrogen sulfide generation within the carbon contactors created odor problems and the influent was chlorinated using a chemical feed pump.[b] This practice was discontinued after a short period and further hydrogen sulfide odors were not encountered.

Flow rate control to the columns was by three means: 1) speed control of the supply pump which was limited by the 35 psi maximum operating pressure of the pump seals, 2) the flow control valves[c] in the supply lines and 3) manual throttling of the ball valves on the supply line for each contactor. Breakup of occasional agglomerations within the contacting units was found to be necessary every few weeks and an air tap was set into the base of all contactors for this purpose. A flow schematic is shown in Fig. 3.

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[a] Teel 1P817, Dayton 3M293
[b] MEC-O-MATIC, 475-C
[c] Dole Mfg. Co.

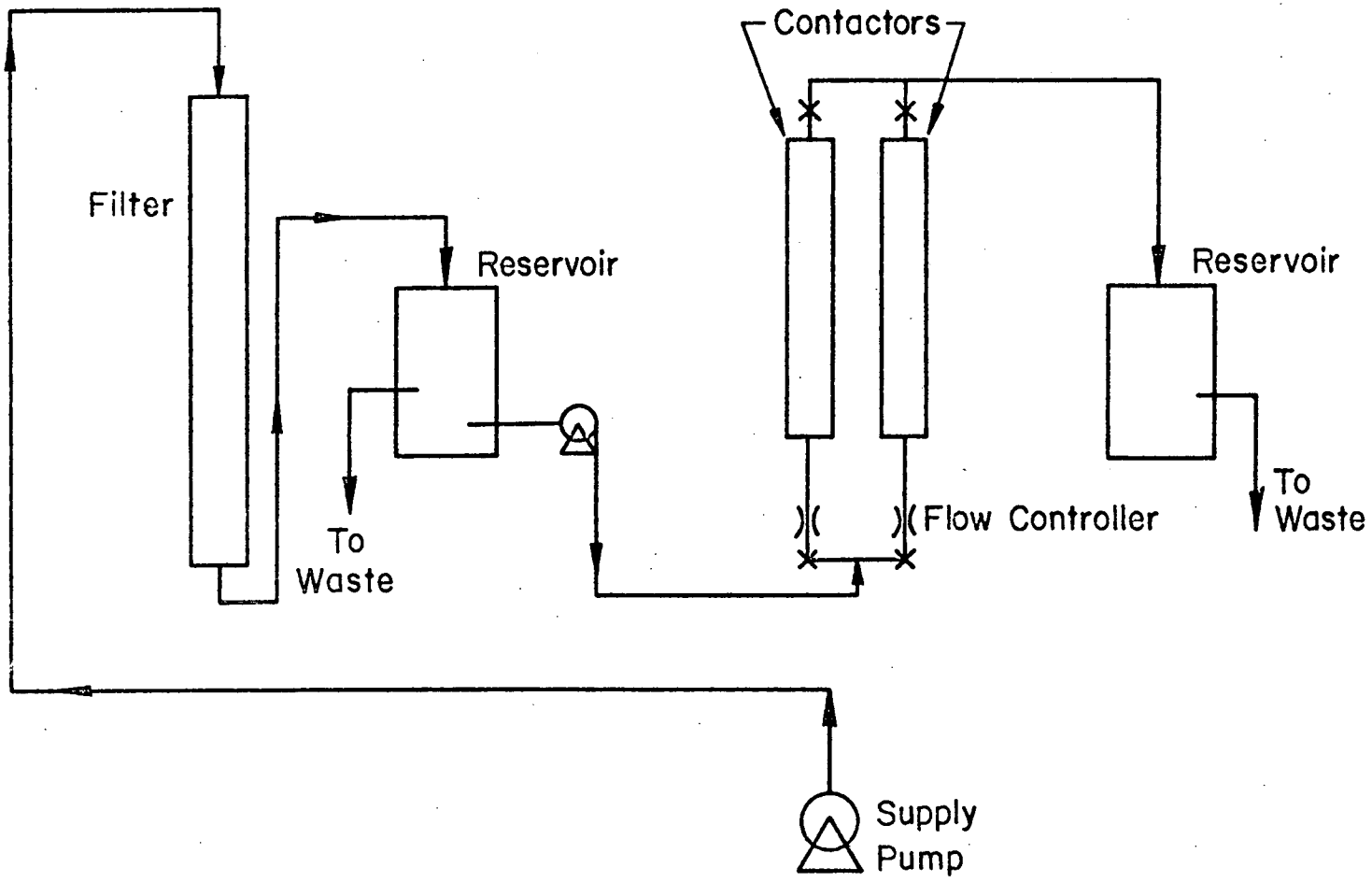


Fig. 3 Contacting Schematic - Phase I

Regeneration Scheme: Phase I - The second major flow system was for regeneration of the spent carbon. The first system involved removing the caps from the contactors and inserting a porous stone diffusor on the end of a piece of plastic pipe into the carbon, until it was near the bottom. By inserting the air supply assembly while the contactor was filled with fluid, and with the air flow maintained down through the pipe and out of the diffusors, it was a simple matter to place the diffusor at the bottom of the carbon bed. This system was abandoned because the agitation of the water caused carbon to overflow since there was inadequate freeboard. Also, the carbon bridged and an agglomeration of carbon boiled over the top of the contactors.

Modifications to this basic system were ineffectual, leading to the fabrication of another system. The contactor units again had the caps removed, and an open top extension was connected. The extension had a 1/2 inch screened connection to prevent carbon particles entering the recirculation lines. Recirculating water flowed upward through the carbon beds. Minor problems associated with this system were due to the head limitations of the submersible pumps and clogging of the inlet screen with carbon particles and material that had been scoured off. Dissolved oxygen concentrations were maintained by insertion of the diffusor into the constant head reservoir where the submersible pumps were located. It was simple to monitor the dissolved oxygen level and control the dissolved oxygen level using the air supply rate. Flow regulation was accomplished by adjustment of the position of the constant head reservoir.

The final regeneration system was a simple modification of the second system. The contactor extensions were abandoned and the original caps were kept in place. The constant head reservoir was installed at the level of the tops of the column to allow minimum head loss and water was again recirculated upflow through the carbon. The water would flow through the top into the constant head reservoir, where the diffusors would saturate the water with dissolved oxygen. The submersible pump would then pump it down to the bottom of the contactor and up through the activated carbon. The flow rate was maintained near incipient fluidization of the upper 2 to 3 inches of the carbon bed which was approximately 8 gpm/sq ft. The final flow scheme is shown in Fig. 4.

Operating Scheme: Phase II - Evaluation of the potential for pseudo-continuous in-situ biological regeneration of the activated carbon was the main thrust of the second phase of the research. To provide an environment conducive to aerobic biological activity, the carbon contactor was aerated continuously. A parallel aerated inert surface sand contactor provided a base line comparison for the biological activity in the contactors.

The same influent was used in this portion of the study and the wastewater was filtered as in Phase I prior to the contacting columns. Figure 5 shown a schematic flow diagram of the process.

Contacting Scheme: Phase III - This portion of the project combines features of both previous phases of study. The operating scheme of Phase II was continued, with the effluent from the aerated carbon

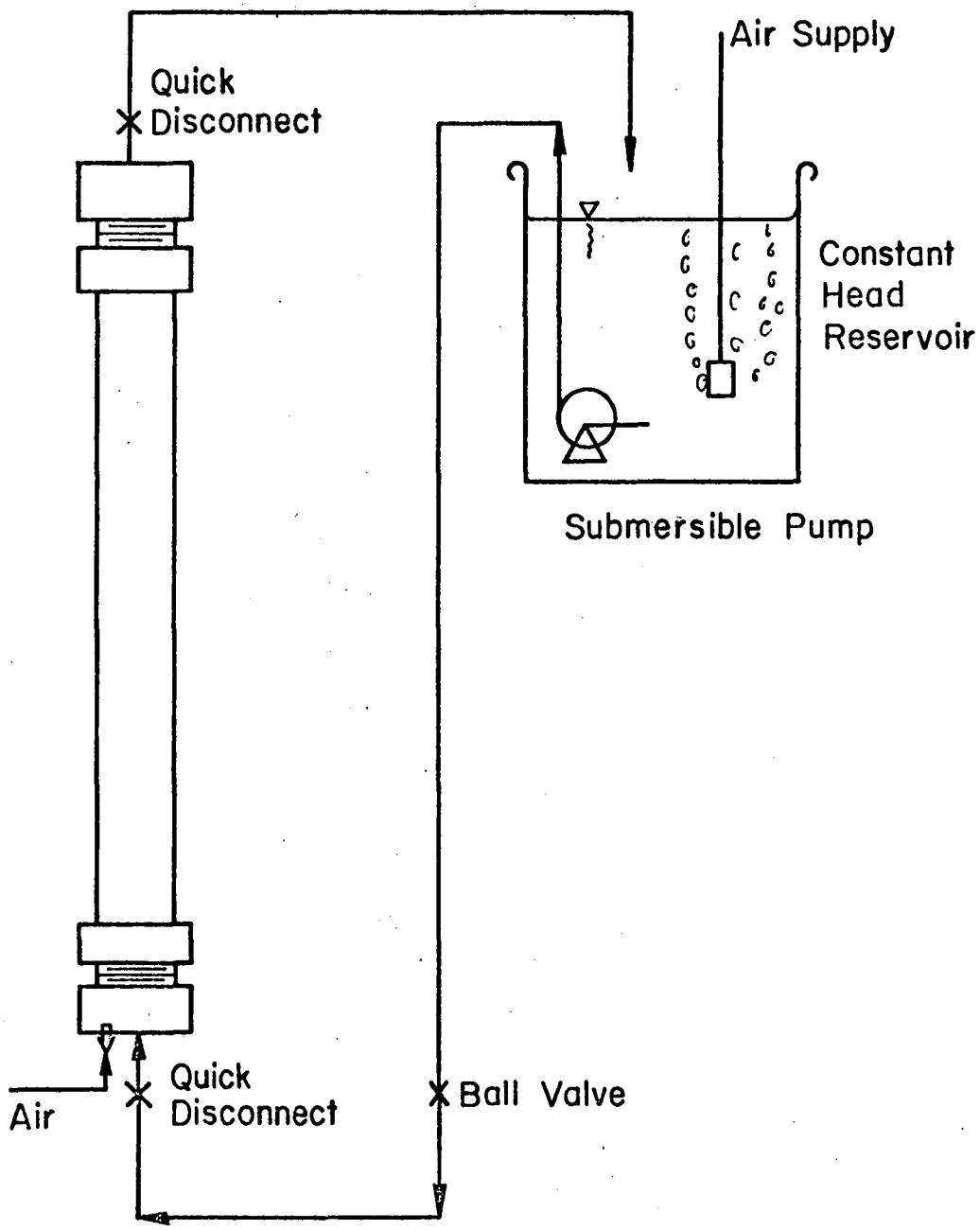


Fig. 4 Regeneration Schematic

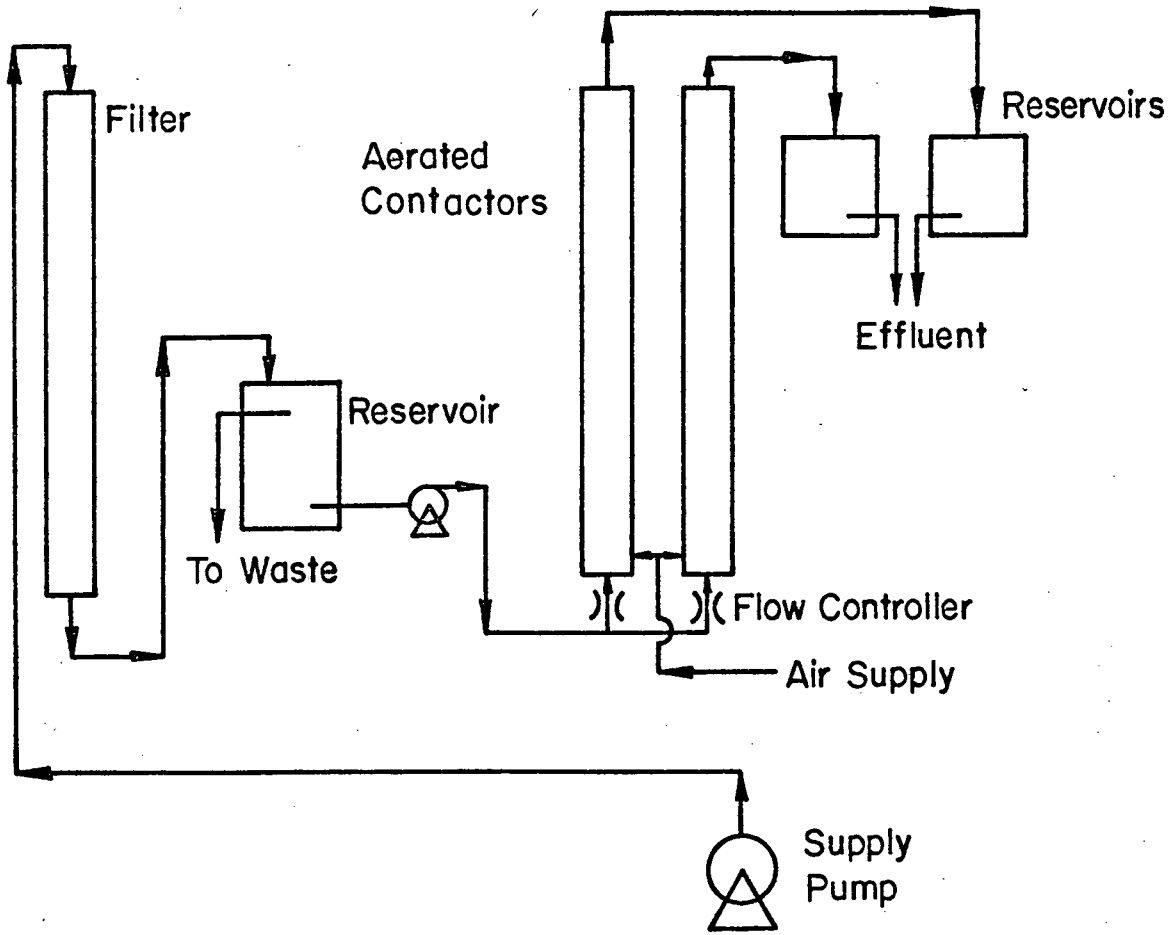


Fig. 5 Contacting Schematic - Phase II

contactor being used as the influent for two carbon contactors in series as shown in Fig. 6. This operating scheme provides a well processed wastewater for the final carbon contacting. The contact period was considerably longer than in Phase I in order to more adequately simulate a quite dilute tertiary wastewater treatment situation.

Off-line regeneration of the carbon contactors used a set-up essentially identical to that used in Phase I as shown in Fig. 4.

## EQUIPMENT DESCRIPTION

The several pieces of apparatus used in the project are described in this section. One major problem that must be recognized in applying research results is scaling up pilot plant equipment to full scale design. Knowledge of the pilot plant equipment and operational problems is needed to adequately scale up to full size design.

Dual Media Filter - The dual media filter shown in Fig. 7 was fabricated from 10 inch steel pipe with blind flanges and tapped for 3/4 inch PVC pipe. The filter was equipped with backwash lines, pressure gages and a 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 3/4 X 1/2 inch gravel up to the top of the inlet funnel. Additional layers, each 3 inches deep, 1/4 X 1/2, 1/8 X 1/4 and 1/16 X 1/8 inches made up the balance of the underdrain gravel.

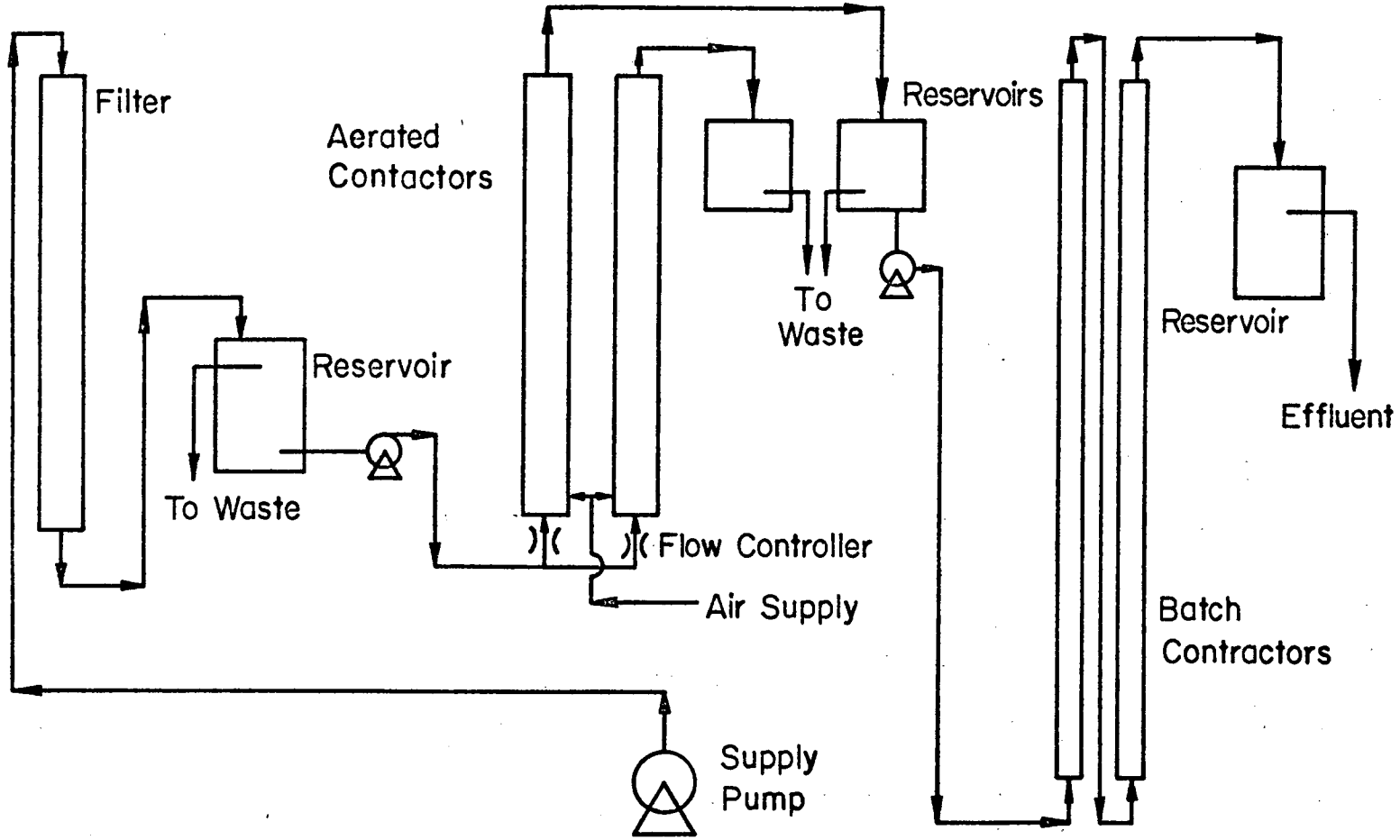


Fig. 6 Contacting Schematic - Phase III

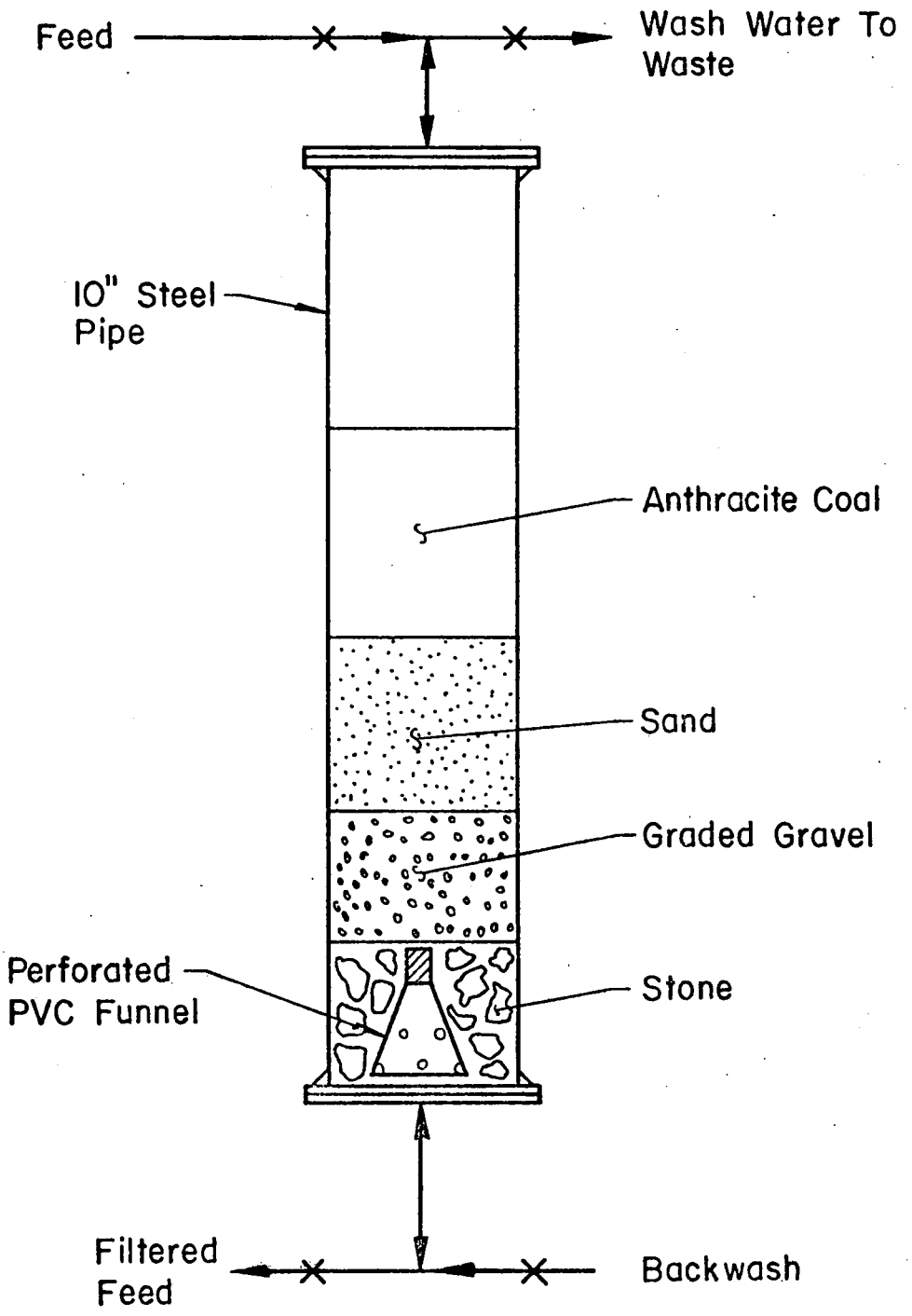


Fig. 7 Dual Media Filter

The upper filter media was 20 inches 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 12 inch layer of sand below the anthracite coal had an 0.5 mm effective size and a uniformity coefficient of 1.30.

Carbon Contactors - The carbon contactors used in Phase I were operated in parallel in sets of two. These contactors were nominal three inch plexiglas or PVC pipe, 2.75 inch ID and 3.06 inch ID respectively. The contactors were six feet long in Phase I and eleven feet long for the Phase III research.

The contactors were constructred with insert male adaptors at both ends, and capped with drain waste vent (DWV) caps. Details of the batch contactors are shown in Fig. 8. All units had stainless steel screens mounted within the caps for support of the carbon.

After a first aborted run with four feet of carbon in the six foot contactor, the carbon charge to the columns was adjusted to three feet during Phase I and approximately nine feet for Phase III.

Aerated Contactors - For the Phase II portion of the project, the wastewater was treated in two continuously aerated upflow contactors. The aerated contactors, Fig. 9, were constructed of 10 inch (9.80 inch ID) PVC sewer pipe ten feet long. Each unit was mounted vertically on a one foot long 10 inch steel pipe base and inlet section. The PVC and steel pipe sections were connected using 16 inch square flanges. A rubber gasket between the flanges compressed by C-clamps provided a pressure tight connection.

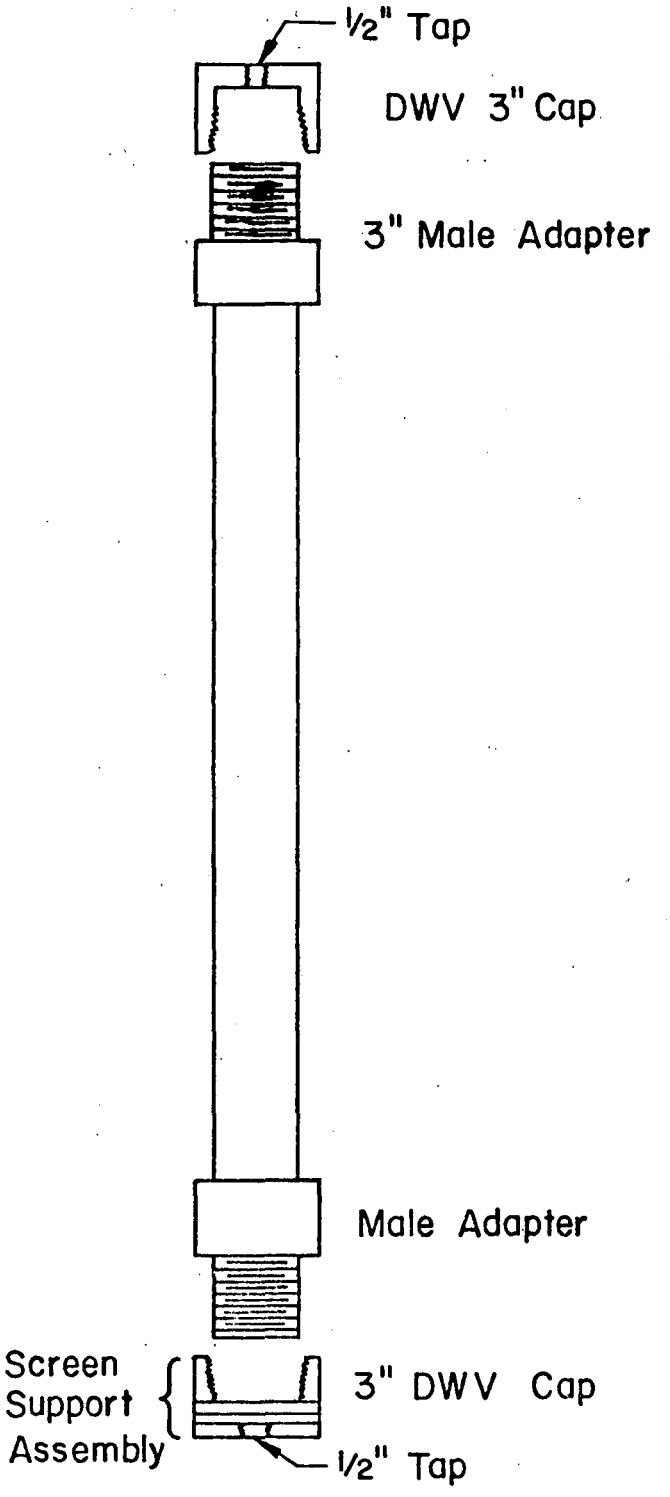


Fig. 8 Carbon Contactors

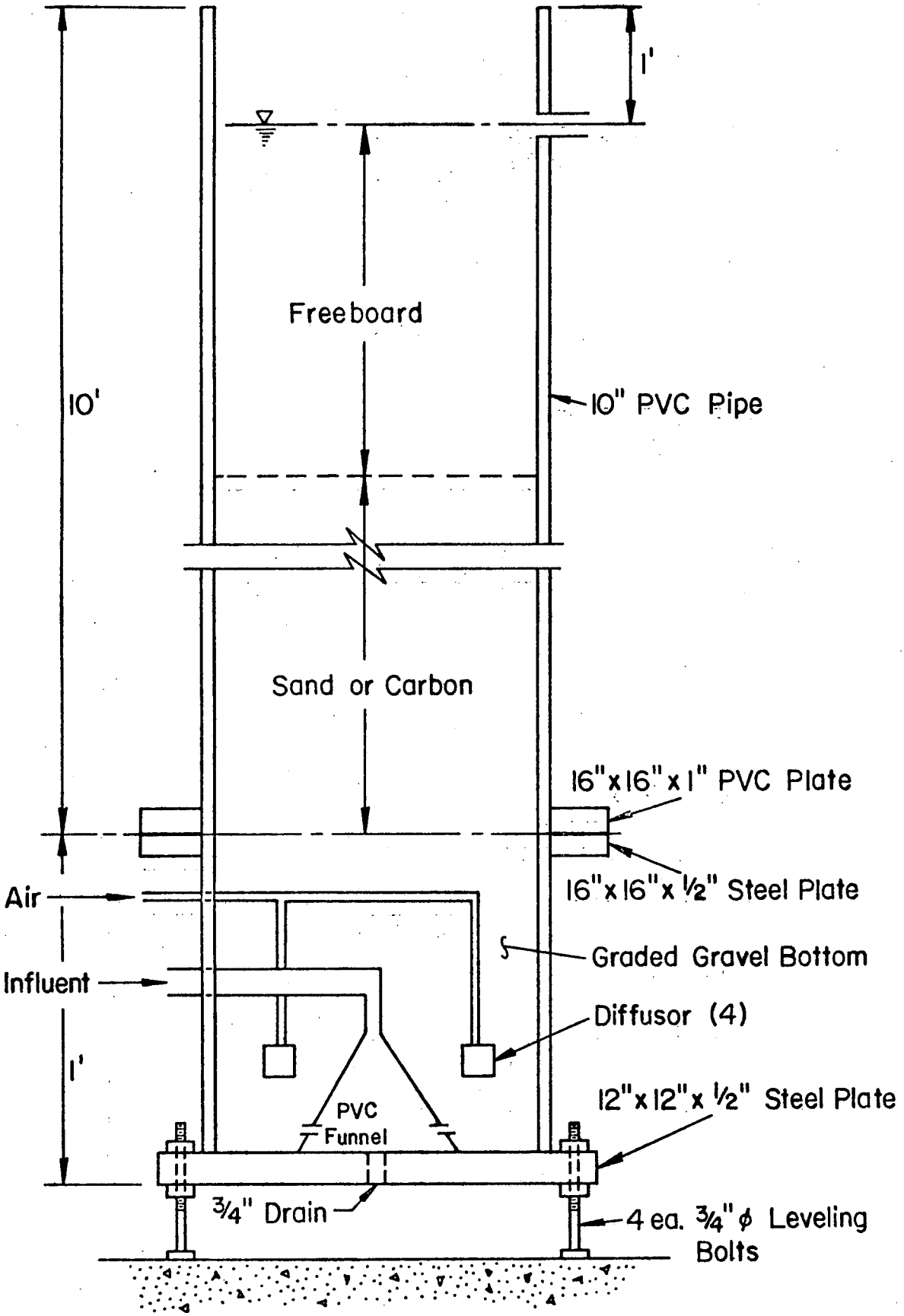


Fig. 9 Aerated Contactor

Influent to the contactors was distributed through an inverted 8 inch PVC funnel which was perforated with two rows of 1/4 inch holes. The base section was filled with 1/8 X 1/4 gravel up to the flange connection level. A second pipe inlet to the base section was for the air supply which flowed upward cocurrent with the wastewater. The air was diffused through four laboratory type carborundum diffusor stones.

Both aerated contactors had five feet 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[a] 300, 8 X 30 mesh size.

Air Supply - A conventional compressor-receiver tank set provided the compressed air for the aerated contactors and for the batch contactor regeneration scheme previously shown in Fig. 4. The air pressure was reduced and the flow rate controlled by needle valves on the outlet of rotameters as shown in Fig. 10.

Samplers - Composite influent and effluent samples were obtained with a unique, clock-timer actuated guillotine sampler developed especially for this research project. This sampler consisted of a solenoid actuated scissors mechanism that pinched off rubber sample lines which were connected to each of the influent and effluent constant head reservoirs. The composite sampler was fabricated in essentially three pieces: the timer mechanism, the

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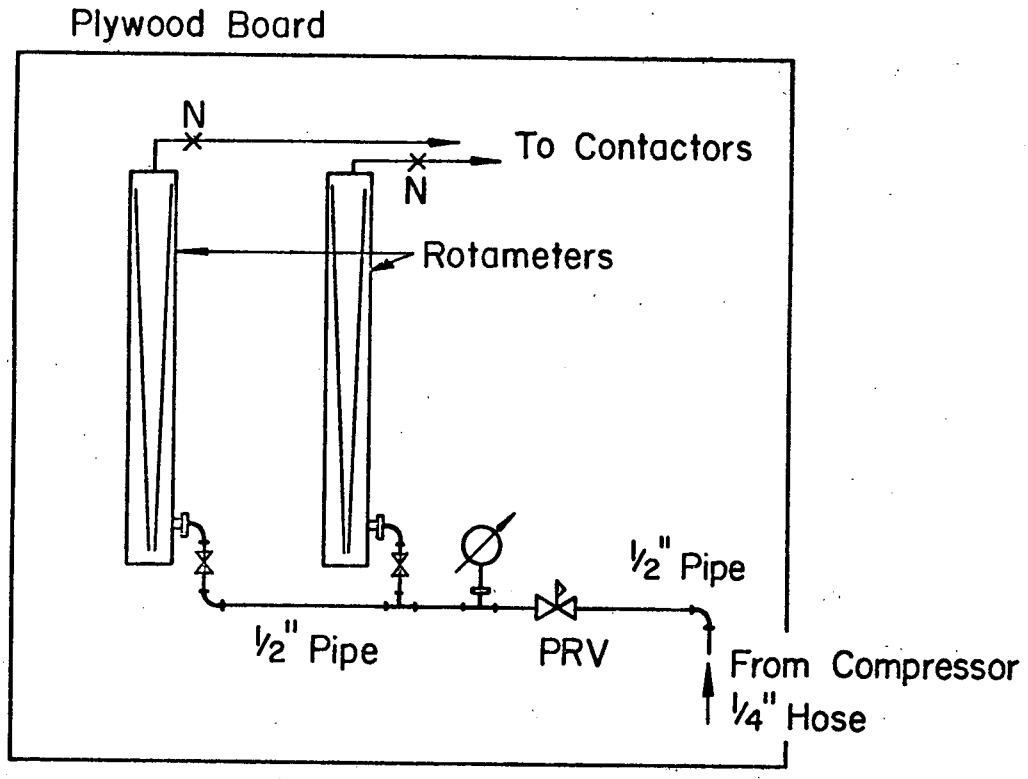
[a] Calgon Corporation




N Needle Valve

PRV Pressure Regulating Valve

Fig. 10 Air Supply Detail

solenoid action and the scissor action mechanism, or guillotine. The sampler details are shown in Fig. 11. It was found necessary to insert a heavy duty spring (about 20 lbs/inch) to protect the solenoid mechanism from shock loads. The system was fail safe, since the scissors were counter weighted and would keep the sampler closed in the event of power or equipment failures.

During Phases III, the batch carbon contactor effluents were sampled using a pair of solenoid actuated valves on a tee connection to the piping from each contactor. The timer mechanism used for the guillotine sampler above also actuated the valves on the batch connectors.

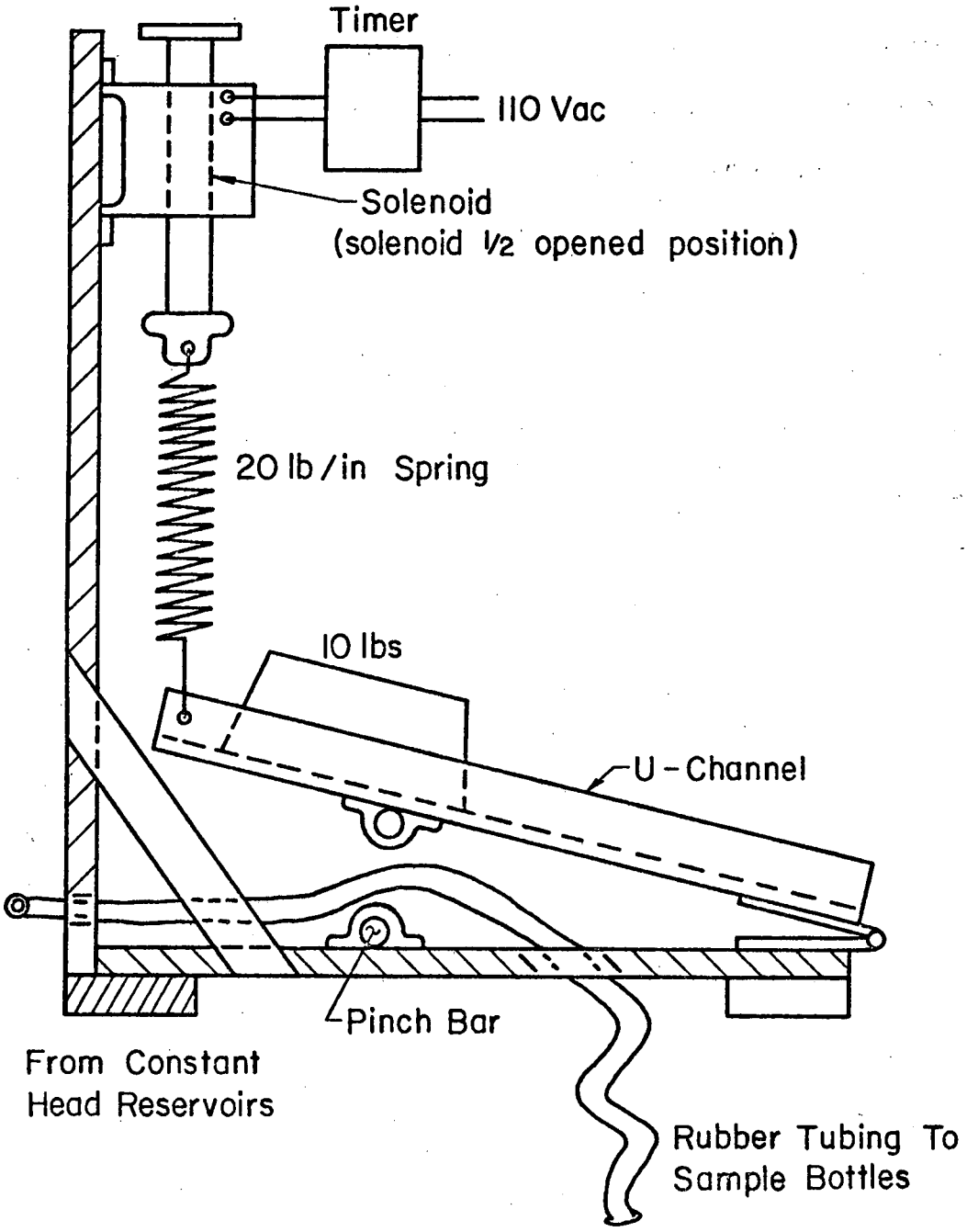



Fig. 11 Guillotine Sampler

# V. OPERATION OF RESEARCH FACILITIES

## ANALYTICAL METHODS

Chemical Oxygen Demand - The COD method for dilute samples as outlined in Standard Methods (15) was used. This method is quite sensitive to the environmental conditions in the laboratory and extreme care, particularly with cleaning glassware is necessary to obtain consistent results.

Biochemical Oxygen Demand - Procedures of Standard Methods were used except that during Phase III, a nitrification inhibitor[a] was used.

Dissolved Oxygen - Dissolved oxygen (DO) was monitored in the regeneration system recirculation fluid using a probe instrument[b]. The DO in the regeneration system was above 7.0 mg/ℓ at all times. Other DO measurements, as in the BOD test, were performed as in Standard Methods (15) except that phenylarsene oxide (PAO)[a] was used in place of the thiosulfate solution for the iodometric titration.

Iodine Number - The Iodine Number was determined using the procedure of Culp and Culp (16). The use of a ball mill to pulverize the carbon sample is strongly recommended, as use of mortar and pestle for more than a few carbon samples becomes tiresome.

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[a] Hach Chemical Company
[b] Yellow Springs Instrument Company

Nitrogen Forms - Ammonia nitrogen was determined by the direct nesslerization technique of Standard Methods (15). Nitrite and nitrate nitrogen concentrations were determined using the procedures of Standard Methods but with prepared reagents[a] for each test.

Sampling Procedures and Preservation - Carbon samples were taken from the columns during regeneration by insertion of a thief grab sampler through the top of the carbon columns. Samples taken were approximately 5 grams of carbon.

Composite samples of the influent and effluent wastewaters were taken by the guillotine sampler and the solenoid valve samplers previously described. The samples drained into one gallon glass jugs which had sulfuric acid added for sample preservation, except when BOD tests were to be run. The sample jugs were packed in ice for sample preservation when BOD analyses were to be performed. In the warm equipment room where the research was conducted, this procedure was barely adequate to keep the sample temperature below 10-12°C.

## MONITORING PILOT PLANT OPERATIONS

The COD was used to monitor the performance during the contacting operations. Other tests were performed, but the COD test was the primary one. All samples were composite samples. The collection of samples was on a semi-regular basis with the schedule

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[a]Hach Chemical Company

adjusted to time requirements in the laboratory or classroom on the part of the research assistants. Operational aspects of the Bethlehem Sewage Treatment Plant also were an important consideration in the overall operations of the research facilities.

All analyses were run as soon as possible, in particular the BOD and nitrogen tests. However, some of the COD samples which were preserved by acidification were stored at 4°C for up to two days. The results did not appear to indicate any problems from this procedure.

Temperature was monitored during the contacting periods and in one regeneration, the temperature of the recirculating water was adjusted to 40°C. The elevated water temperature was maintained by adding a heater element to the constant head reservoir which was actuated by a temperature controller[a].

The adjustment of pH to 6.0 or 8.0 for those experimental periods which had controlled pH for regeneration was accomplished by adding 1N $H_2SO_4$ or 1N NaOH on a daily basis.

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[a]Model 51A, Yellow Springs Instrument Company

# VI. RESULTS AND ANALYSIS

The numbering of the runs throughout the research was based on a modified decimal system. The leading digit to the left of the decimal point refers to the number of the activated carbon batch. The first number to the right of the decimal point displays the number of complete cycles through contact and regeneration. For instance, the first batch of carbon was referred to as run 1.1 during the initial contacting, and the initial regeneration. The second time through, it was referred to as run 1.2. The numbering for the third batch of activated carbon added a second number to reflect the pH of the regeneration. One contactor was regenerated at pH 6 and was referred to as 3.16, the other contactor in the set was regenerated at pH 8 and was referred to as 3.18. The second time through the contacting-regeneration cycle, the batches were referred to, respectively, as 3.26 and 3.28.

Continuous aerated contacting was used during Phases II and III, with the runs designated 4.1 and 4.2 for the carbon contacting even though it was the same carbon batch under initial contacting. There was an appreciable time lag between these runs. The parallel runs using sand in the aerated contactors were designated as 4.1S and 4.2S, again even though both runs used the same batch of sand.

For Phase III batch contacting, the influent was the effluent from run 4.2. The run designation gets more complicated since the carbon batches and contactors operated in series. During this period,

the third digit designates the first or second position in the series operation. For example, the first contacting of batch 5 and batch 6 are runs 5.11 and 6.12 since batch 5 was in the lead position. The second portion of batch 6 initial contacting was designated as run 6.11 since it was moved into the lead position and run 7.12 with carbon batch 7 was started.

TABLE 2

EXPERIMENTAL RUNS CONDUCTED

| | RUN | CYCLES | WEIGHT OF CARBON LBS | REGENERATION CONDITIONS |
|---|---|---|---|---|
| Phase I | 1.1 | 1 | 3.22 | |
| | 1.2 | 2 | 3.22 | Batch 1 - Ambient |
| | 1.3 | 3 | 3.22 | |
| | 2.1 | 1 | 4.00 | |
| | 2.2 | 2 | 4.00 | Batch 2 - Ambient |
| | 3.16 | 1 | 3.00 | - pH 6, 30°C |
| | 3.18 | 1 | 3.00 | Batch 3 - pH 8, 30°C |
| | 3.26 | 2 | 3.00 | - pH 6, 40°C |
| | 3.28 | 2 | 3.00 | - pH 8, 30°C |
| Phase II | 4.1 | 1 | 68.1 | Batch 4 - Aerated Contactor |
| | 4.1S | 1 | - | Sand - Aerated Contactor |
| Phase III | 4.2 | 1 | 68.1 | |
| | 4.2S | 1 | - | |
| | 5.11 | 1 | 12.0 | Batch 5 - Ambient |
| | 6.12 | 1 | 12.0 | Batch 6 - Ambient |
| | 6.11 | 1 | 12.0 | Batch 6 - Ambient |
| | 7.12 | 1 | 12.0 | Batch 7 - Ambient |
| | 7.11 | 1 | 12.0 | Batch 7 - Ambient |
| | 5.22 | 2 | 12.0 | Batch 5 - Ambient |
| | 5.21 | 2 | 12.0 | Batch 5 - Ambient |
| | 7.22 | 2 | 12.0 | Batch 7 - Ambient |

COD REMOVAL DURING CONTACT: PHASE I

The influent wastewater and the effluent from the contractors was sampled as previously outlined. A plot of the influent and effluent COD concentration for runs 1.1, 1.2 and 1.3 is shown in Fig. 12. Comparable data for carbon batches 2 and 3 are in Fig. 13 and Fig. 14.

The COD removal observed in these contact periods must be evaluated in terms of the intent of the research which was to evaluate the effectiveness of the biological regeneration. The contactors were operated at 4 gpm/sq ft with a carbon contact period approximately 6 minutes based on empty bed volume, considerably less than the 20 to 30 minutes normal design detention periods. However, the apparent carbon capacity can be evaluated from the data.

In order to compare the different runs with different weights of carbon and varying influent COD concentrations, the apparent carbon capacity is plotted against the COD applied per unit weight carbon in Fig. 15, 16 and 17. This method of analysis also incorporates the effect of flow rate variations which occurred during the contacting period.

Table 3 summarizes the apparent carbon capacity during the various contacting periods. The percentage reduction of the COD was low, but this was due primarily to the short contact time. There does appear to be some loss of capacity through the biological regeneration, however, even after the third regeneration, the batch 1 carbon still had an apparent capacity of 0.250 lbs COD/lb carbon,

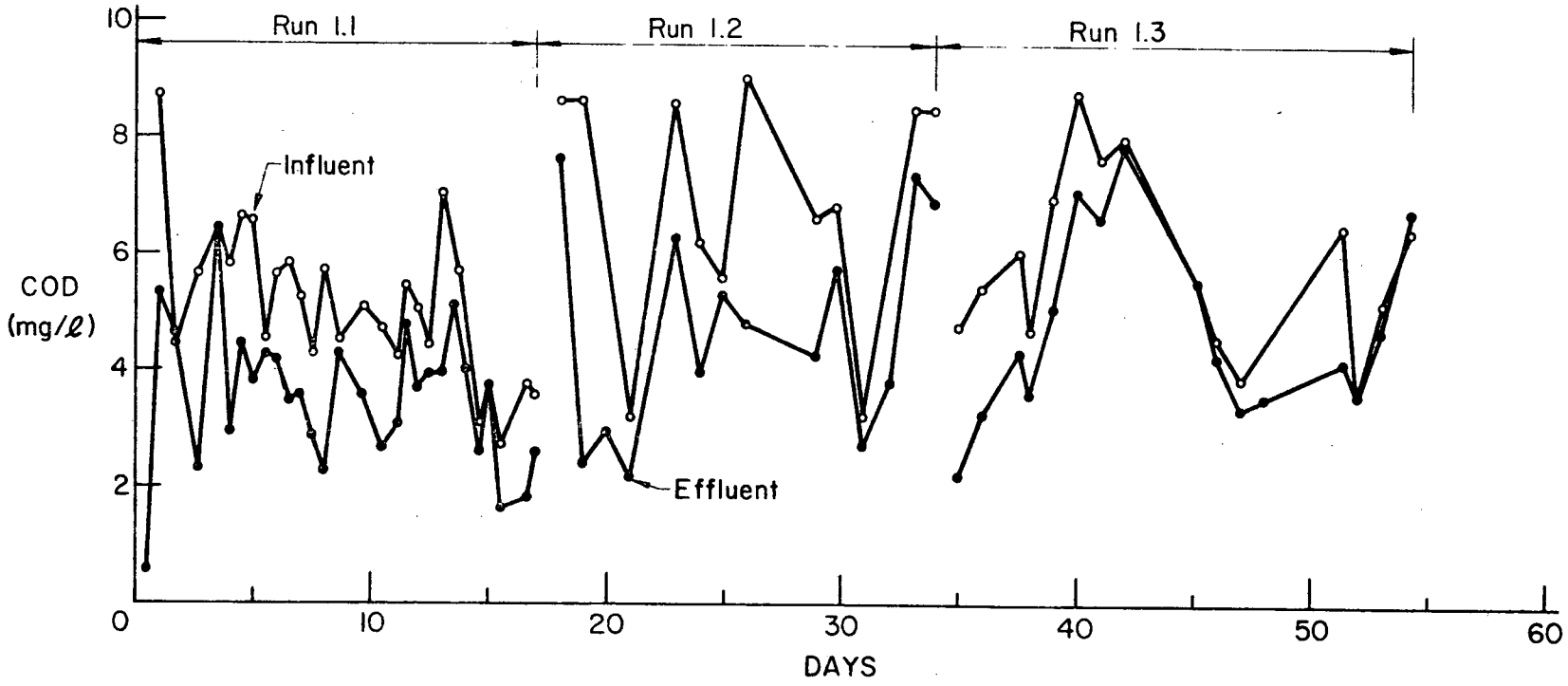


Fig. 12 COD versus Contact Time - Run 1

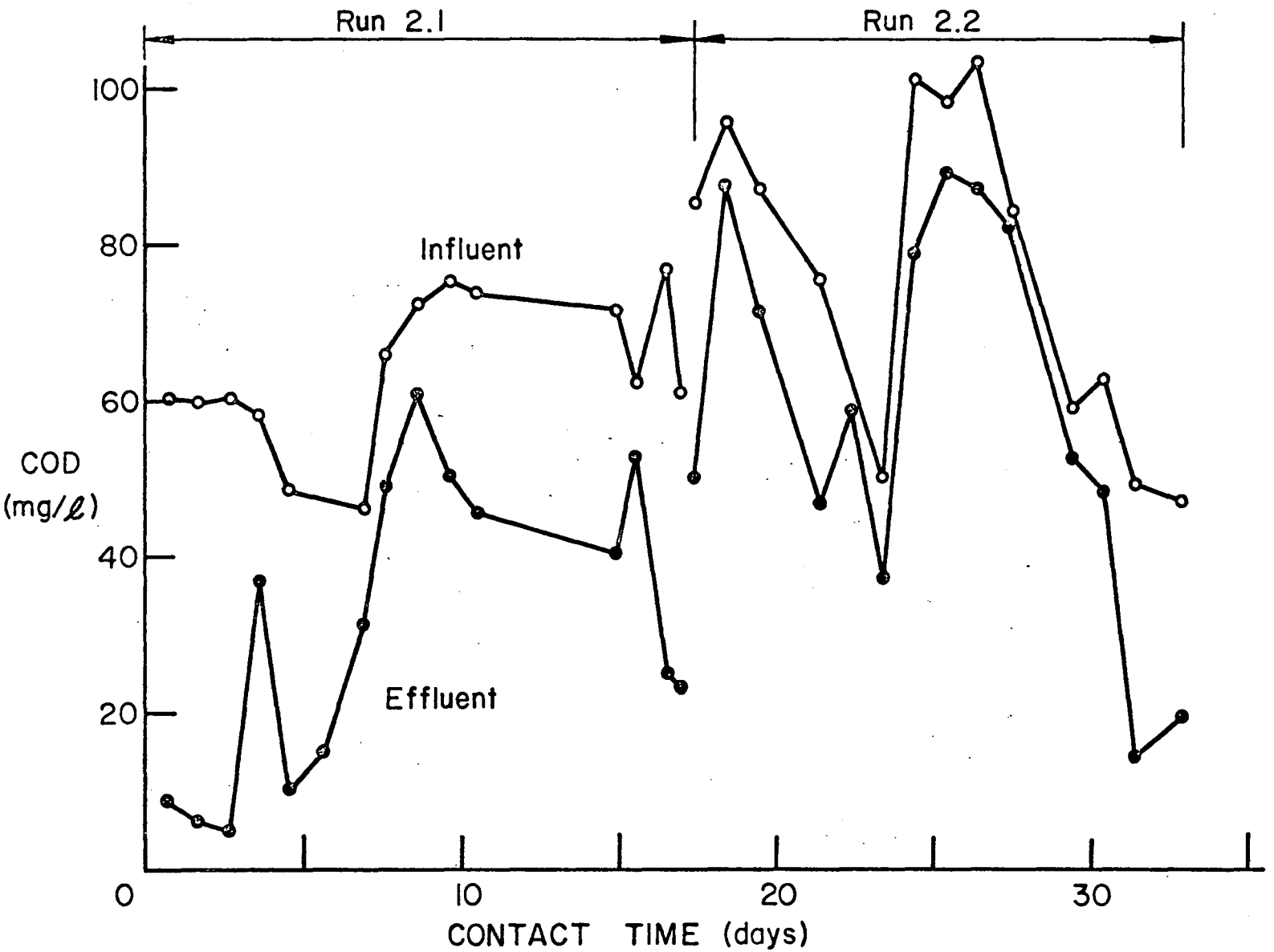


Fig. 13 COD versus Contact Time - Run 2

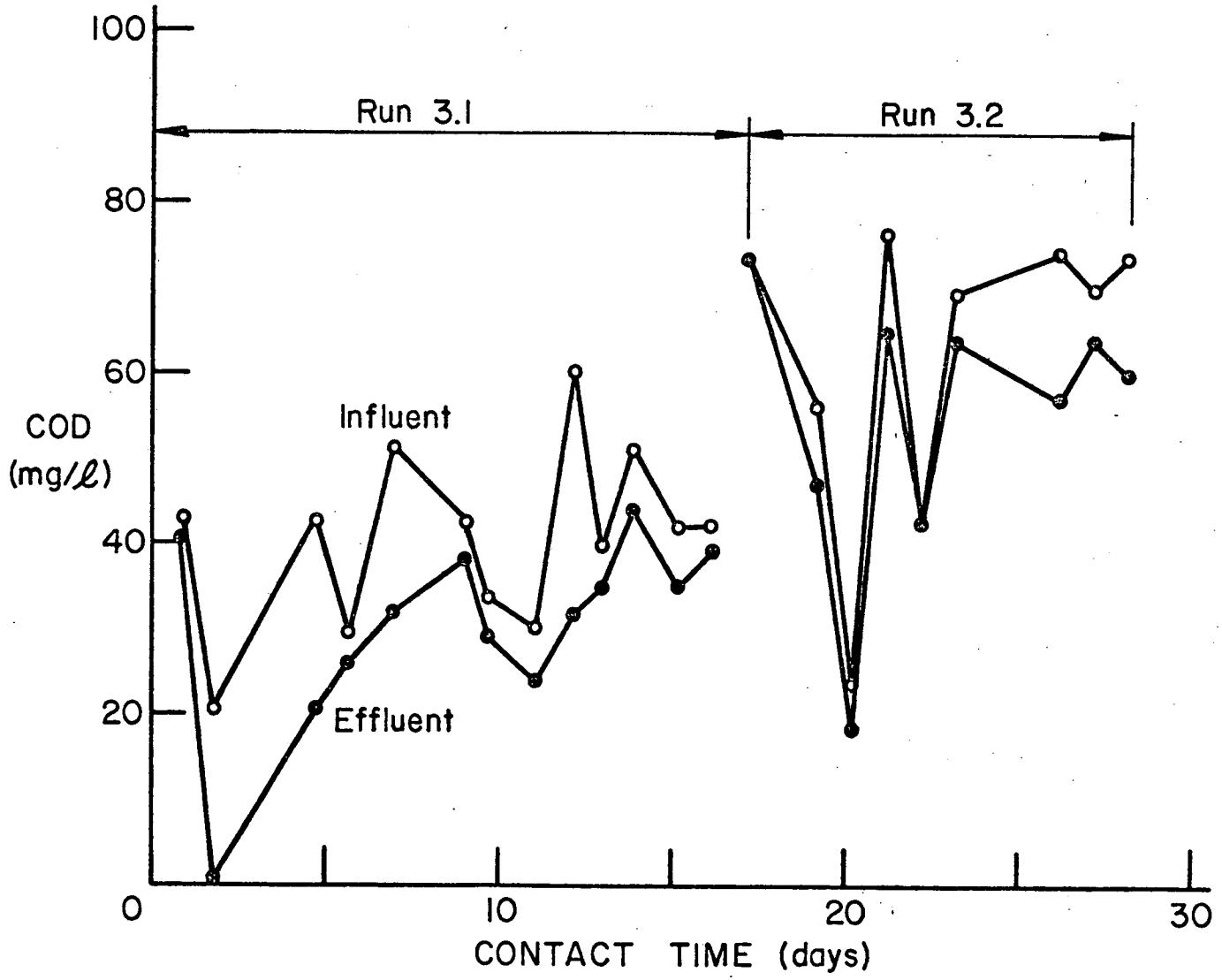


Fig. 14 COD versus Contact Time - Run 3

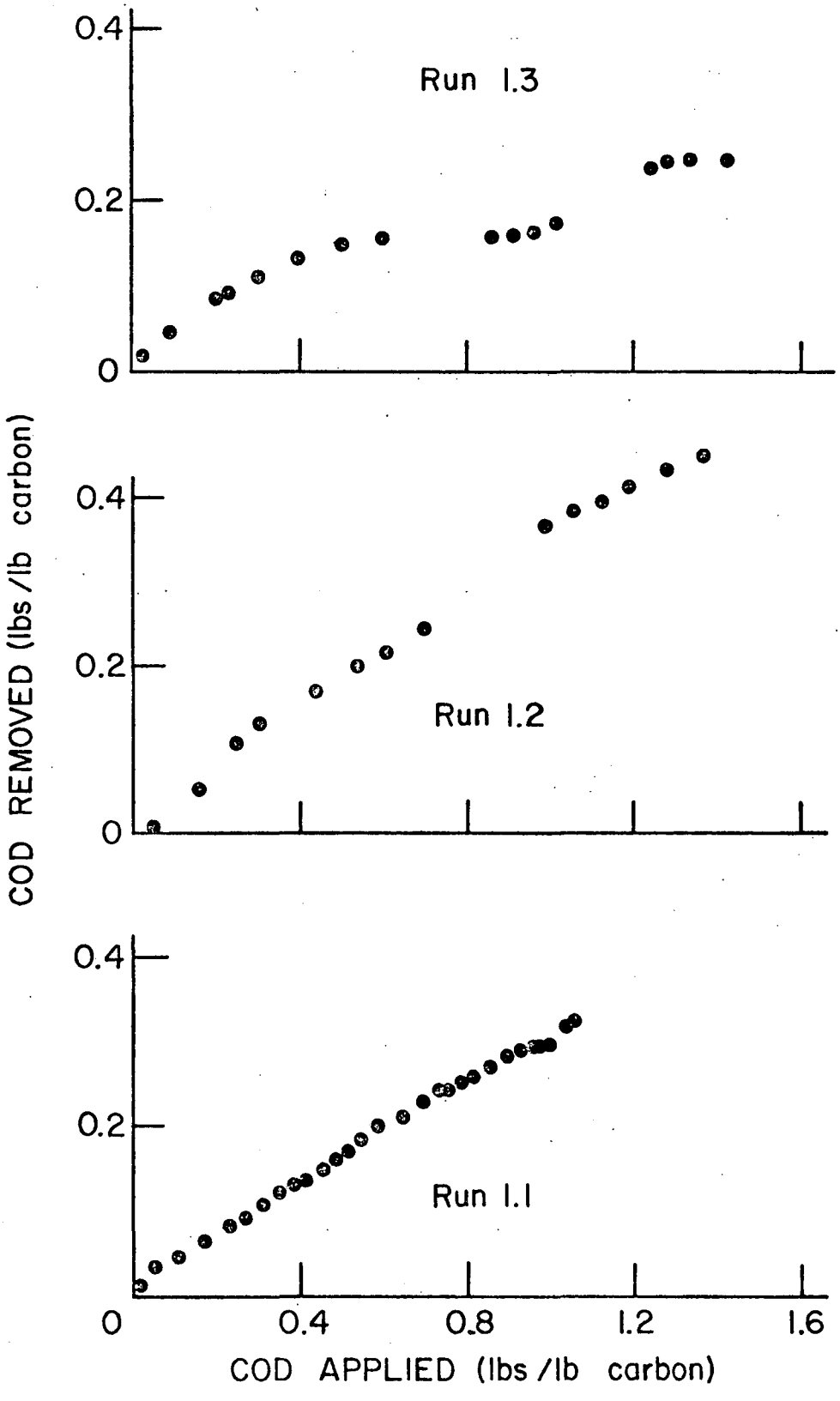


Fig. 15 COD Removal - Run 1

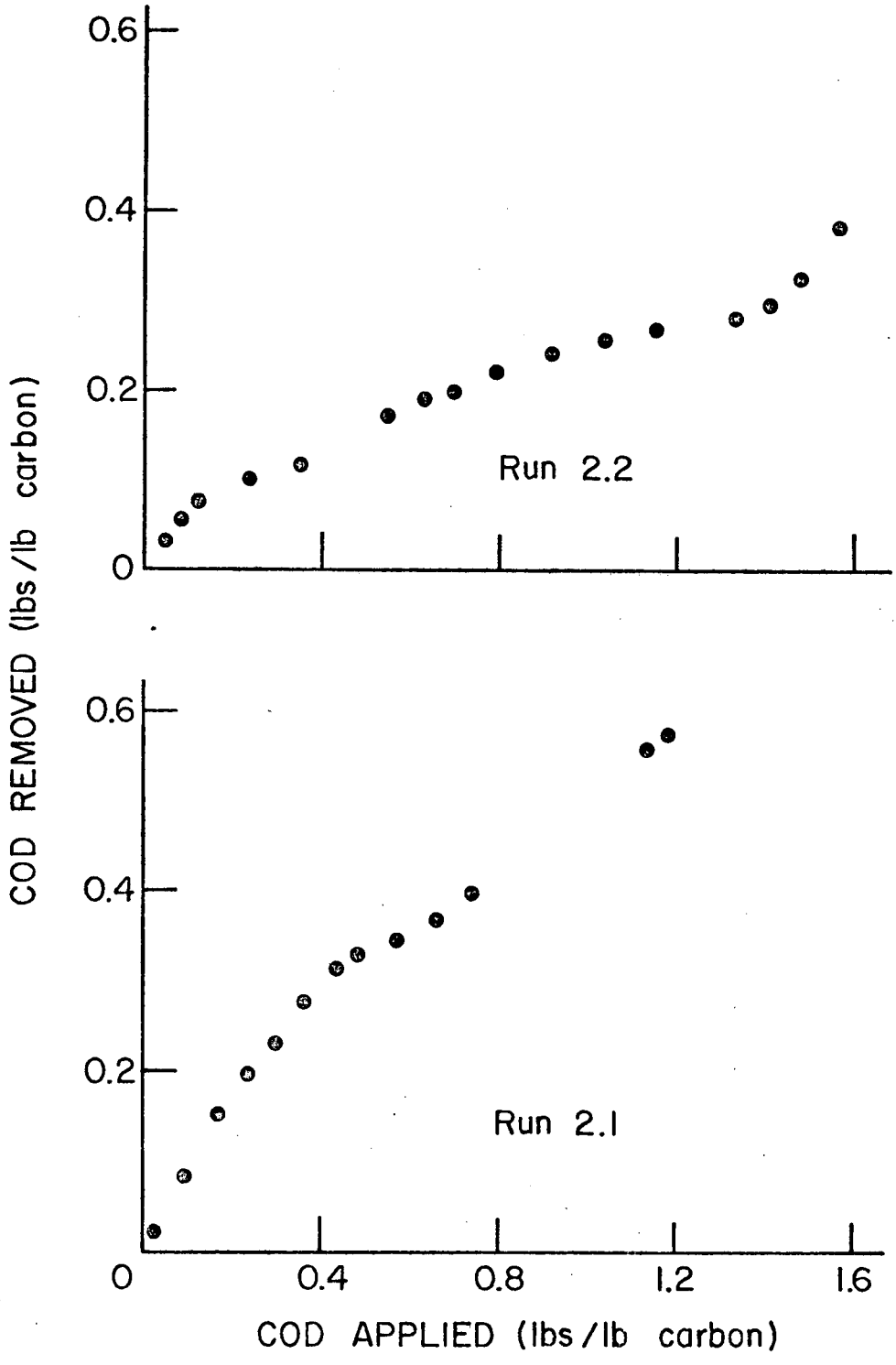


Fig. 16 COD Removal - Run 2

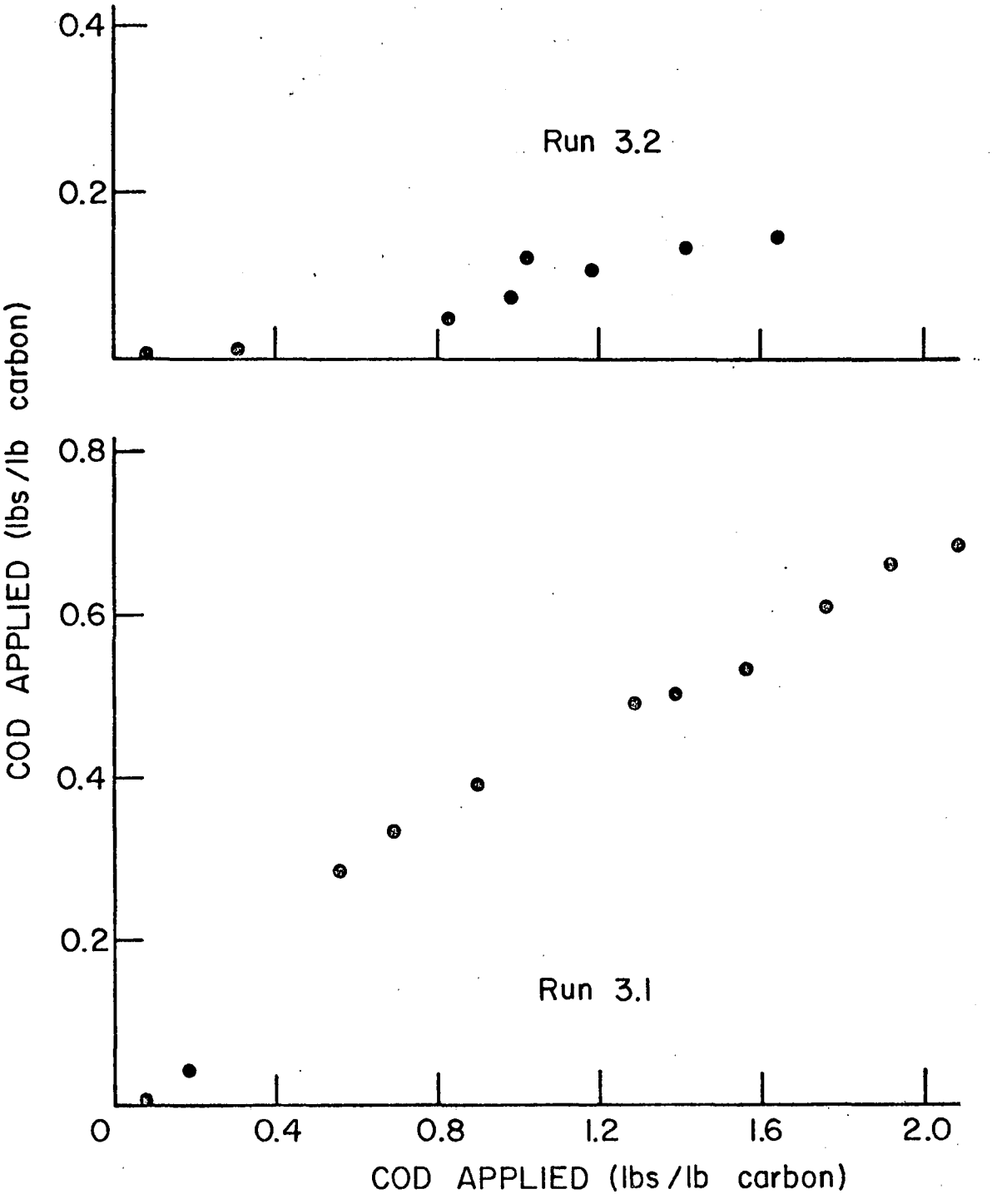


Fig. 17 COD Removal - Run 3

TABLE 3

SUMMARY OF COD REMOVAL AND CARBON CAPACITIES: PHASE I

| Run | Average COD Influent mg/l | Average COD Effluent mg/l | Apparent Carbon Capacity Lbs/ COD/Lb Carbon 5 Days | 10 Days | 15 Days | TOTAL Carbon Capacity Lb COD/Lb Carbon | Time Contacted Days |
|---|---|---|---|---|---|---|---|
| 1.1 | 51.3 | 35.7 | 0.125 | 0.221 | 0.298 | 0.327 | 17.0 |
| 1.2 | 67.9 | 47.4 | 0.151 | 0.307 | 0.409 | 0.445 | 17.0 |
| 1.3 | 57.6 | 47.4 | 0.109 | 0.158 | 0.192 | 0.250 | 20.25 |
| Run 1 Total | 57.0 | 41.5 | - | - | - | 1.022 | 54.25 |
| 2.1 | 62.8 | 31.3 | 0.233 | 0.381 | 0.560 | 0.574 | 15.54 |
| 2.2 | 74.8 | 56.5 | 0.148 | 0.244 | 0.297 | 0.383 | 17.38 |
| Run 2 Total | 69.0 | 44.3 | - | - | - | 0.957 | 32.92 |
| 3.1 | 37.5 | 23.8 | 0.100 | 0.171 | 0.239 | 0.241 | 15.2 |
| 3.2 | 60.2 | 53.0 | 0.026 | 0.080 | - | 0.124 | 13.0 |
| Run 3 Total | 46.6 | 35.5 | - | - | - | 0.365 | 28.2 |

which is quite respectable. The total carbon capacity of 1.022 lbs COD/lb carbon shown in run 1.1 through run 1.3 is quite good and shows that there is appreciable recovery of the carbon capacity during biological regeneration.

EFFECTIVENESS OF BIOLOGICAL REGENERATION: PHASE I

In addition to the apparent capacity of the carbon observed in the contacting period of each run, it was desired to have some measure of the carbon capacity during regeneration in order to evaluate the adequacy of the biological regeneration. One procedure considered was the adsorption isotherm. The initial intent was to determine the isotherms after various periods of biological regeneration in order to compare the recovery of carbon capacity to that point in time.

Normal procedures for adsorption isotherms require pulverizing the carbon to a powder, however in this research, a procedure using specific sizes of carbon was used instead, namely the 100 X 200 mesh size. The main reason that the carbon was not pulverized for the isotherm determination was because pulverizing would expose new carbon surfaces, not previously available, which would tend to show more recovery of the adsorption capacity than was really available in the granular carbon used in the columns.

Because of the kinetic limitations, the true capacity would not be measured by this procedure, but instead some fraction of the capacity would be determined. By using uniform sizes and times

of testing, this fraction would be constant and the relative values would allow comparisons to be made.

Using the procedure previously outlined, COD adsorption isotherms were run on the first batch of activated carbon, denoted run 1.1. The isotherms were determined at 20°C for 0, 1, 3, 5, 7 and 10 days of regeneration. The results were not as precise as hoped and the data was scattered as shown in Fig. 18. The general progression of carbon capacity recovery from the biological regeneration is shown by the isotherms, but it was decided to try the iodine number instead of the isotherm procedure. This change was made because less time was required to determine the iodine number and the fact that only a relative measure of regeneration effectiveness was needed, since the carbon capacity in the succeeding contacting period is the real proof of recovery of the carbon capacity by biological regeneration.

Figures 19, 20 and 21 show the progression of the iodine numbers for the first three carbon batches. Even with this straight forward test there is a great deal of scatter in the data and the easy way to monitor the biological regeneration is still to be found.

In light of these results, the balance of the research relied heavily on the subsequent contacting as the proof of carbon capacity recovery.

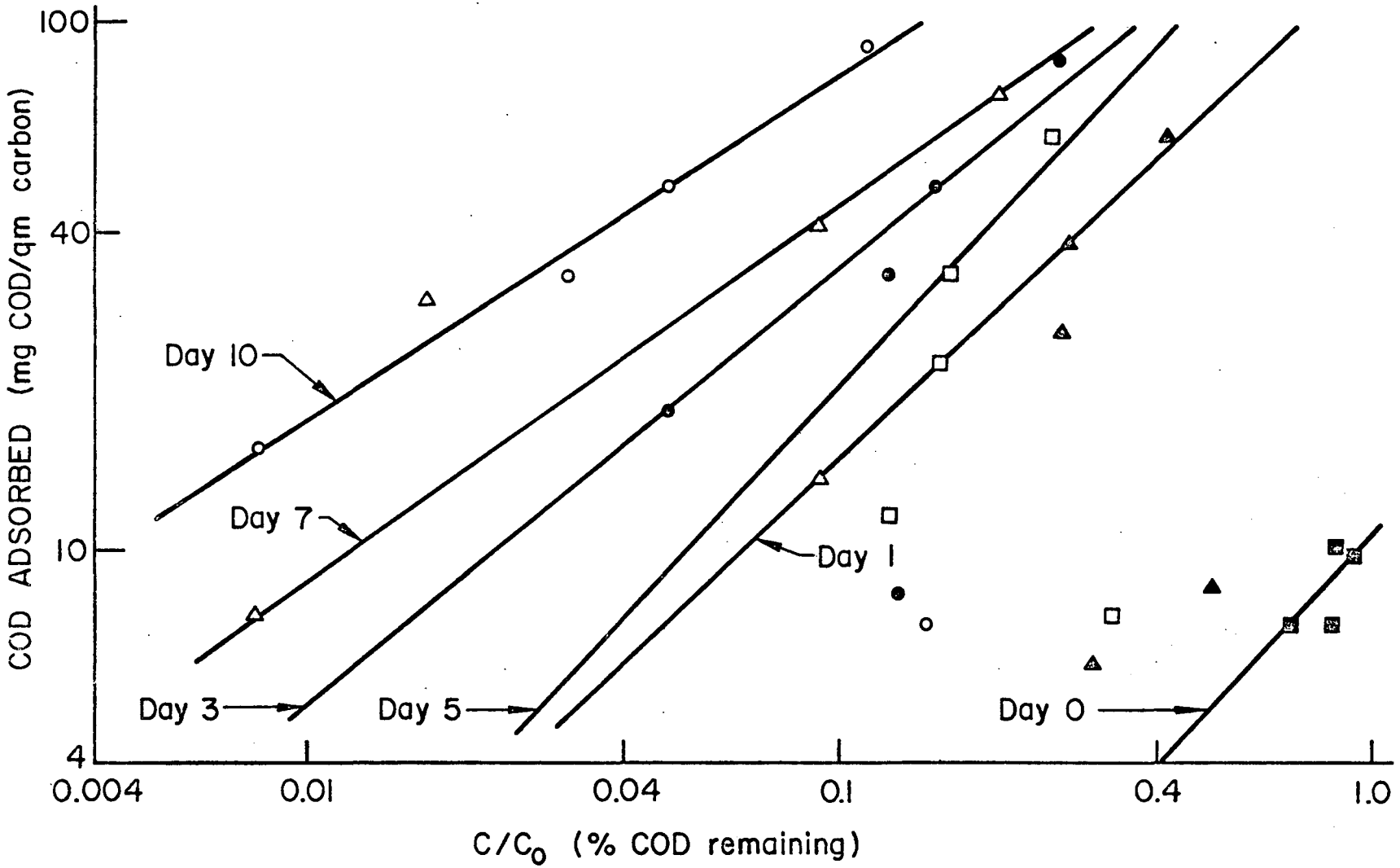


Fig. 18 Adsorption Isotherms - Run 1

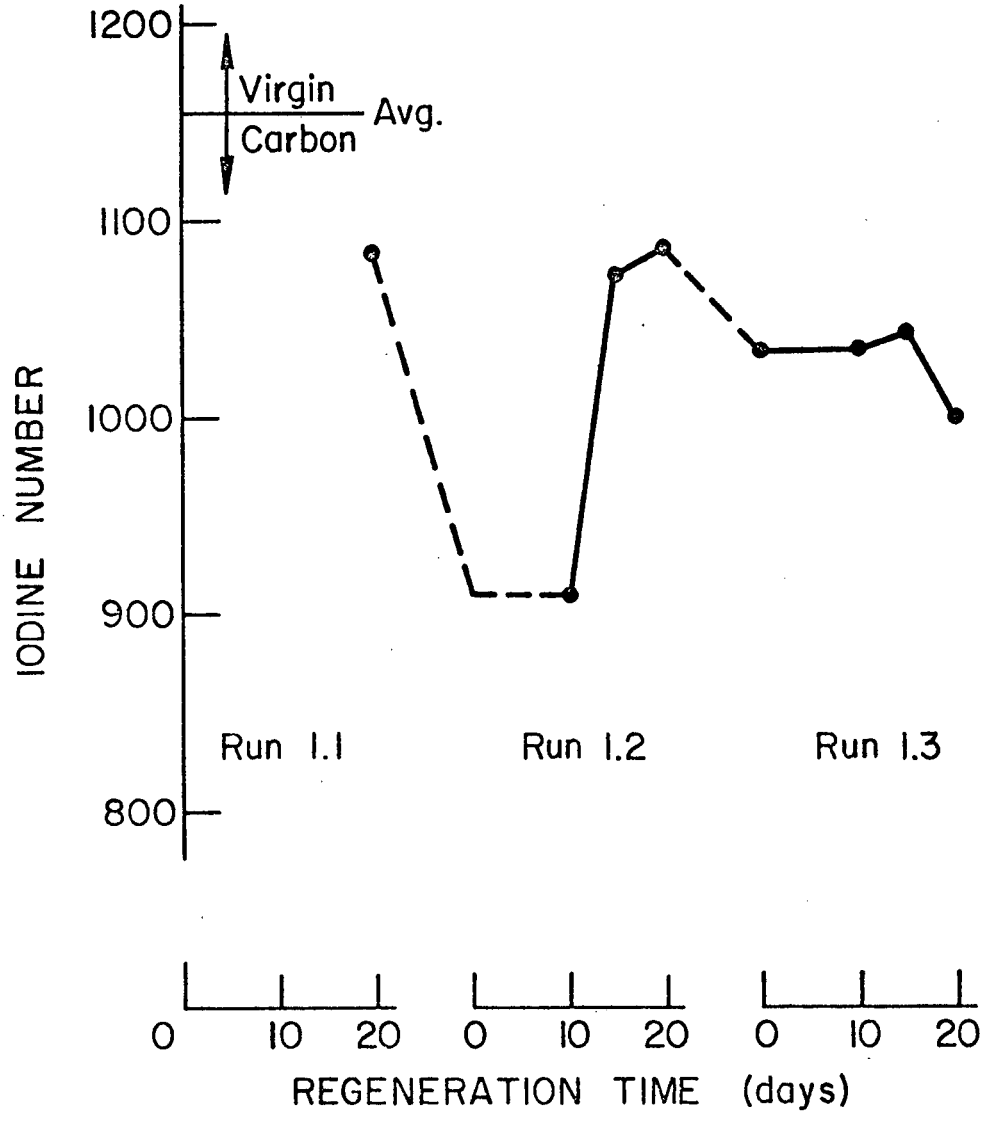


Fig. 19 Iodine Number During Regeneration - Run 1

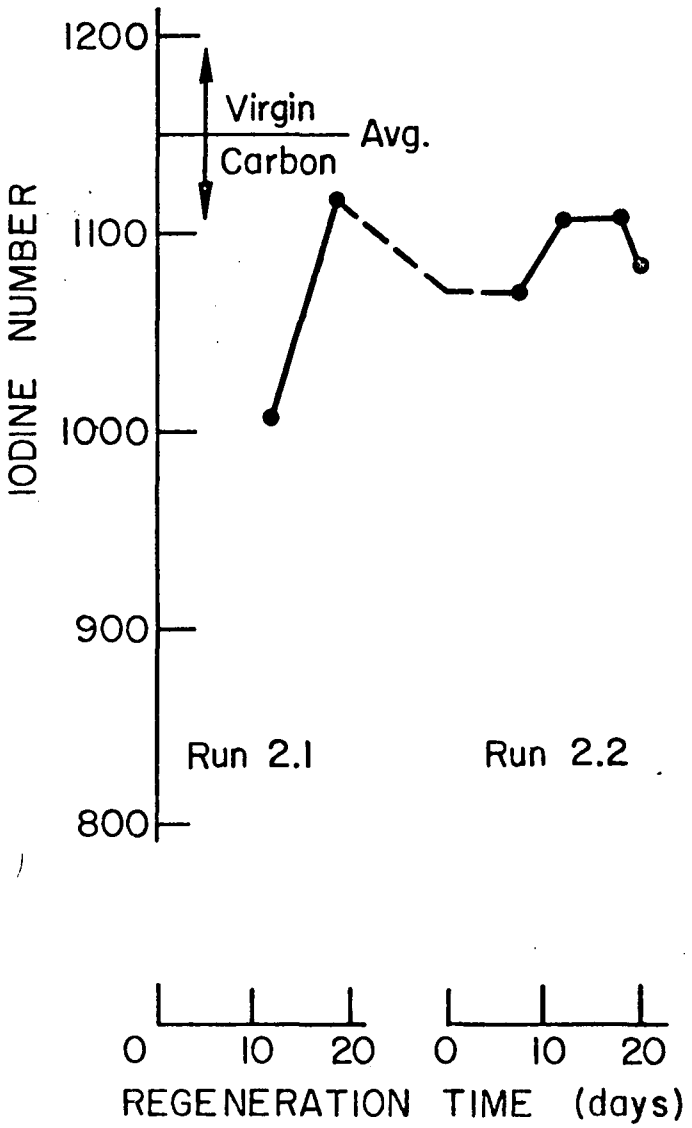


Fig. 20 Iodine Number During Regeneration - Run 2

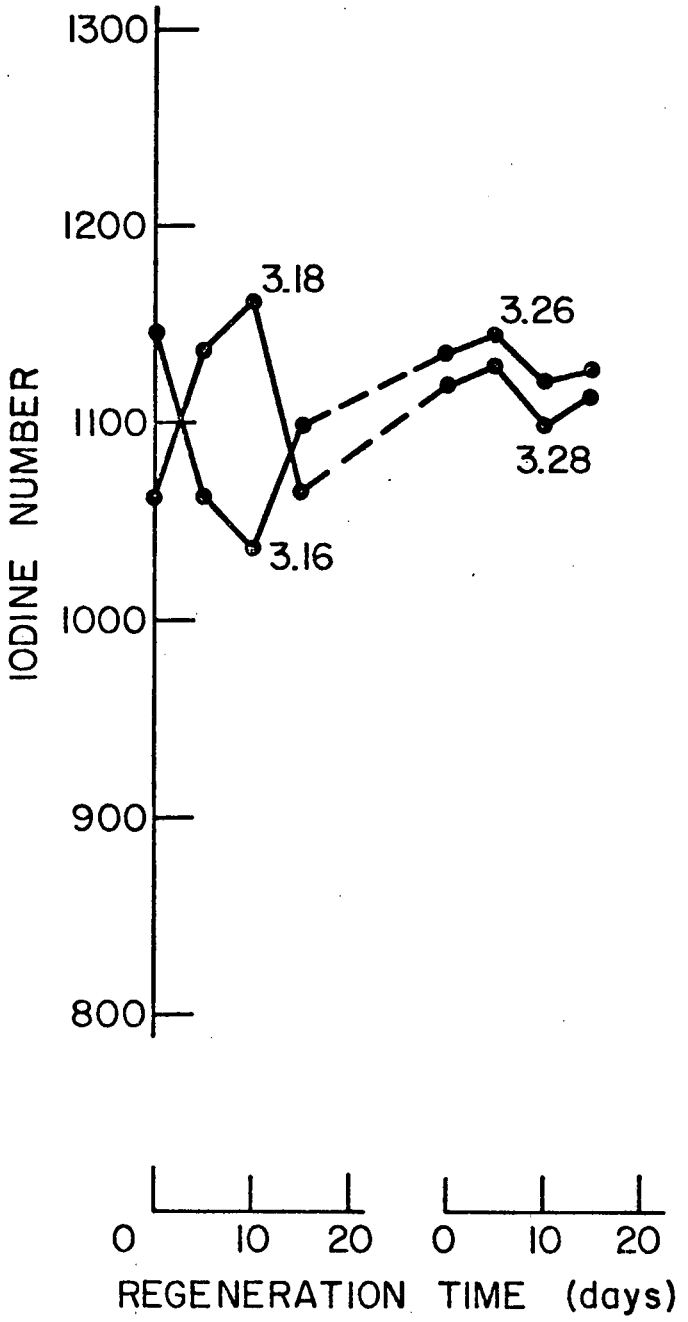


Fig. 21 Iodine Number During Regeneration - Run 3

Effect of pH and Temperature on Regeneration - The data in Fig. 21 for the variation in iodine number during regeneration when the pH of the recirculating water was adjusted indicate very little effect. Comparing the performance of the regeneration for the different carbon batches, it can be seen that the performance of batch 3 with adjusted pH, compared to the first and second batches which were unadjusted, was somewhat less. This is probably due to an accidental discharge of anhydrous hydrochloric acid into the carbon storage area. This accident affected activated carbon batch 3 and was a factor which was unknown until run 3 was underway.

Observations of the temperature dependency of the regeneration yield much the same conclusions as did the pH dependency observations. The condition of the activated carbon due to the accidental contact with the anhydrous hydrochloric acid probably was such a dominant factor that both temperature and pH effects were too small to be observed.

## COD REMOVAL DURING AERATED CONTACTING: PHASE II

As a logical extension of the off-line batch biological regeneration, Phase II of the research investigated the ability of aerated upflow contactors to continuously regenerate in-situ the surfaces of the granular activated carbon. A 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 some very miniscule physical adsorption which would occur.

The contactors were operated at approximately 1.5 gpm/sq ft providing a contact time of 25 minutes based on empty bed volume. The freeboard above the five foot 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 causing odor problems from the $H_2S$ generated.

The influent and effluent COD for the aerated contactor operation is shown in Fig. 22. The superiority of the carbon over inert sand media is well demonstrated. The effectiveness of the aerated mode of operation is shown even better in Fig. 23. The apparent carbon capacity in the aerated contactor for 64 days of operation was 0.43 lbs COD/lb carbon. There is no apparent reduction in the rate of COD removal in the carbon contactor, even after the 64 day period. As will be seen in Phase III, the COD removal does continue at approximately the same rate.

## COD REMOVAL DURING AERATED CONTACT: PHASE III

In view of the COD removal observed in the aerated contactors in Phase II, the aerated contactor operation was continued. Figure 24 shows the influent and effluent COD for the aerated sand and carbon contactors for this period.

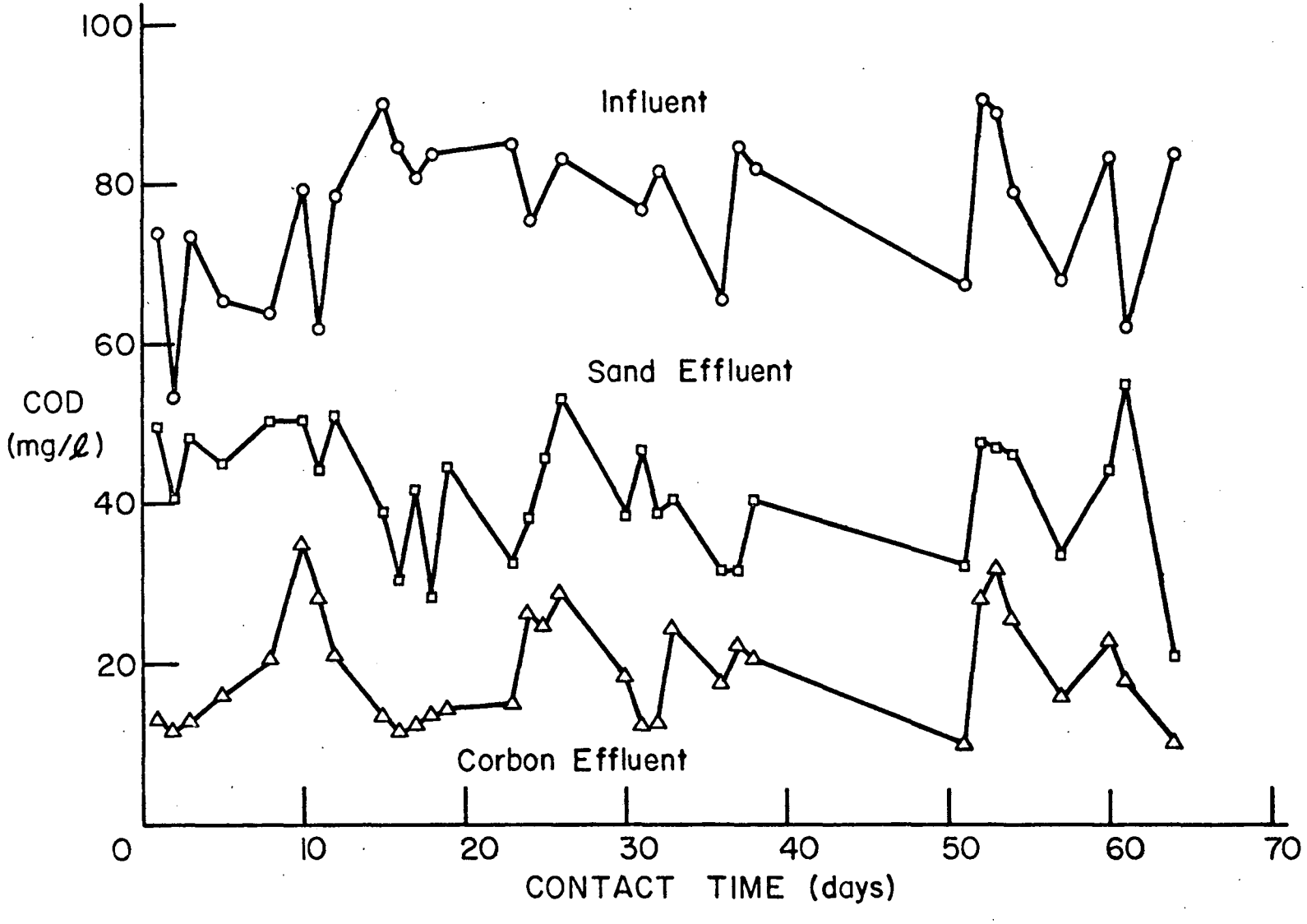


Fig. 22 COD versus Contact Time - Phase II

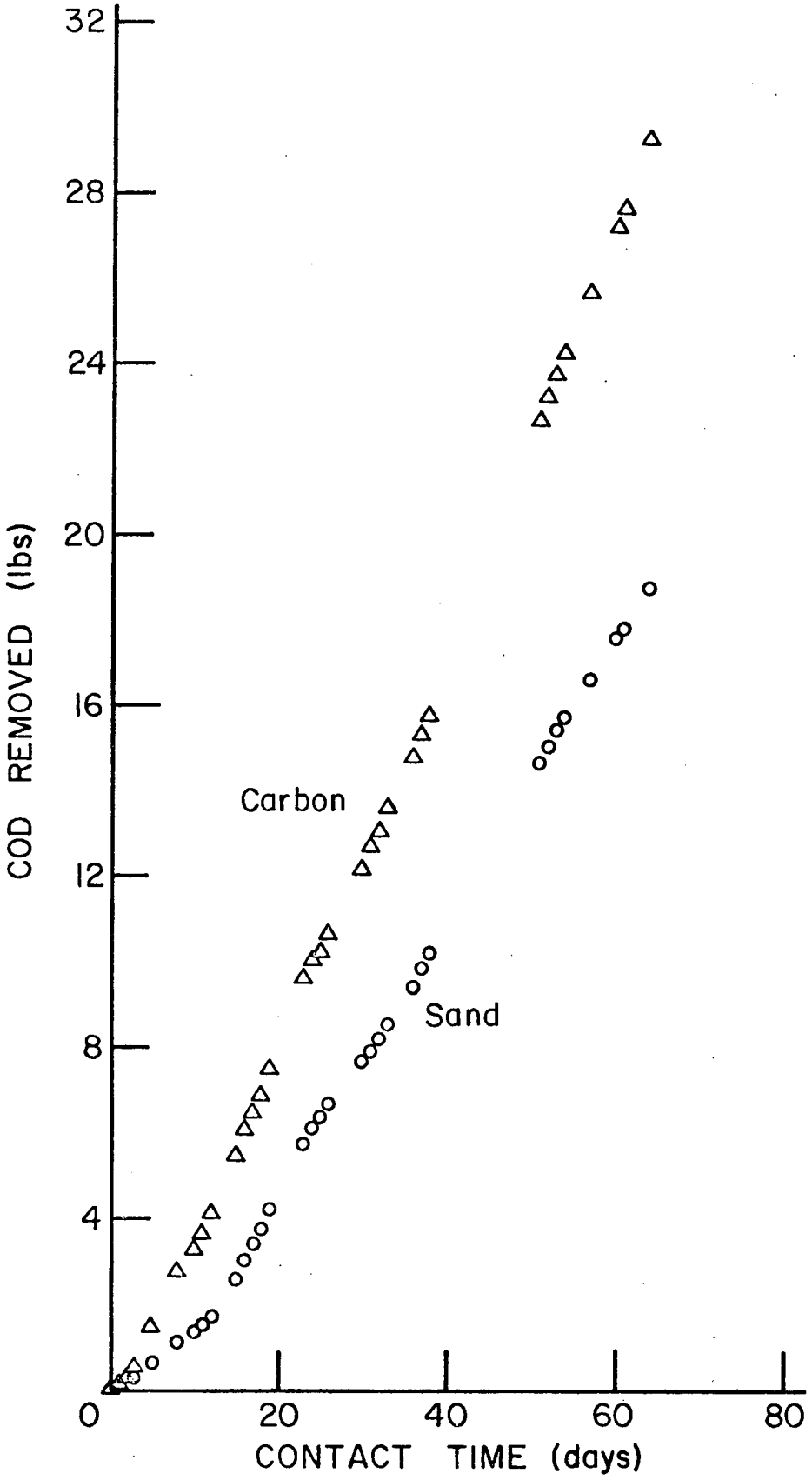


Fig. 23 COD Removal - Phase II

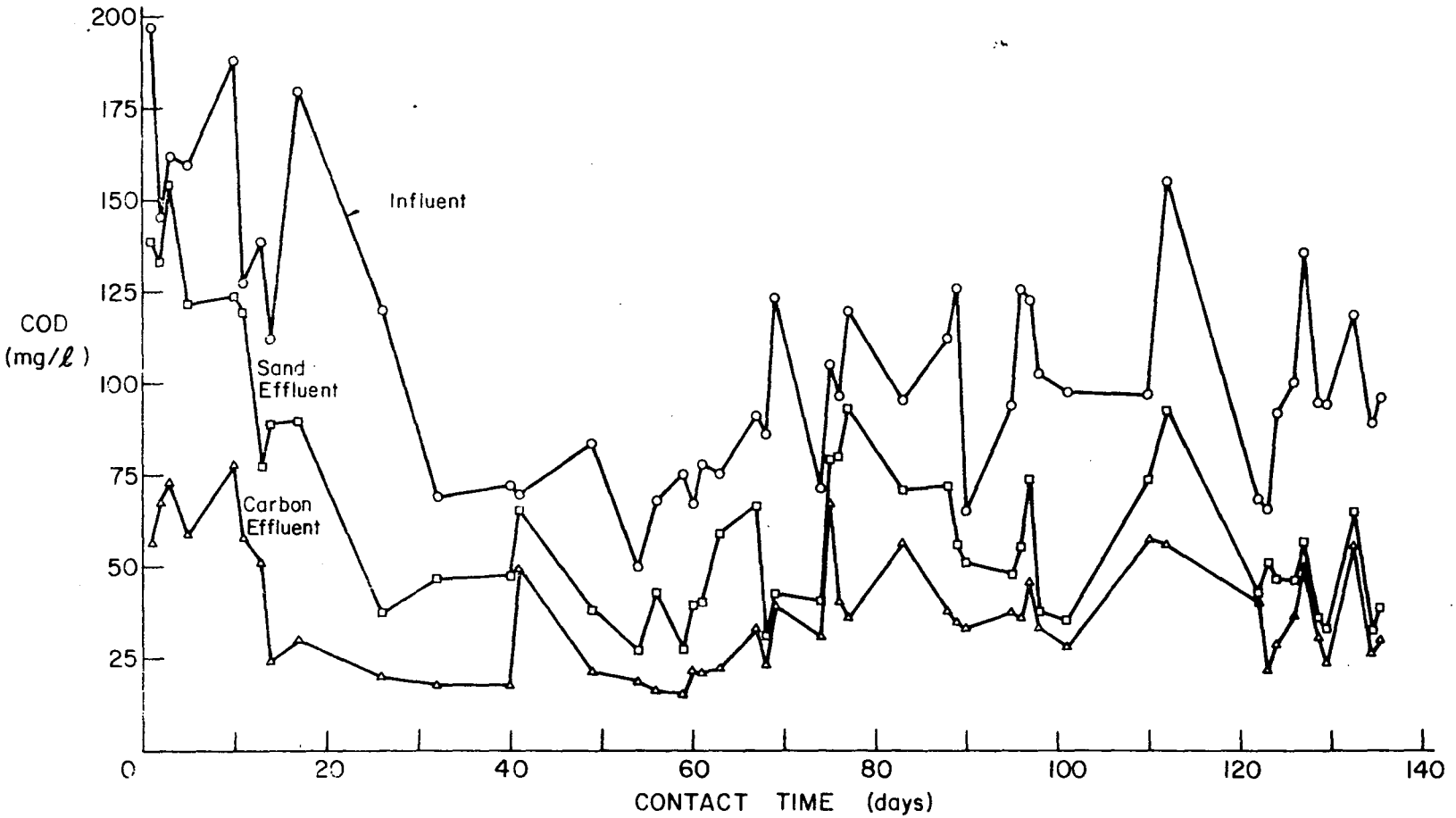


Fig. 24 COD versus Contact Time - Phase III

During the first 67 days, the aerated contactors were operated at about 3 gpm/sq ft, double the rate used in the 64 days of operation in Phase II. The balance of the Phase III 135 day operation, or 68 days, were at 1.5 gpm/sq ft hydraulic loading. Operation at 3 gpm/sq ft provides a contact time of approximately 13 minutes while the 1.5 gpm/sq ft rate provides 25 minutes of contact, both based on the empty bed volume.

As Figure 25 shows, the reduction in hydraulic loading rate affected the efficiency of the aerated sand contactor. This would be expected since mainly biological activity was involved in this contactor. The greater hydraulic loading rate did not appear to affect the COD removal efficiency of the aerated carbon contactor.

The results of the aerated contactor operation are summarized in Table 4. The apparent carbon capacity of 1.87 lbs COD/lb carbon

TABLE 4

SUMMARY OF AERATED CONTACTOR OPERATION: PHASE II AND III

| Run | Media | Hydraulic Rate gpm/sq ft | Days | Average COD Influent mg/ℓ | Effluent mg/ℓ | Carbon Capacity lbs COD/lb Carbon |
|---|---|---|---|---|---|---|
| 4.1S | Sand | 1.50 | 64 | 77.1 | 41.6 | - |
| 4.2S | Sand | 3.00 | 67 | 111.1 | 75.7 | - |
| 4.2S | Sand | 1.50 | 69 | 102.4 | 55.3 | - |
| TOTAL | Sand | - | 200 | 94.6 | 55.2 | - |
| 4.1 | Carbon | 1.50 | 64 | 77.1 | 19.1 | 0.430 |
| 4.2 | Carbon | 3.00 | 67 | 111.1 | 36.8 | 1.160 |
| 4.2 | Carbon | 1.50 | 69 | 102.4 | 38.7 | 0.279 |
| TOTAL | Carbon | - | 200 | 94.6 | 30.4 | 1.870 |

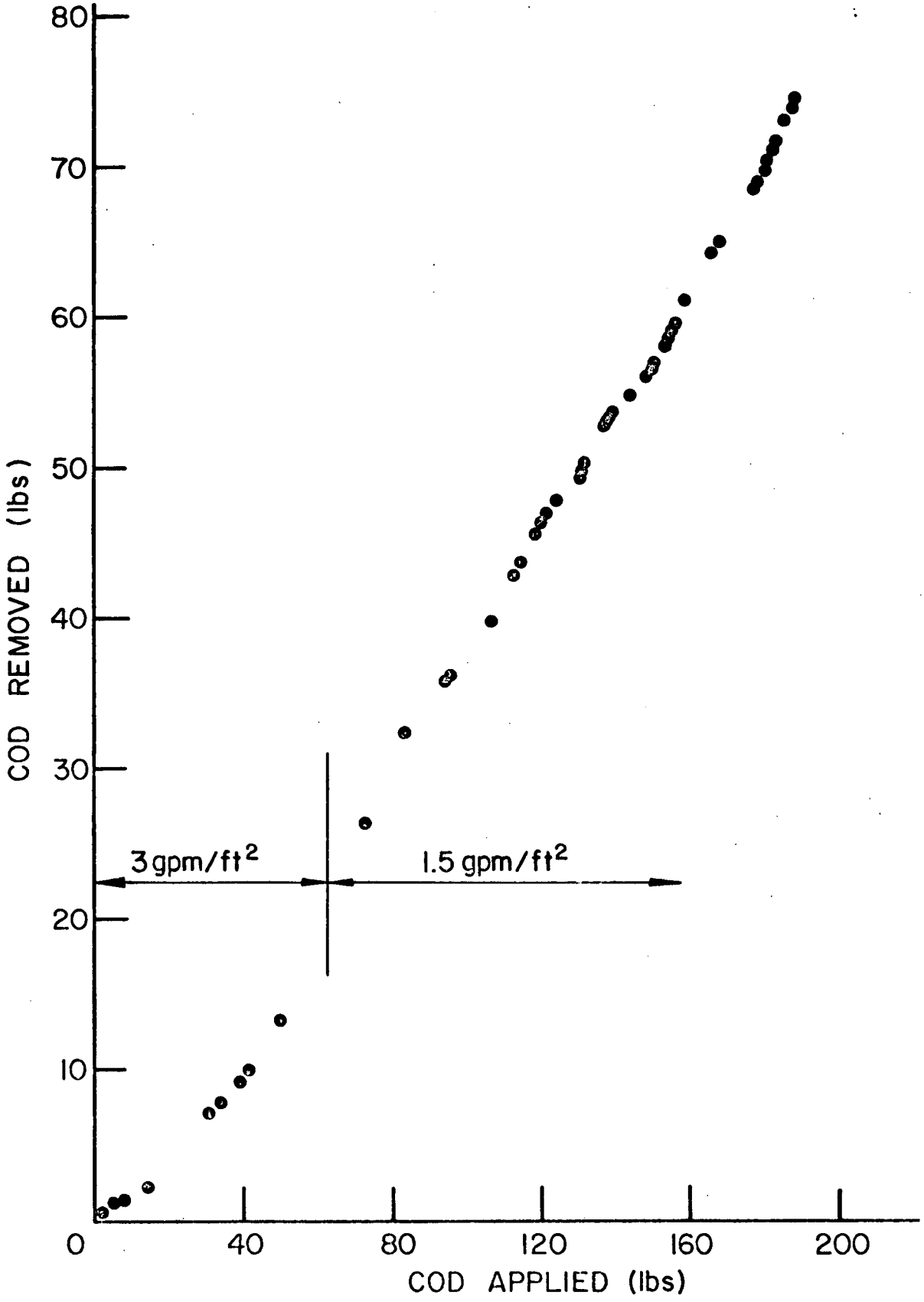


Fig. 25 Aerated Sand Contactor COD Removal

for this mode of operation is a large increase over the more nominal 0.4 lbs COD/lb carbon used in design. As Fig. 26 shows, even after 200 days of contacting and removal of 1.87 lbs COD/lb carbon, the rate of COD removal appears to be as great as the virgin carbon.

## BOD AND NITRIFICATION RESULTS: PHASE II AND III

Limited BOD and nitrogen analyses were made during the aerated contactor operation. The BOD results shown in Table 5 follow the same trends as the COD data have shown.

There were numerous ammonia, nitrite, and nitrate analyses made during Phase II. The majority of the samples analyzed were the ones preserved with acid and the results of those tests were quite erratic.

TABLE 5

BOD RESULTS: PHASE II AND III

| | BOD, mg/ℓ | | |
|---|---|---|---|
| | Influent | Effluent | |
| Day | | Sand | Carbon |
| Phase II | | | |
| 3 | 85.7 | 34.8 | 25.0 |
| 10 | 32.0 | 27.0 | 25.0 |
| 12 | 23.0 | 13.0 | 1.5 |
| 17 | 29.4 | 83.3 | 3.2 |
| 24 | 19.6 | 59.4 | 15.5 |
| 26 | 31.8 | 37.5 | 27.4 |
| 31 | 15.5 | 2.8 | 4.5 |
| 36 | 13.7 | - | 2.9 |
| 38 | 22.2 | 11.8 | 17.3 |
| Phase III | | | |
| 5 | 70.1 | 66.7 | 34.4 |
| 14 | 34.9 | - | 33.0 |
| 26 | 76.0 | 21.8 | 11.6 |
| 28 | 66.0 | 67.1 | 40.5 |
| 34 | 49.2 | 36.8 | 41.3 |
| 56 | 24.7 | 26.2 | 10.4 |
| 61 | 27.4 | 16.1 | 22.5 |

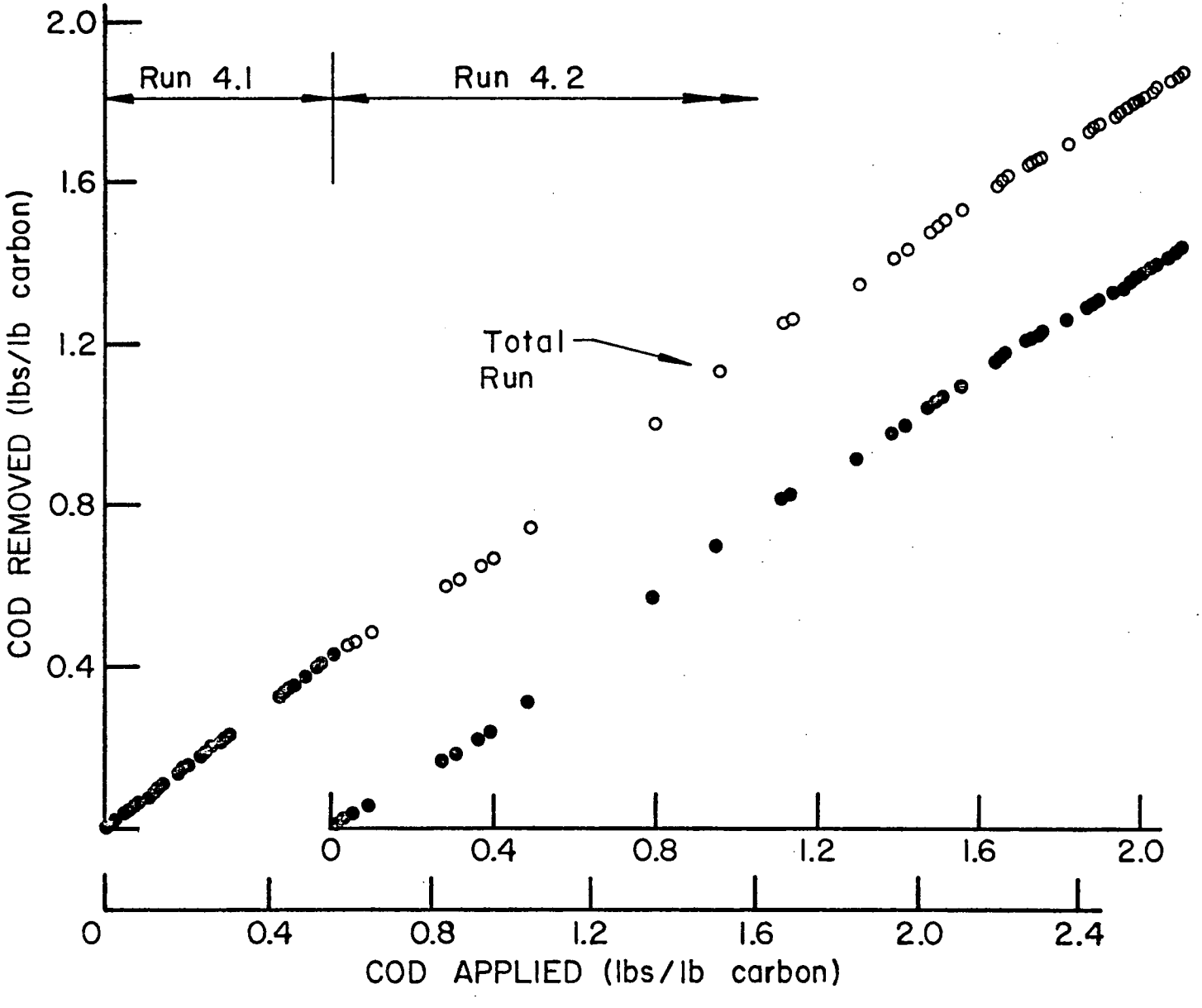


Fig. 26 Unit COD Removal - Phase III

The nitrogen analyses performed on the samples which were packed with ice are shown in Table 6. These results are somewhat more consistent as would be expected, but there is still appreciable variability. The results show considerable nitrification of the wastewater in these aerated contactors.

Much of the apparent inconsistency was probably due to the lack of organic nitrogen measurements and the direct nesslerization technique used for ammonia analysis.

TABLE 6

NITROGEN RESULTS: PHASE II

| Day | Influent | Effluent Sand | Effluent Carbon | |
|---|---|---|---|---|
| 1 | 11.7 | 8.1 | 12.1 | $NH_3$-N |
| | 0.05 | 0.02 | 0.04 | $NO_2$-N |
| | 0.06 | 1.78 | 4.46 | $NO_3$-N |
| 2 | 10.4 | 2.9 | 4.9 | |
| | 0.58 | 12.8 | 9.25 | |
| | 0.06 | 0.04 | 0.75 | |
| 3 | 18.9 | 2.9 | 0.20 | |
| | 0.06 | 0.75 | 0.75 | |
| | 0.79 | 11.80 | 8.60 | |
| 17 | 23.5 | 10.7 | 1.7 | |
| | - | - | - | |
| | 0.65 | 22.0 | 13.80 | |
| 24 | 11.3 | 0.0 | 13.5 | |
| | 0.05 | 0.42 | 0.33 | |
| | 0.65 | 26.8 | 10.2 | |
| 26 | 20.4 | 15.1 | 10.7 | |
| | 0.06 | 0.11 | 0.39 | |
| | 0.67 | 5.64 | 6.22 | |
| 31 | 20.4 | 9.3 | 4.0 | |
| | 0.05 | 0.21 | 0.39 | |
| | 0.52 | 18.0 | 11.50 | |

COD REMOVAL - BATCH CONTACTORS: PHASE III

The effluent from the aerated carbon contactor was used as the influent to batch carbon contactors similar to those used in Phase I. Longer contactors were provided to increase the detention time to more typical values. These batch contactors were treating a wastewater more typical of a very well treated secondary effluent to allow comparison with the Phase I and II operations.

Three batches of carbon, 12 lbs each were used in this contacting. Two contactors were operated in series and thus 24 lbs of carbon was being contacted. When the lead contactor was taken out of service for regeneration in a manner similar to that used in Phase I, the second contactor was moved into the lead position. Thus, each batch of carbon, after the first, was subjected to use in both lead and second positions.

The operations during this research period are described for each batch of carbon.

Batch 5 - This carbon was first contacted for 11.0 days at approximately 6 gpm/sq ft (run 5.11). The carbon was regenerated for 10 days, sat idle and was then placed back into service in the second position for 10 days at approximately 1.6 gpm/sq ft (run 5.22). Subsequently the contactor was moved into the lead position for 10.5 days at 1.6 gpm/sq ft (run 5.21). The influent and effluent COD during contacting of this carbon batch is shown in Fig. 27.

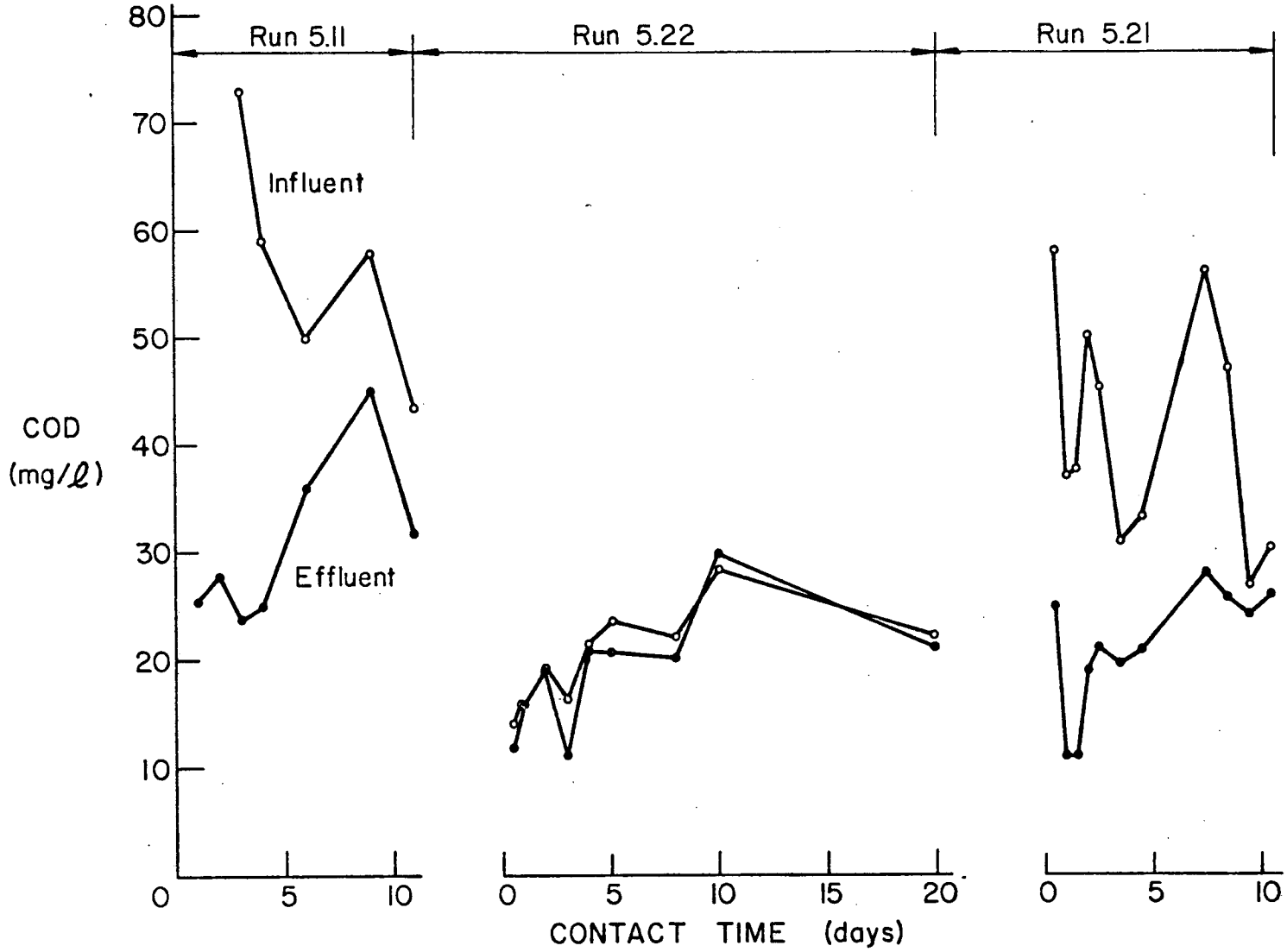


Fig. 27 COD versus Contact Time - Carbon Batch 5

Batch 6 - Run 6.12 was for the sixth carbon batch operating in the second position for 11.0 days at about 6 gpm/sq ft. The contactor moved into the lead position for 17.0 days operating at approximately 6 gpm/sq ft (run 6.11). This batch of carbon was not regenerated due to failure of the pipe contactor. Figure 28 shows the influent and effluent COD during the contacting operation.

Batch 7 - The third batch of carbon used was first contacted for 25.0 days in the second position operating at about 1.6 gpm/sq ft (run 7.12), then moved into the lead position for 20.0 days still at 1.6 gpm/sq ft (run 7.11). This contactor was then taken out of service for regeneration for 20 days and placed back into service for 10.5 days in the second position (run 7.22) still at 1.6 gpm/sq ft. Figure 29 shows the influent and effluent COD concentrations during these different contacting periods.

This Phase III batch contacting was intended to simulate conditions where a tertiary process scheme would be used. Table 7 summarizes this portion of the research operation. Even with virgin carbon and very long detention times (84 minutes total in both contactors at 1.6 gpm/sq ft) the COD removal efficiency was quite low. The apparent carbon capacity is very low, although this may be due to the short operating periods at the lower influent COD concentrations.

It should be noted that during this portion of the research, there were many problems of power failures, pump inadequacies and

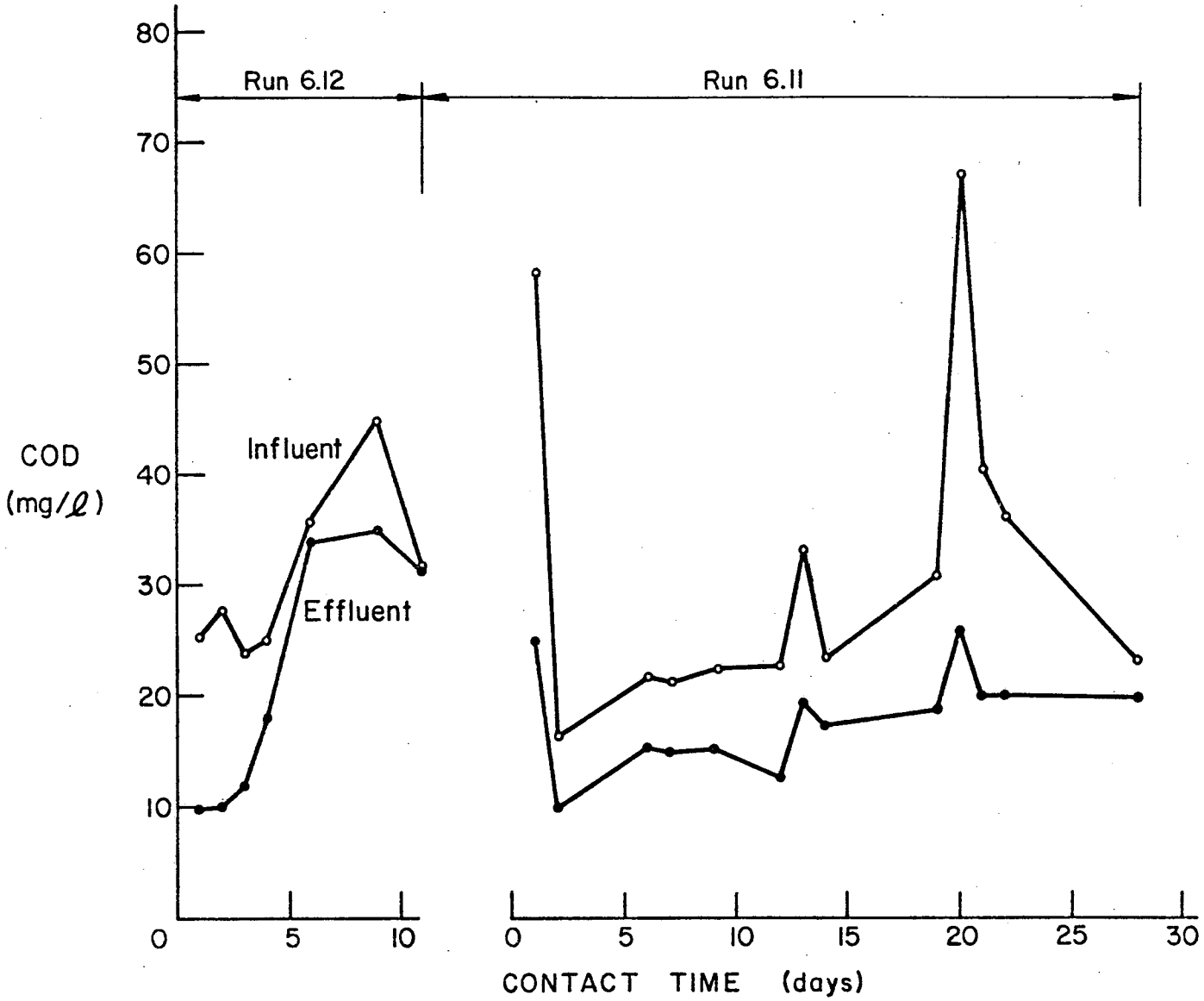


Fig. 28 COD versus Contact Time - Carbon Batch 6

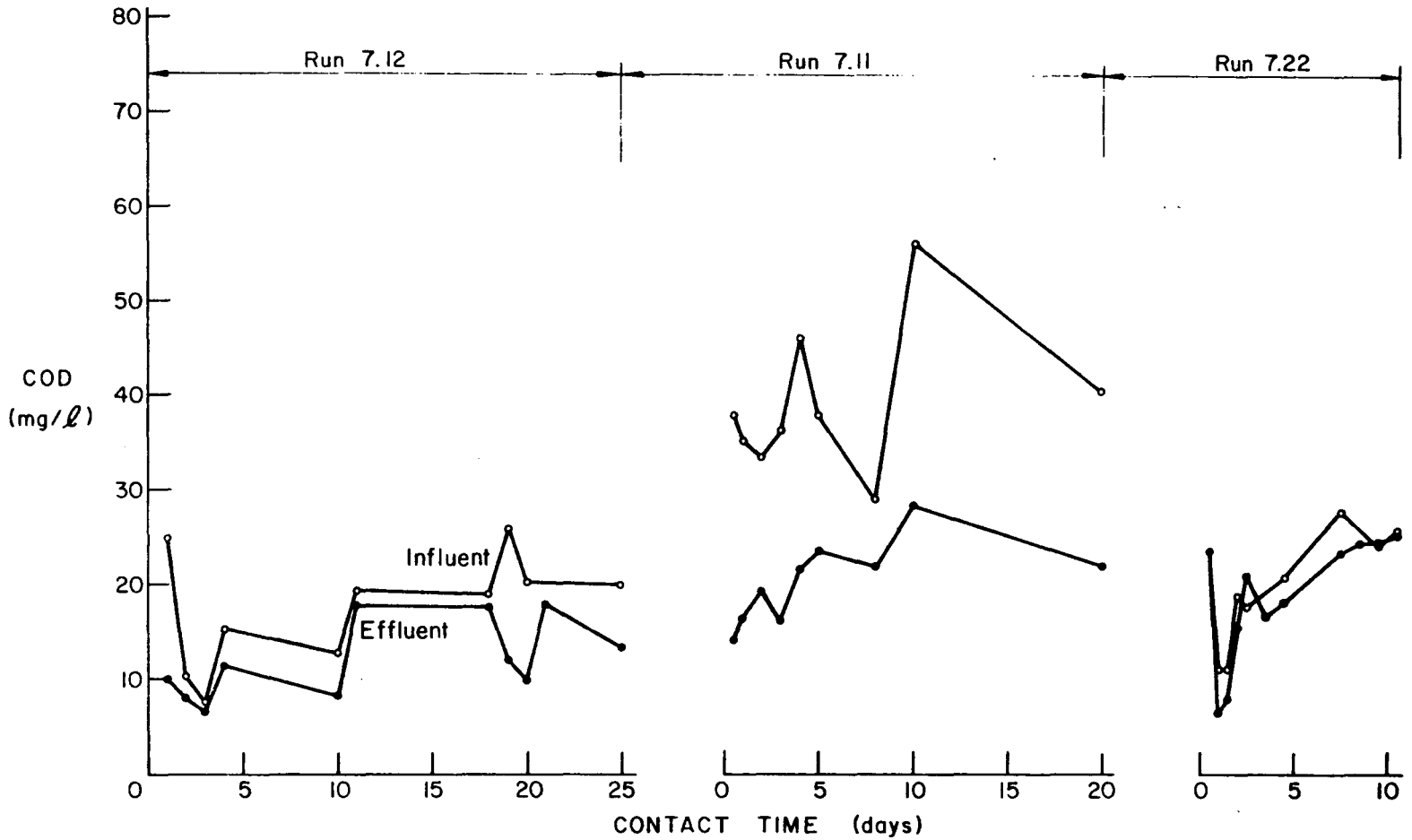


Fig. 29 COD versus Contact Time - Carbon Batch 7

TABLE 7

SUMMARY OF BATCH CONTACTING: PHASE III

| Run | COD Applied[a] mg/ℓ | lbs | COD Removed[b] lbs | lbs/lb Carbon | % |
|---|---|---|---|---|---|
| 5.11[b] | 58.2 | 1.948 | 0.868 | 0.072 | 44.6 |
| 5.22 | 20.4 | 0.198 | 0.016 | 0.001 | 8.1 |
| 5.21 | 41.2 | 0.394 | 0.186 | 0.016 | 47.2 |
| 6.12[b] | 30.6 | 1.080 | 0.304 | 0.025 | 28.1 |
| 6.11[b] | 32.2 | 0.831 | 0.326 | 0.027 | 39.2 |
| 7.12[b] | 18.8 | 0.494 | 0.162 | 0.013 | 32.8 |
| 7.11 | 44.0 | 0.350 | 0.152 | 0.013 | 43.4 |
| 7.22 | 21.0 | 0.207 | 0.026 | 0.002 | 12.6 |

[a]First 10 days of operation in each run
[b]Hydraulic rate of 6 gpm/sq ft for these runs; all other at 1.6 gpm/sq ft

inoperable periods. The data from this research period should be viewed with caution.

It is important to note that the virgin carbon could not "polish" this effluent wastewater down to very low COD values. This agrees with the intital characterization of the Bethlehem wastewater. Also this raises some questions about the validity of the low COD levels listed as "typical" in the EPA process design manual (10, p 1-3) and other generalized effluent quality listings (16).

# VII. DISCUSSION

There are numerous aspects to consider in analyzing the experimental data. Even within the relatively controlled pilot plant operations there were periods of rather high COD in the feed streams and the variability of the influent COD was appreciable.

One of the major problems that occurs in analyzing the experimental results is attempting to separate the COD removal due to adsorption and that due to biological metabolism. This is particularly true in the case of the batch contactor operations where the carbon is exposed to an environment conducive to biological activity during the regeneration and then placed into service where the substrate, the influent, is immediately amenable for metabolism by the carryover biological community from the regeneration action. This, coupled with the enriched substrate conditions due to adsorption certainly will foster biological activity in the contactors. In this research, the contactors were backwashed with tap water prior to going back into service in order to flush out as much of the biological community as possible. With the aerated contactors, the situation is even worse, where the biological activity was being intensively promoted for the in-situ regeneration.

The first phase of the research was addressed to the investigation of off-line biological regeneration of exhausted carbon. In contrast to previous research (13), where a separate biological mass

was maintained, the present study relied solely upon the presence of the biological community within the exhausted carbon contactor. The results indicate the adequacy of this concept which eliminates the need for maintaining a separate biomass to perform the regeneration.

The initial use of COD adsorption isotherms to monitor the regeneration performance was unsuccessful as was the subsequent use of iodine numbers, although the COD adsorption isotherm procedure probably was discarded too soon and may prove to be the best procedure. Other tests such as molasses number and decolorizing index should be studied, but the only true indicator of how the biologically regenerated carbon will perform is to put it back into contacting service.

The results of the Phase I batch regeneration mode summarized in Table 3 show that carbon capacities in excess of 1.0 lb COD/lb carbon can be achieved and that the biologically regenerated carbon is able to remove COD at a rate comparable to that of virgin carbon. The regeneration scheme of recirculating the aerated water in the contactor to promote biological activity was simple, effective and capable of being transferred directly to practice.

Situations where off-line batch biological regeneration could have immediate use are the small scale tertiary and PCT plants which are too small to economically justify thermal regeneration facilities. Since the biological regeneration extends the apparent carbon capacity in excess of 1.0 lbs COD/lb carbon, the carbon

required for these smaller plants can be reduced. As Fig. 2 shows, increasing the carbon capacity from 0.4 to 1.0 lb COD/lb carbon would reduce the carbon operating costs from $0.57 down to $0.28/1,000 gallons, essentially a 50 percent reduction in costs.

The concept of off-line batch biological regeneration of the exhausted carbon also effects the plants which can now barely justify thermal regeneration facilities (10). Using biological regeneration, the size of the plant at which thermal regeneration becomes economically feasible will become larger.

A third situation for using off-line batch biological regeneration would be in facilities which now have thermal regeneration, or are in the process of designing them. Considering the use of biological regeneration as a supplemental type of carbon capacity recovery, the furnace capacity could be reduced, perhaps by as much as one-half.

The economic aspect of the biological regeneration for off-line batch operation should be considered in existing facilities and those under design.

The combined Phase II and III aerated contactor operating period of 200 days gave an apparent carbon capacity of 1.87 lbs COD/lb carbon. Figure 26 shows that the rate of COD removal does not appear to be decreasing even after the 200 days of service. This lends credulence to the thought that the activated carbon surface area is indeed being continuously regenerated in-situ. With a capacity of 1.87 lbs COD/lb carbon and an influent COD concentration of 95 mg/ℓ, the average for

runs 4.1 and 4.2, the required carbon dosage would be 425 lbs carbon per million gallons. The influent COD concentration is in the range between that expected in a tertiary plant and a PCT plant. This required dosage of 425 lbs/MG compares well with the general range expressed in the EPA design manual (10) of 200 - 400 lbs/MG for tertiary plants and 500 - 1,800 lbs/MG for PCT plants.

The importance of the above comparison lies in the fact that the aerated contactor concept does not include the expensive thermal regeneration system and required carbon inventory which is indicated by current design guidelines. Elimination of the thermal regeneration and carbon inventory is a 29% reduction in a typical carbon treatment system (10, p 5-30). This is a major advance in the economics of activated carbon systems.

The aerated contactor operating mode should be considered in future design for both tertiary and PCT plants. In particular, the PCT plants would receive a tremendous economic benefit from this mode of operation. The economics, coupled with elimination of the $H_2S$ odor operating problem makes the aerated contactor concept a very attractive alternate operating mode for carbon treatment systems.

The inert sand media contactor shows the value of the biological activity since the removal in this unit was essentially biological. The greater COD removal in the carbon contactor shows the value of the large surface area of the carbon in enriching the substrate to allow biological activity to flourish.

With the excellent COD removal observed in the aerated carbon contactor, it would be very easy to gloss over or ignore the inert sand contactor which only removed 60% as much COD as did the carbon contactor. However, the performance of the sand unit should be considered in light of the mass loading rates. The organic loading rate on the five foot deep sand contactor throughout the 200 day operating period was 340 lbs COD per 1000 cu ft per day (ptcfd) and the removal was over 140 ptcfd COD. This amount of mass removal exceeds what would be expected of roughing trickling filters or super high rate activated sludge plants treating a much more concentrated wastewater. The economic impact of the sand contactor performance lies in the fact that the sand is virtually free compared to the carbon cost of $0.35 to $0.50 per lb. Further economic analysis may show that aerated inert media contactors can be combined with "polishing" carbon beds to produce a highly treated wastewater at a lower cost than other process combinations.

Another aspect of the aerated contactor operation which could be a positive aspect is the degree of nitrification observed. The data was too meager to allow a definition of this aspect and further studies should be considered to delineate the potential of nitrification in aerated contactors.

One of the important aspects of the Phase III experimental results is the observation that the effluent from the aerated carbon contactor contain relatively little organic material, measured by COD, which is capable of being adsorbed. Even the virgin carbon

showed little additional COD removal after treatment in the aerated carbon contactor.

These results also show that the biologically regenerated carbon functioned equally well as the virgin carbon in the lead position, e.g. run 5.21, compared to runs 6.11 and 7.11, all as shown in Table 7. When the biologically regenerated carbon was in the second position, runs 5.22 and 7.22, the COD removal was not as good as the virgin carbon in runs 6.12 and 7.12. Neither the virgin carbon nor the regenerated carbon functioned very well. Run 6.12 shows better operation, however the higher hydraulic rate allowed more COD to be applied and this run should not be compared with run 7.12. There were severe operating problems for these batch contacting runs and the results should be viewed with some skepticism.

It would be enlightening to attempt a characterization of the organic material in the influent and effluent from batch contactors, usually under anaerobic conditions, in comparison with the effluent from aerated contactors. The Phase III batch contacting showed that there was an appreciable concentration of organic material which was not adsorbed, even after 42 minutes of contact time in the second position contactor. Considering the total of 84 minutes contact time in both contactors, the organic removal was very low.

If the biological activity in the aerated contactors was really anaerobic in the micro-environment around the granular carbon as proposed by Weber, et al (14), one would expect the contactor

effluent to contain the breakdown products of the anaerobic activity, such as acetic and propionic acids as well as other smaller organic molecules which are less adsorbable but are quite biodegradable and not refractory. However, if the biological activity was truly aerobic in nature, both in a macro- and micro-environment sense, we would expect the residual organic material to be more complex, and hence, less biodegradable or truly refractory in nature.

The BOD data was rather limited, but it does show that in the situation where the COD was in the 10-20 mg/ℓ range, the BOD was also quite low, near about 5 mg/ℓ. If the residual organics from the contactors were more simple molecules from anaerobic activity, these easily degrraded materials would tend to cause higher BOD values, perhaps even higher than the COD values since the COD test does not completely measure the simple organic acids such as acetic or propionic. Thus, from a negative speculative view, these organic products are probably the residual materials that were in the influent wastewater stream. However, the meager data is not adequate to support either speculative view and future research should be considered to establish the nature of the treated wastewaters and the mechanisms involved in the contactor biological activity.

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## IX. APPENDIX - COD DATA

| Date | Day | COD, mg/ℓ Influent | COD, mg/ℓ Effluent |
|---|---|---|---|
| Run 1.1 | | | |
| 011873 | 0.00 | - | - |
| 011973 | 0.50 | 47.00 | 5.70 |
| 011973 | 1.00 | 87.60 | 53.40 |
| 012073 | 1.67 | 43.90 | 46.50 |
| 012173 | 2.67 | 56.90 | 23.10 |
| 011273 | 3.50 | 64.40 | 64.40 |
| 011273 | 4.00 | 57.90 | 29.60 |
| 012373 | 4.50 | 66.60 | 44.50 |
| 012373 | 5.00 | 65.60 | 38.10 |
| 012473 | 5.54 | 44.90 | 42.90 |
| 012473 | 6.00 | 56.70 | 41.70 |
| 012573 | 6.54 | 58.70 | 34.80 |
| 012573 | 7.00 | 52.70 | 35.80 |
| 012673 | 7.52 | 42.50 | 28.80 |
| 012673 | 8.00 | 57.50 | 22.70 |
| 012773 | 8.67 | 44.90 | 42.90 |
| 012873 | 9.67 | 51.00 | 35.80 |
| 012973 | 10.50 | 47.20 | 26.80 |
| 012973 | 11.17 | 42.20 | 31.00 |
| 013073 | 11.50 | 55.00 | 47.80 |
| 013073 | 12.00 | 51.00 | 36.90 |
| 013173 | 12.50 | 44.00 | 39.30 |
| 013173 | 13.04 | 71.00 | 39.70 |
| 020173 | 13.54 | 61.90 | 51.20 |
| 020173 | 14.04 | 48.60 | 40.40 |
| 020273 | 14.67 | 30.60 | 26.10 |
| 020273 | 15.04 | 37.10 | 37.60 |
| 020273 | 15.54 | 26.90 | 16.70 |
| 020273 | 16.67 | 37.90 | 18.40 |
| 020573 | 17.00 | 35.40 | 26.00 |

| Date | Day | COD, mg/ℓ Influent | COD, mg/ℓ Effluent |
|---|---|---|---|
| Run 1.2 | | | |
| 030173 | 0.00 | - | - |
| 030273 | 1.00 | 86.60 | 76.30 |
| 030373 | 2.00 | 86.50 | 24.10 |
| 030473 | 3.00 | 57.70 | 29.70 |
| 030573 | 4.00 | 31.60 | 21.84 |
| 030673 | 5.88 | 86.50 | 63.00 |
| 030773 | 6.95 | 61.80 | 39.70 |
| 030873 | 7.92 | 55.70 | 53.10 |
| 030973 | 8.92 | 90.60 | 48.10 |
| 031273 | 11.92 | 66.00 | 42.50 |
| 031373 | 12.83 | 68.50 | 57.50 |
| 031473 | 13.92 | 31.90 | 27.20 |
| 031573 | 15.08 | 57.60 | 37.90 |
| 031673 | 16.13 | 85.20 | 73.60 |
| 031873 | 17.00 | 84.90 | 68.90 |

| Date | Day | COD, mg/ℓ Influent | COD, mg/ℓ Effluent |
|---|---|---|---|
| Run 1.3 | | | |
| 040573 | 0.00 | - | - |
| 040673 | 1.00 | 47.30 | 22.10 |
| 040773 | 2.00 | 54.70 | 32.60 |
| 040873 | 3.58 | 60.70 | 43.10 |
| 040973 | 4.00 | 46.50 | 36.00 |
| 041073 | 5.00 | 70.40 | 50.80 |
| 041173 | 6.00 | 88.00 | 70.80 |
| 042173 | 7.00 | 76.10 | 66.10 |
| 041373 | 8.00 | 80.30 | 78.60 |
| 041673 | 11.17 | 55.30 | 55.30 |
| 041773 | 12.00 | 44.80 | 42.30 |
| 041873 | 13.00 | 38.20 | 33.30 |
| 041973 | 14.00 | 44.10 | 35.50 |
| 042273 | 17.38 | 65.10 | 41.70 |
| 043273 | 18.00 | 34.50 | 36.00 |
| 042473 | 19.00 | 51.10 | 46.80 |
| 042573 | 20.25 | 64.40 | 67.60 |

| Date | Day | COD, mg/ℓ Influent | Effluent |
|---|---|---|---|
| Run 2.1 | | | |
| 020673 | 0.00 | - | - |
| 020773 | .71 | 60.60 | 8.90 |
| 020873 | 1.67 | 59.80 | 6.10 |
| 020973 | 2.67 | 60.60 | 4.90 |
| 021073 | 3.63 | 58.10 | 37.00 |
| 021173 | 4.54 | 48.40 | 10.30 |
| 021273 | 5.63 | 47.20 | 15.10 |
| 021373 | 6.92 | 46.00 | 31.40 |
| 021473 | 7.63 | 66.30 | 49.20 |
| 021573 | 8.63 | 72.50 | 61.00 |
| 021673 | 9.63 | 75.50 | 50.40 |
| 021773 | 10.54 | 73.60 | 45.50 |
| 022173 | 14.92 | 71.70 | 40.30 |
| 022273 | 15.54 | 61.80 | 53.00 |

| Date | Day | COD, mg/ℓ Influent | Effluent |
|---|---|---|---|
| Run 2.2 | | | |
| 031973 | 0.00 | - | - |
| 032073 | 1.00 | 77.20 | 25.00 |
| 032073 | 1.42 | 60.60 | 23.20 |
| 032173 | 1.88 | 85.00 | 50.20 |
| 032273 | 2.88 | 96.20 | 87.30 |
| 032373 | 3.92 | 87.00 | 71.40 |
| 032573 | 5.88 | 75.40 | 46.70 |
| 032673 | 6.88 | 61.90 | 58.90 |
| 032773 | 7.88 | 49.80 | 37.20 |
| 032873 | 8.88 | 101.40 | 78.80 |
| 032973 | 9.92 | 97.80 | 89.10 |
| 033073 | 10.88 | 103.80 | 87.10 |
| 033173 | 11.88 | 85.90 | 82.20 |
| 040273 | 13.88 | 58.90 | 52.60 |
| 040373 | 14.88 | 63.10 | 48.30 |
| 040473 | 15.88 | 49.10 | 14.40 |
| 040573 | 17.38 | 46.80 | 19.50 |

| Date | Day | COD, mg/ℓ Influent | COD, mg/ℓ Effluent |
|---|---|---|---|
| Run 3.1 | | | |
| 060673 | 0.00 | - | - |
| 060773 | 0.92 | 43.40 | 40.60 |
| 060873 | 1.79 | 20.30 | .80 |
| 061173 | 4.75 | 43.00 | 20.70 |
| 061273 | 5.67 | 29.10 | 25.90 |
| 061373 | 6.96 | 51.70 | 32.00 |
| 061573 | 9.04 | 42.70 | 38.20 |
| 061673 | 9.71 | 33.60 | 29.00 |
| 061773 | 11.10 | 29.90 | 23.90 |
| 061873 | 12.20 | 60.60 | 31.70 |
| 061973 | 13.00 | 39.40 | 34.80 |
| 062073 | 13.90 | 51.40 | 44.00 |
| 062173 | 15.20 | 41.90 | 34.90 |

| Date | Day | COD, mg/ℓ Influent | COD, mg/ℓ Effluent |
|---|---|---|---|
| Run 3.2 | | | |
| 071273 | 0.00 | - | - |
| 071373 | 1.00 | 42.00 | 39.10 |
| 071473 | 2.00 | 73.80 | 73.40 |
| 071673 | 4.00 | 56.00 | 47.00 |
| 071773 | 5.00 | 23.20 | 18.50 |
| 071873 | 6.00 | 76.80 | 64.80 |
| 071973 | 7.00 | 43.60 | 42.40 |
| 072073 | 8.00 | 69.60 | 63.80 |
| 072373 | 11.00 | 74.30 | 57.10 |
| 072473 | 12.00 | 69.60 | 63.80 |
| 072573 | 13.00 | 73.80 | 60.00 |

| Date | Day | COD, mg/ℓ Influent | Effluent Carbon | Effluent Sand |
|---|---|---|---|---|
| Run 4.1 and 4.1S | | | | |
| 072273 | 0.00 | - | - | - |
| 072373 | 1.00 | 74.40 | 13.00 | 49.80 |
| 072473 | 2.00 | 53.10 | 11.50 | 40.50 |
| 072573 | 3.00 | 73.80 | 12.90 | 48.40 |
| 072773 | 5.00 | 65.50 | 16.10 | 45.00 |
| 073073 | 8.00 | 63.60 | 20.50 | 50.60 |
| 080173 | 10.00 | 79.80 | 35.10 | 50.60 |
| 080273 | 11.00 | 61.60 | 28.30 | 44.20 |
| 080373 | 12.00 | 78.60 | 21.10 | 51.10 |
| 080673 | 15.00 | 90.70 | 13.50 | 39.00 |
| 080773 | 16.00 | 84.00 | 11.50 | 30.50 |
| 080873 | 17.00 | 80.70 | 12.40 | 41.80 |
| 080973 | 18.00 | 84.00 | 13.70 | 28.30 |
| 081073 | 19.00 | 84.60 | 14.50 | 44.50 |
| 081473 | 23.00 | 85.40 | 15.20 | 32.60 |
| 081573 | 24.00 | 75.10 | 26.40 | 38.30 |
| 081673 | 25.00 | 77.90 | 24.80 | 45.70 |
| 081773 | 26.00 | 83.50 | 28.90 | 53.30 |
| 082173 | 30.00 | 78.00 | 18.40 | 38.40 |
| 082273 | 31.00 | 76.70 | 12.30 | 46.80 |
| 082373 | 32.00 | 82.00 | 12.50 | 38.80 |
| 082473 | 33.00 | 79.10 | 24.40 | 40.60 |
| 082773 | 36.00 | 64.90 | 17.60 | 31.60 |
| 082873 | 37.00 | 85.00 | 22.40 | 31.80 |
| 082973 | 38.00 | 81.90 | 20.80 | 40.50 |
| 091173 | 51.00 | 67.10 | 10.00 | 32.20 |
| 091273 | 52.00 | 90.90 | 28.20 | 47.70 |
| 091373 | 53.00 | 89.00 | 32.00 | 46.90 |
| 091473 | 54.00 | 78.40 | 25.60 | 46.10 |
| 091773 | 57.00 | 67.80 | 15.90 | 33.70 |
| 092073 | 60.00 | 83.90 | 23.00 | 44.30 |
| 092173 | 61.00 | 61.90 | 17.90 | 55.00 |
| 092473 | 64.00 | 84.10 | 10.20 | 21.00 |

| Date | Day | COD, mg/ℓ Influent | Effluent Carbon | Effluent Sand |
|---|---|---|---|---|
| Run 4.2 and 4.2S | | | | |
| 060574 | 0.00 | - | - | - |
| 060674 | 1.00 | 197.30 | 56.60 | 138.70 |
| 060774 | 2.00 | 145.10 | 67.60 | 133.20 |
| 060874 | 3.00 | 162.10 | 73.10 | 154.20 |
| 061974 | 5.00 | 159.10 | 58.90 | 121.80 |
| 062474 | 10.00 | 188.60 | 77.80 | 124.00 |
| 062574 | 11.00 | 126.90 | 57.70 | 119.20 |
| 062774 | 13.00 | 139.10 | 51.10 | 77.70 |
| 062874 | 14.00 | 111.60 | 24.30 | 89.20 |
| 070174 | 17.00 | 180.30 | 30.00 | 90.10 |
| 071074 | 26.00 | 120.80 | 19.80 | 37.60 |
| 071674 | 32.00 | 68.90 | 17.70 | 47.20 |
| 072474 | 40.00 | 72.60 | 18.00 | 48.00 |
| 072574 | 41.00 | 69.70 | 49.80 | 65.70 |
| 080274 | 49.00 | 84.30 | 21.70 | 38.60 |
| 080774 | 54.00 | 49.60 | 18.80 | 27.20 |
| 080974 | 56.00 | 68.40 | 16.30 | 43.20 |
| 081274 | 59.00 | 76.00 | 15.30 | 27.40 |
| 081374 | 60.00 | 66.80 | 21.80 | 39.70 |
| 081474 | 61.00 | 78.60 | 21.30 | 40.80 |
| 081674 | 63.00 | 75.20 | 22.60 | 59.60 |
| 082074 | 67.00 | 92.10 | 33.50 | 66.90 |
| 082174 | 68.00 | 86.10 | 23.50 | 31.50 |
| 082274 | 69.00 | 124.30 | 39.50 | 42.90 |
| 082774 | 74.00 | 71.20 | 31.10 | 41.10 |
| 082874 | 75.00 | 106.00 | 67.50 | 79.50 |
| 082974 | 76.00 | 96.60 | 40.70 | 80.60 |
| 083074 | 77.00 | 120.40 | 36.40 | 93.70 |
| 090574 | 83.00 | 95.60 | 56.70 | 71.30 |
| 091074 | 88.00 | 113.00 | 38.00 | 72.60 |
| 091174 | 89.00 | 126.30 | 35.10 | 56.40 |
| 091274 | 90.00 | 65.20 | 33.30 | 51.40 |
| 091774 | 95.00 | 94.60 | 37.80 | 48.20 |
| 091874 | 96.00 | 126.40 | 36.20 | 55.70 |
| 091974 | 97.00 | 123.60 | 46.20 | 74.20 |
| 092074 | 98.00 | 102.80 | 33.50 | 37.90 |
| 092374 | 101.99 | 98.10 | 28.40 | 35.60 |
| 100274 | 110.00 | 97.20 | 57.90 | 74.60 |
| 100474 | 112.00 | 156.30 | 56.20 | 93.30 |
| 101474 | 122.00 | 68.60 | 40.40 | 42.90 |
| 121074 | 123.00 | 65.80 | 22.00 | 51.40 |
| 121174 | 124.00 | 92.60 | 29.10 | 47.10 |
| 123074 | 126.00 | 101.20 | 36.90 | 46.50 |
| 123174 | 127.00 | 137.10 | 50.20 | 57.30 |
| 010275 | 128.50 | 95.20 | 30.80 | 36.40 |
| 010375 | 129.50 | 94.40 | 24.00 | 33.20 |
| 010675 | 132.50 | 120.00 | 56.20 | 65.60 |
| 010875 | 134.50 | 89.10 | 26.70 | 32.80 |
| 010975 | 135.50 | 97.30 | 30.40 | 39.60 |

| Date | Day | COD, mg/ℓ Influent | Effluent |
|---|---|---|---|
| Run 5,11 | | | |
| 060574 | 0.00 | - | - |
| 060674 | 1.00 | 56.64 | 25.39 |
| 060774 | 2.00 | 67.59 | 27.83 |
| 060874 | 3.00 | 73.12 | 23.72 |
| 061974 | 4.00 | 58.90 | 25.00 |
| 072574 | 6.00 | 49.80 | 35.86 |
| 073074 | 9.00 | 58.00 | 45.00 |
| 080274 | 11.00 | 43.36 | 31.72 |

| Date | Day | COD, mg/ℓ Influent | Effluent |
|---|---|---|---|
| Run 5.22 | | | |
| 091074 | 0.00 | - | - |
| 091074 | 0.50 | 14.12 | 11.83 |
| 091174 | 1.00 | 16.40 | 15.80 |
| 091274 | 2.00 | 19.32 | 18.94 |
| 091874 | 3.00 | 16.07 | 11.07 |
| 091974 | 4.00 | 21.60 | 20.80 |
| 092074 | 5.00 | 23.59 | 20.60 |
| 092374 | 8.00 | 21.90 | 20.10 |
| 100474 | 10.00 | 28.40 | 29.80 |
| 101474 | 20.00 | 22.00 | 21.00 |

| Date | Day | COD, mg/ℓ Influent | Effluent |
|---|---|---|---|
| Run 5,21 | | | |
| 122974 | 0.00 | - | - |
| 123074 | 0.50 | 58.02 | 24.90 |
| 123074 | 1.00 | 36.94 | 11.02 |
| 123174 | 1.50 | 37.64 | 11.00 |
| 123174 | 2.00 | 50.20 | 18.95 |
| 010175 | 2.50 | 45.97 | 20.97 |
| 010275 | 3.50 | 30.85 | 19.52 |
| 010375 | 4.50 | 33.20 | 20.80 |
| 010675 | 7.50 | 56.20 | 28.00 |
| 010775 | 8.50 | 47.24 | 25.59 |
| 010875 | 9.50 | 26.69 | 24.02 |
| 010975 | 10.50 | 30.40 | 25.89 |

| Date | Day | COD, mg/ℓ Influent | Effluent |
|---|---|---|---|
| Run 6.12 | | | |
| 060574 | 0.00 | - | - |
| 060674 | 1.00 | 25.39 | 9.77 |
| 060774 | 2.00 | 27.83 | 10.00 |
| 060874 | 3.00 | 23.72 | 11.86 |
| 061974 | 4.00 | 25.00 | 18.00 |
| 072574 | 6.00 | 35.86 | 33.86 |
| 073074 | 9.00 | 45.00 | 35.00 |
| 080274 | 11.00 | 31.72 | 31.32 |

| Date | Day | COD, mg/ℓ Influent | Effluent |
|---|---|---|---|
| Run 6.11 | | | |
| 080774 | 0.00 | - | - |
| 080874 | 1.00 | 58.40 | 25.00 |
| 080974 | 2.00 | 16.31 | 10.00 |
| 081374 | 6.00 | 21.78 | 15.43 |
| 081474 | 7.00 | 21.30 | 15.00 |
| 081674 | 9.00 | 22.60 | 15.30 |
| 081974 | 12.00 | 22.83 | 12.71 |
| 082074 | 13.00 | 33.46 | 19.49 |
| 082174 | 14.00 | 23.46 | 17.40 |
| 082774 | 20.00 | 31.06 | 18.94 |
| 082874 | 21.00 | 67.45 | 26.12 |
| 082974 | 22.00 | 40.68 | 20.15 |
| 083074 | 23.00 | 36.43 | 20.25 |
| 090474 | 28.00 | 23.19 | 20.00 |

| Date | Day | COD, mg/ℓ Influent | Effluent |
|---|---|---|---|
| Run 7.12 | | | |
| 080774 | 0.00 | - | - |
| 080874 | 1.00 | 25.00 | 10.00 |
| 080974 | 2.00 | 10.00 | 8.00 |
| 081374 | 6.00 | 15.43 | 11.42 |
| 081974 | 12.00 | 12.71 | 8.27 |
| 082074 | 13.00 | 19.49 | 17.91 |
| 082774 | 20.00 | 18.96 | 17.61 |
| 082874 | 21.00 | 26.12 | 12.08 |
| 082974 | 22.00 | 20.15 | 9.89 |
| 083074 | 23.00 | 20.25 | 18.03 |
| 090474 | 28.00 | 20.00 | 13.42 |

| Date | Day | COD, mg/ℓ Influent | COD, mg/ℓ Effluent |
|---|---|---|---|
| Run 7.11 | | | |
| 091074 | 0.00 | - | - |
| 091074 | 0.50 | 37.98 | 14.12 |
| 091174 | 1.00 | 35.10 | 16.40 |
| 091274 | 2.00 | 33.33 | 19.32 |
| 091874 | 3.00 | 36.24 | 16.07 |
| 091974 | 4.00 | 46.20 | 21.60 |
| 092074 | 5.00 | 37.85 | 23.59 |
| 092374 | 8.00 | 28.80 | 21.90 |
| 100474 | 10.00 | 56.20 | 28.40 |
| 101474 | 20.00 | 40.36 | 22.00 |

| Date | Day | COD, mg/ℓ Influent | COD, mg/ℓ Effluent |
|---|---|---|---|
| Run 7.22 | | | |
| 122974 | 0.00 | - | - |
| 123074 | 0.50 | 24.90 | 23.46 |
| 123074 | 1.00 | 11.02 | 6.53 |
| 123174 | 1.50 | 11.00 | 7.98 |
| 123174 | 2.00 | 18.95 | 15.52 |
| 010175 | 2.50 | 20.97 | 17.54 |
| 010275 | 3.50 | 19.52 | 16.73 |
| 010375 | 4.50 | 20.80 | 18.20 |
| 010675 | 7.50 | 28.00 | 23.50 |
| 010775 | 8.50 | 25.59 | 24.41 |
| 010875 | 9.50 | 24.02 | 24.61 |
| 010975 | 10.50 | 25.89 | 25.30 |

SELECTED WATER RESOURCES ABSTRACTS

INPUT TRANSACTION FORM

1. Report No. | 2. | 3. Accession No. W

4. Title: Biological Regeneration of Activated Carbon in Advanced Wastewater Treatment

5. Report Date

6.

8. Performing Organization Report No.

7. Author(s): Johnson, Robert L.

Department of Civil Engineering
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Bethlehem, Pennsylvania

10. Project No. A-032-PA

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12. Sponsoring Organization

13. Type of Report and Period Covered

15. Supplementary Notes

16. Abstract

Enchancement of biological activity was used for off-line batch regeneration of exhausted carbon and in aerated contactors for in-situ regeneration.

After three off-line batch biological regeneration cycles, the carbon capacity exceeded 1.0 lbs COD/lb with no apparent reduction in the COD removal rate compared to virgin carbon. In 200 days of aerated contactor operation the apparent capacity was 1.87 lbs COD/lb carbon. The influent COD of 94.6 mg/ℓ was reduced to 30.4 m/ℓ at 1.5 gpm/sq ft with 25 minutes detention. A parallel aerated sand contactor removed over 140 lbs COD/day per 1000 cu ft (ptcfd) at 340 ptcfd loading rate.

Existing data, carbon operating costs for small physical-chemical treatment plants could be reduced 50% by using aerated contactors and comparable economic savings can be achieved by using the biological acitivity in tertiary treatment.

17a. Descriptors

*Carbon Regeneration,*Carbon Treatment, *COD Removal, *BOD Removal, Activated Carbon, Sand, Aeration, Biological Activity, Costs.

17b. Identifiers

17c. COWRR Field & Group 05D

18. Availability

19. Security Class. (Report)

20. Security Class. (Page)

21. No. of Pages

22. Price

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