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Title: TREATMENT OF ACTIVATED SLUDGE PROCESS

EFFLUENT BY CARBON ADSORPTION

Abstract approved: 

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An evaluation of the service time of an activated carbon adsorption column and the organic carbon removal efficiency treating activated sludge process effluent was completed at aerator detention times of three, five, and ten hours. Parameters used for evaluation of treatment were biochemical oxygen demand, chemical oxygen demand, total organic carbon, and carbon service time.

As a result of this research study the following conclusions were made:

1. Direct filtration of an activated sludge process effluent at low hydraulic loading provides adequate particulate matter removal to prevent fouling of the activated carbon beds.

2. The BOD removal by sand filtration-activated carbon adsorption varies between 75 and 92 percent when aerator detention time is varied from three to ten hours.

3. The service time of an activated carbon adsorption bed is decreased as the activated sludge process aerator detention time is increased.

Treatment of Activated Sludge  
Process Effluent by  
Carbon Adsorption

by

Stewart Lee Davis

A THESIS

submitted to

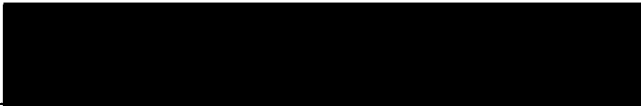
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## TREATMENT OF ACTIVATED SLUDGE PROCESS EFFLUENT BY CARBON ADSORPTION

### INTRODUCTION

Materials containing carbon have been used for the convenience and welfare of mankind for many centuries. Fuels containing carbon have provided heat to prepare food and provide warmth since man has controlled fire. As early as 1550 B.C. carbon was used for medicinal purposes (10). The adsorptive powers of activated carbon were first reported by Scheel, who in 1773 described experiments on gases exposed to carbon. The first industrial application came a few years later when carbon was used to clarify liquors in the refining of cane sugar (6).

While activated carbon has been used in water treatment for many years to control taste and odor producing substances, only recently has its application to waste water treatment plant effluent been considered. Joyce and Sukenik (7) have shown the usefulness of carbon in removing material from secondary effluents. Carbon adsorption processes usually follow physical or chemical processes which remove particulate material which tends to blind the surface of the carbon granules, thus reducing the useful service time of the carbon.

Powdered carbon has typically been used in water treatment applications rather than granular activated carbon beds. However,

the development of regeneration techniques for carbon has placed new interest on its use in waste water treatment. Use of granular carbon allows more efficient use of the carbon and eliminates the need to determine optimum carbon dosage as required when using powdered carbon. Also the quantities of carbon required to remove the organic material from secondary sewage effluents make a process which is reversible necessary and require reuse of the carbon. Joyce and Sukenik (7) have demonstrated the ability of granular activated carbon to fill this role. By exposing carbon to an atmosphere of 34 percent steam and 66 percent air at 1740° F the organic material adsorbed is oxidized to carbon dioxide and water.

Activated carbon is a good adsorbent for organic molecules and a poor adsorbent for inorganic electrolytes. Therefore, the material removed will be organic molecules and the portion passing through carbon adsorption beds will be primarily inorganic electrolytes and some non-adsorbable organic molecules.

## PURPOSE AND SCOPE

The purpose of this research was to evaluate the service time of an activated carbon adsorption column and the organic carbon removal efficiency treating activated sludge process effluent.

The investigation of carbon adsorption as a means of further treating completely mixed activated sludge process effluent was evaluated. Parameters used for evaluation of treatment were Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), and carbon service time. Aerator detention times of three, five, and ten hours were used in this evaluation. A program of sludge wasting from the system was used to maintain the mixed liquor suspended solids (MLSS) in the aerator at 2000 mg/l.

## LITERATURE REVIEW

### Activated Sludge

The first attempts to improve the condition of waste water by blowing air through it were in Europe in 1882 (11). About 1913 the activated sludge process was developed by flocculation of biological growths which were able to absorb organic matter from waste water and convert it to simple end products such as carbon dioxide and water.

Since the activated sludge process was developed there have been several modifications and improvements made to the process. Activated sludge processes and modifications are listed below:

1. Conventional activated sludge
2. Modifications to conventional activated sludge
  - a. Tapered aeration
  - b. Step aeration
3. Short term aeration
4. Extended aeration
5. Complete-mixing activated sludge

### Conventional Activated Sludge

In the conventional activated sludge process the treatment of the influent flow begins as the waste water enters a primary clarifier

where settleable solids are removed. The overflow from the primary clarifier passes to the aeration tank where it mixes with the active biological solids to form the mixed liquor. The mixed liquor is displaced into a final clarifier where the biological floc settles and is returned to the aeration tank to maintain the desired mixed liquor suspended solids (MLSS) and to assimilate more organic material from the flow into the aeration tank. The sludge not required to maintain the solids level in the aeration tank is wasted to the primary clarifier and subsequently to a sludge disposal process.

The conventional activated sludge process operates at loading factors varying from 0.2 to 0.5 lb BOD/day/lb Mixed Liquor Volatile Suspended Solids (MLVSS) (8, 12). The aeration time ranges from four to eight hours. The ratio of the return sludge flow to the influent flow is usually about 0.20 and the volume of excess sludge to be wasted is about 1.5 percent of the influent flow (12).

#### Modifications to Conventional Activated Sludge

The modifications to the process usually provide some variation of distributing the influent flow or air supply along the length of the aeration tank. The tapered aeration process (12) is designed to provide decreasing amounts of oxygen to the waste as the oxygen demand is gradually reduced as the organic material is removed by the biological suspended solids along the length of the tank. Another

system which is used to level out the oxygen requirements along the length of the tank is step aeration (12). In this process the influent flow is distributed along the length of the tank thereby supplying a more uniform oxygen demand. The loading factor and aeration time for these systems are the same as for the conventional activated sludge process.

#### Short Term Aeration

Short term aeration processes have high loading factors, varying from 0.5 up to 5 lb BOD/day/lb MLVSS (12) and the aeration time varies from 0.5 to 2.5 hours.

#### Extended Aeration

The extended aeration process loading factor is less than either short term or conventional activate sludge process, ranging from 0.05 to 0.2 lb BOD/day/lb MLVSS (12) and aeration times vary from 10 to 24 hours.

#### Complete-Mixing Activated Sludge

Lesperance (8) and Cassell, Sulzer, and Lamb (3) state different organism populations predominate at varying load factors. Cassell, Sulzer, and Lamb (3) report when two populations compete and neither have a great selective advantage a varying quality of effluent

is produced. McKinney (9) has shown that a complete-mixing activated sludge process results in a more uniform biological population than the conventional activated sludge process. The complete-mixing activated sludge process provides a uniform organic load to the aerator allowing the system to approach equilibrium whereas in the conventional activated sludge system microbial population undergoes a continual shifting of predominating population which results in a varying quality of effluent.

#### Application to Domestic Waste Treatment

The activated sludge process is capable of removing 80-95 percent of the BOD present in domestic waste water. Many activated sludge plants are in operation throughout the United States. Numerous package plants have been installed in housing subdivisions, trailer courts, and forest camps. The standards of effluent quality varies widely across the United States as does the operation of these plants.

Culp and Hansen (4) report 88 percent BOD reduction by extended aeration in pilot plant studies at Philomath, Oregon.

#### Activated Carbon Adsorption

Adsorption is the phenomenon which exists when molecules of one material are bound to the surface of another material. Physical

and chemical forces are responsible for the process of adsorption. Chemisorptive forces are much stronger than physical forces but are of minor importance in carbon adsorption so only physical forces will be discussed.

### Mechanism of Adsorption

Adsorption is usually explained in terms of the surface tension of the solid. Molecules within a solid are subject to equal forces in each direction, whereas an unbalanced force exists at the surface. This unbalance of forces can only be brought to equilibrium by other molecules being attracted and attached to the surface.

The attractive forces which are relatively weak are called Van der waals forces after the Dutch physicist who first recognized them. These forces are physical in nature and seldom exceed a few kcal/mole; therefore adsorbed molecules are released easily by regenerative processes.

### Nature of the Surface

The chemical nature of the adsorbent surface influences its ability to attract adsorbate molecules. In solution the principle that "like" dissolves "like" may also be applied to adsorption. Polar surfaces may prefer polar adsorbates and non-polar surfaces may prefer non-polar adsorbates. Polar molecules are those molecules



whose positive and negative centers do not coincide. Polar molecules also have a dipole moment which causes it to move into a preferred position when placed under the influence of an electrical field.

A pure carbon surface is non-polar and thus exhibits an affinity for non-polar molecules; however, in activated carbon some carbon-oxygen complexes are present which provide a slightly polar surface and allow adsorption of polar compounds. Activated carbon is a poor adsorbent for inorganic electrolytes, but due to its large surface area per gram it will adsorb aromatic and unsaturated aliphatic compounds.

#### Surface Area

If the chemical nature of the surface is considered to play a secondary role in adsorption, then the adsorptive properties of activated carbon can be attributed to surface area and pore structure (10). The major portion of surface area is contributed by pores of molecular dimensions. Because of the spatial arrangement of atoms within molecules it seems reasonable that a molecule will not penetrate into a pore smaller than a certain critical size and will be excluded from pores smaller than this; hence, the molecules are "screened out" by pores smaller than a diameter which is a characteristic of the adsorbate.

The competition of large and small molecules for adsorbent surface is not complicated by the blocking of pores by large molecules

due to the irregular shape of both pores and molecules and constant molecular motion. The greater mobility of the smaller molecule allows it to diffuse ahead of the large molecule and penetrate the fine pores first.

### Service Time Relationship

Service time of a carbon bed can be defined as the period of time an influent stream of concentration,  $c_o$ , can be passed through the carbon bed at a given hydraulic loading without the effluent concentration,  $c$ , becoming equal to  $c_o$ . The Bohart-Adams equation (2) is expressed as

$$\ln (c_o/c - 1) = \ln (e^{kN_o x/v} - 1) - kc_o t \quad (1.)$$

where  $c_o$  and  $c$  are the influent and effluent concentration of adsorbate, respectively. The material to be removed may exert BOD and COD or contain organic carbon or some other constituent. The concentration is expressed in lbs of material per  $\text{ft}^3$  of liquid. The  $k$  term is the reaction rate constant with units of  $1/\text{hr}$ ,  $N_o$  is the adsorptive capacity of the carbon expressed as lbs of material removed per  $\text{ft}^3$  of carbon,  $x$  is the depth of the carbon bed in feet,  $v$  is the linear flow rate of the adsorption wave in  $\text{ft}/\text{hr}$ , and  $t$  is the service time of the carbon layer in hours. Because  $e^{kN_o x/v}$  is normally much greater than unity, simplification of equation (1.)

yields:

$$t = (N_o / c_o v)(x - v / k N_o (\ln(c_o / c - 1))). \quad (2.)$$

At  $t = 0$  we can solve for the bed depth which is just sufficient to prevent effluent of concentration greater than  $c$ . Solving equation (2.) for the critical bed depth,  $X_o$ , yields:

$$x_o = (v / k N_o)(\ln(c_o / c - 1)) \quad (3.)$$

The adsorptive capacity can be determined directly from the slope of service time versus bed depth plots and the rate constant,  $k$ , may be determined from the value of the intercept of the straight line portion of the plot. Figure 1 shows a plot of this type. The slope of the line is equal to  $N_o / c_o v$ , the intercept value on the ordinate is equal to  $1 / k c_o (\ln(c_o / c - 1))$ , and the intercept on the abscissa,  $x_o$ , is the critical bed depth. If the velocity of the adsorption wave through the carbon column is determined and the concentration of the adsorbate is known then constants in the two expressions may be determined.

#### Application to Domestic Waste Treatment

The use of adsorption as a process for treatment of waste water is dependent upon the kinetics of adsorption. Adsorption of the pollutants in a waste water must occur within a practical time of contact. A second requirement is that the adsorbent has a large capability for

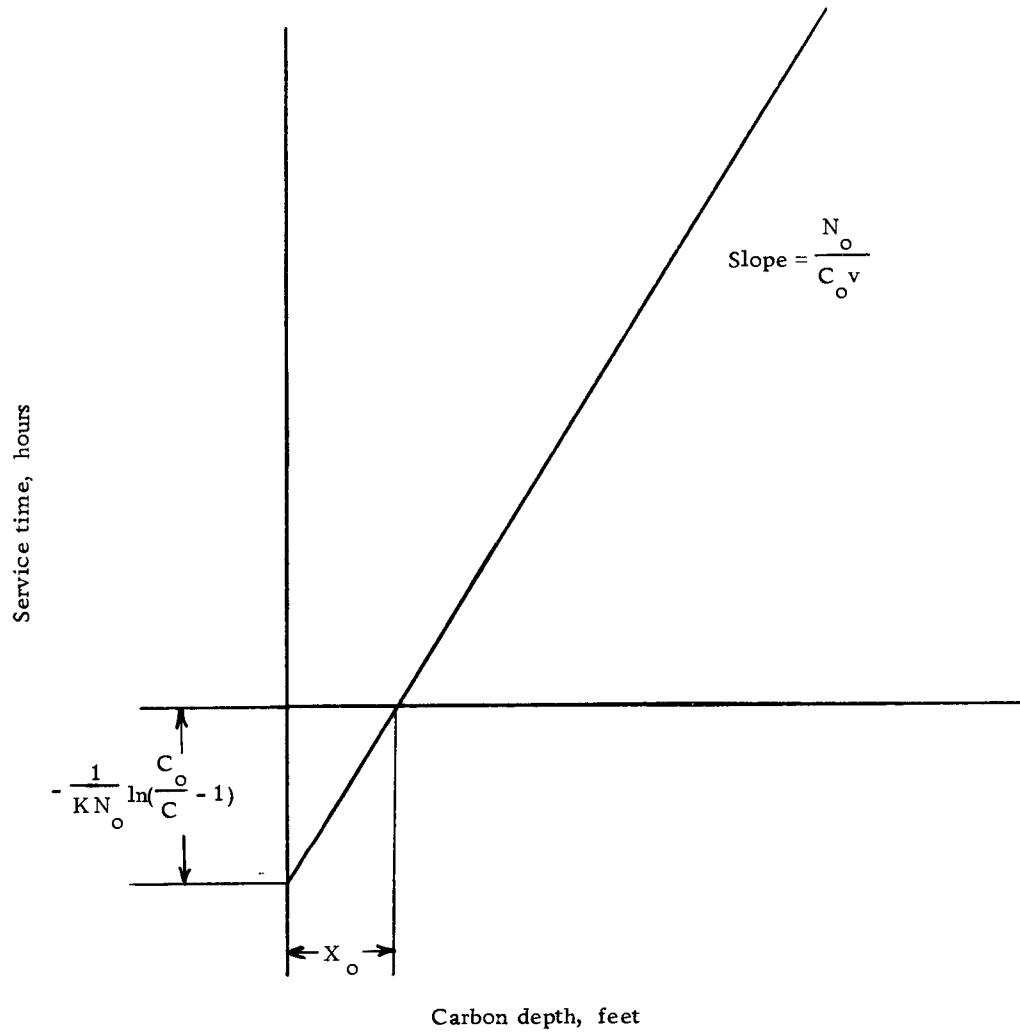


Figure 1. Service time relationship.

removing adsorbate from solution. The rate of removal dictates the contact time required. The capacity of the adsorbent for adsorbate molecules determines the useful life of the carbon.

Activated carbon is presently the most widely used adsorbent because a variety of molecules are attracted to its surface and because it has a large adsorptive capacity. As stated earlier the usefulness of activated carbon in removing pollutants from secondary sewage effluents has been demonstrated. In studies conducted at the South Lake Tahoe Public Utility District treatment plant Culp and Slechta (5) report granular activated carbon columns consistently produced an effluent of good quality. Their carbon column studies show that hydraulic loading in the range of 4.0 to 6.5 gpm/ft<sup>2</sup> did not affect the capacity or performance of the carbon at a given contact time.

## EXPERIMENTAL PROCEDURES

The facilities at the Water Demonstration Laboratory located next to the Corvallis Sewage Treatment Plant were used in this study. Pumps located at various points throughout the treatment plant provided a constant waste flow of 10 gpm thus insuring a supply of fresh sewage at all times. Primary clarifier effluent was used as influent to the activated sludge pilot plant used in this study.

### Experimental Plan

The operational plan shown in Table 1 outlines the conditions for the activated sludge system for the three aeration tank detention times. The detention time is the time for the contents of the aeration tank to be replaced by flow into the tank. The flow into the tank includes both the influent and the sludge return flow.

Table 1. Operational plan.

Detention time (hrs.)	Influent flow rate (gpm)	Return sludge ratio (%)	MLSS (mg/l)	Settling time (hrs.)
3	6.4	0.25	2000	0.80
5	4.0	0.25	2000	1.36
10	2.0	0.25	2000	3.58

### Apparatus

The treatment system consisted of an aeration tank, settling tank, sand filter, and carbon column. The aerator was a circular tank with a volume of 1500 gallons. The air entered through a circular sparger ring below a rotating turbine blade which sheared the bubbles to provide better transfer of oxygen to the liquid.

The settling tank consisted of a circular tank with a notched weir around the periphery and equipped with a scraper located on the bottom to move sludge to a return pump intake. The volume of the settling tank was 400 gallons.

The sand column, made of 5.5 in I.D. acrylic tube, filled with 40 in of sand with an effective size of 0.50 mm and a uniformity coefficient of 1.55 was used to remove the particulate matter in the activated sludge effluent.

The carbon column was constructed of a 2.44 in I.D. stainless steel tube with 5/16 in sample ports located every 6 in along the column. The column was filled with 52 in of Calgon Filtrasorb Type 300, 8 × 30 mesh carbon. The weight of this amount of carbon is 4.5 lbs. A flow diagram of the system is shown in Figure 2.

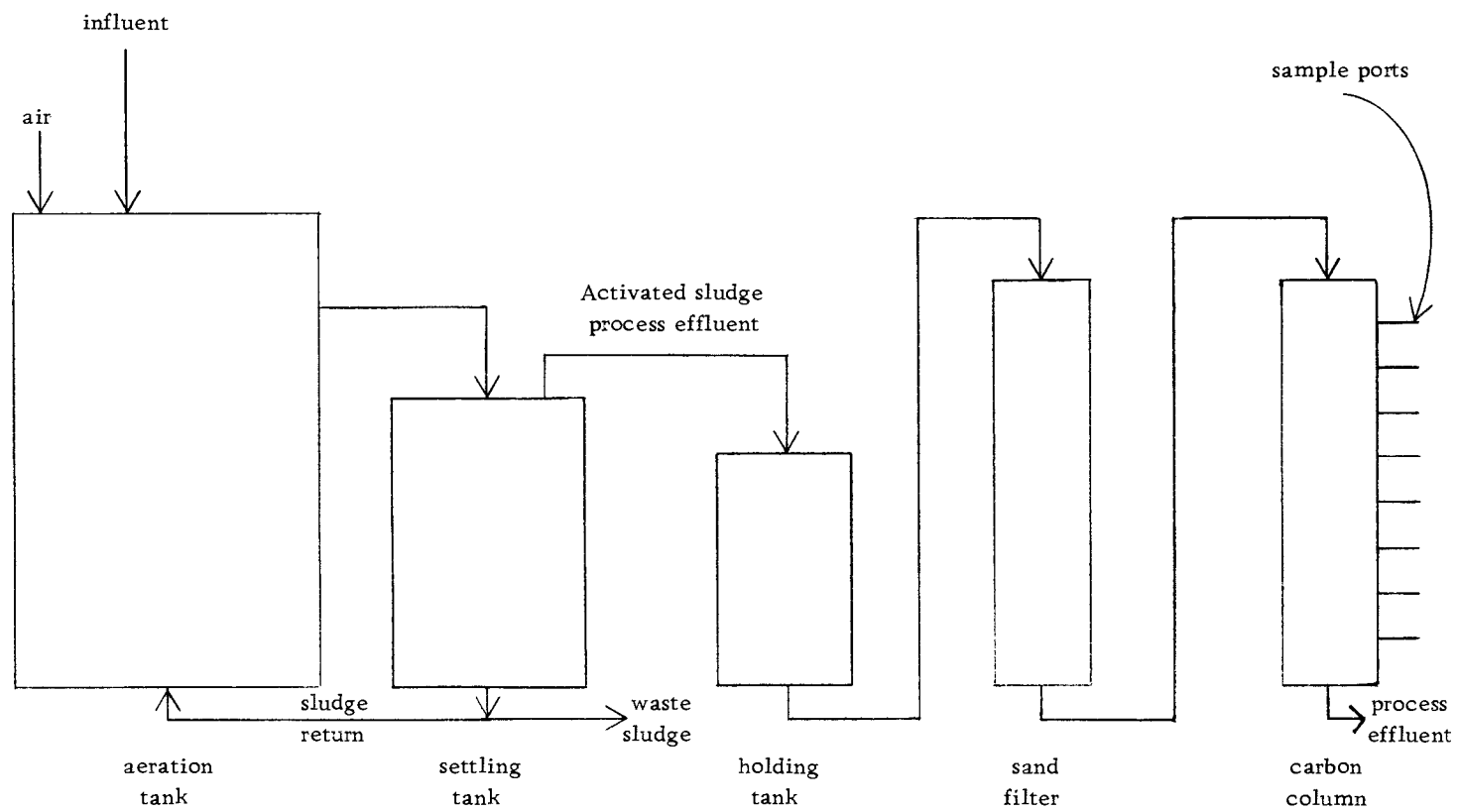


Figure 2. System flow diagram.



### Procedure

The activated sludge process was operated at each of the detention times for one week to bring the system to equilibrium before beginning a test run for any particular detention time. The effluent was filtered through the sand to remove the particulate matter which is carried over from the settling unit. The flow rate was adjusted to provide a hydraulic loading of  $4 \text{ gpm/ft}^2$  on the carbon column and maintained by a variable head standpipe fed by a positive displacement pump. Operation at the resulting hydraulic loading on the sand filter ( $0.77 \text{ gpm/ft}^2$ ) required backwashing of the sand filter approximately every 12 hours.

Periodically 24 hour composite samples of the influent, activated sludge process effluent, sand filter effluent, and carbon column effluent were collected for BOD, COD, suspended solids, and color analysis. Grab samples were obtained from the sample ports of the carbon column to follow the movement of the adsorption wave through the carbon column.

### Analytical Method

The procedures used in performing the BOD, COD, suspended solid, and color analyses are outlined in Standard Methods for the Examination of Water and Waste Water (1). The dilution technique

using four nutrient salts in seeded dilution water was used to determine BOD values. The potassium dichromate reflux method for industrial wastewater was used to determine the COD values of the samples. The potassium chloroplatinate color standards for water examination were prepared to determine the apparent color of the influent and effluent of the carbon column.

The TOC analysis was used as an indicator of the carbonaceous material present before and after treatment with carbon. The TOC was also used to follow the movement of the adsorption wave through the carbon column by performing TOC analysis on samples collected from the sample ports. The Beckman Carbonaceous Analyzer was used in determining the TOC. The system consists of a Beckman Model IR-315 Infrared Analyzer, a Leeds and Northrup Type "H" Model "S" Strip Chart Recorder and a special sampling system.

The Carbon Analyzer operates on the principle that heated oxygen, in the presence of a proper catalyst, will oxidize any organic material to yield an amount of carbon dioxide. An accurately measured volume of sample is injected into the combustion chamber through the sample port with a hypodermic syringe. The combustion tube, packed with a cobalt oxide impregnated asbestos packing to disperse the sample and catalyze oxidation, is heated to 950°C and swept with a continuous stream of oxygen. The heated oxygen oxidizes any organic material contained in the sample to produce an

amount of carbon dioxide proportional to the carbon present in the sample. The infrared analyzer detects the carbon dioxide and the recorder registers the output signal and records the peak on a chart.

A calibration curve was prepared using carbon standard solutions prepared from sodium oxalate. Each time samples were tested the calibration of the analyzer was checked against the standards.

The samples were prepared for use in the carbon analyzer by filtration through 0.45 micron Millipore filters. The filtrate was acidified to pH 2 and aerated with carbon dioxide free air to remove the carbonate carbon from solution before injection into the carbon analyzer.

## RESULTS OF RESEARCH

An effective means of treating domestic sewage was demonstrated by a combination of two processes; a biological treatment process and a physical treatment process. Biological treatment of domestic sewage by the activated sludge process was followed by sand filtration and carbon adsorption.

### Operational Control

#### Activated Sludge Process

The activated sludge process operates on the basis of aeration of the liquid waste in the presence of biological flocs. As these flocs are acclimated to the waste material a population of organisms which are most efficient in degrading the waste predominates. The biological population will utilize organic material which is present to obtain energy and to synthesize new cells while reducing the organic material to more simple compounds and end products such as carbon dioxide and water. Cell synthesis causes an increase in the MLSS present in the aeration tank. At equilibrium conditions the MLSS concentration will remain constant with the mass of cells created in synthesis equalling the mass of cells wasted in the sludge wasting system or activated sludge process effluent stream whichever the

case may be.

In this study a program of sludge wasting was carried out in an effort to minimize the sludge lost in the effluent. The process was operated so as to maintain the MLSS as near 2000 mg/l as possible. Figure 3 shows that the MLSS were held relatively close to 2000 mg/l during operation of the activated sludge process. The period of time the carbon column was operated at each detention time is also shown.

The Sludge Volume Index (SVI) is characteristic of the settleability of an activated sludge. High values of the SVI (greater than 150) usually indicate a poor settling sludge as well as poor activated sludge process operation. Low values of the SVI are characteristic of good activated sludge process operation.

The activated sludge process effluent was good at three hours detention time despite the high values of SVI shown in Figure 4. The poor settling characteristics at this detention time were caused in part by the variable nature of the organic loading due to periods of dilution of domestic sewage by stormwater flow in the combined sewerage system. This problem was compounded by the short settling time in the settling tank. The sludge blanket trapped solids particles; therefore, a low suspended solids concentration in the activated sludge process effluent was noted.

No problems with the operation of the settling tank were noted

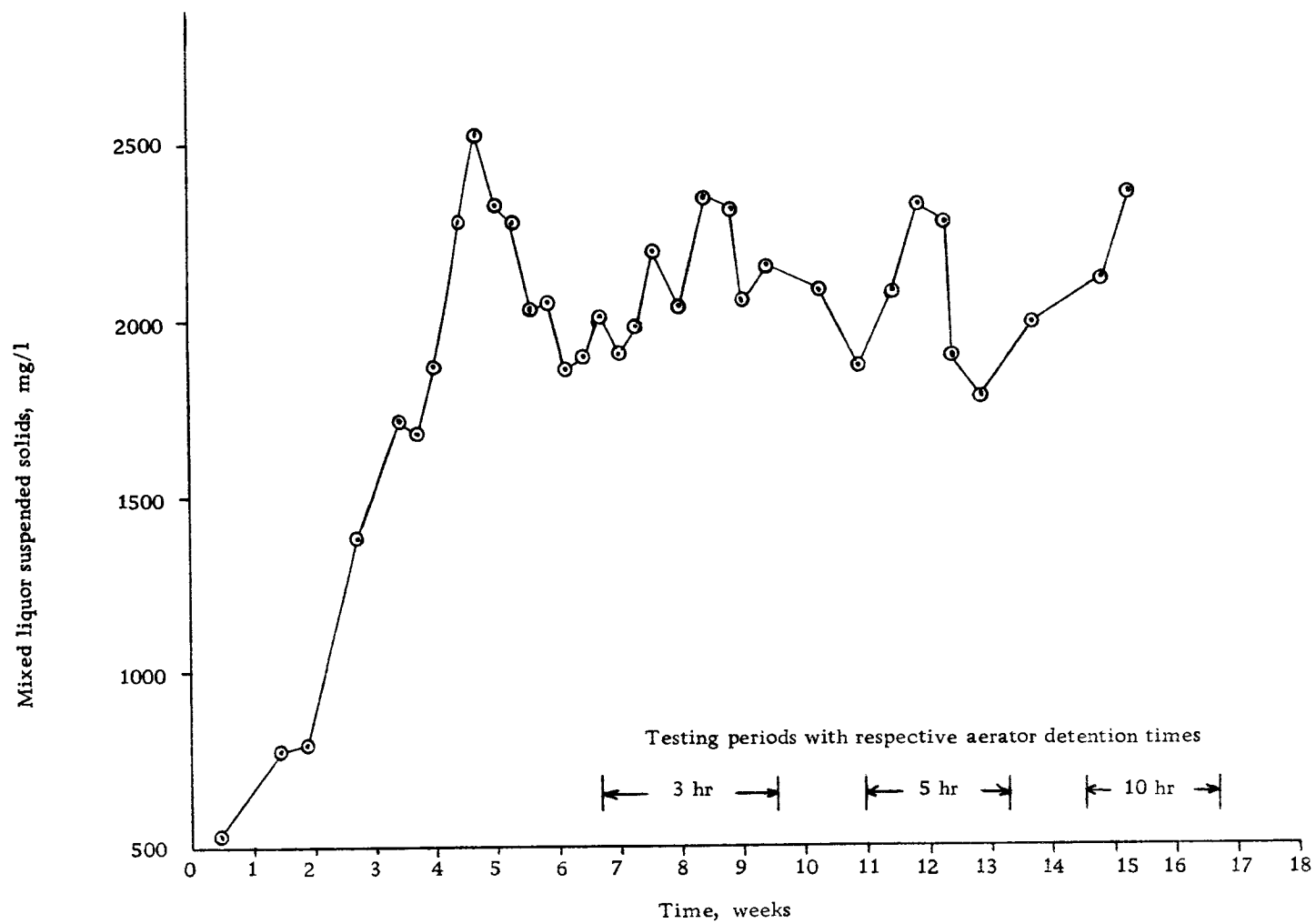


Figure 3. Mixed liquor suspended solids during test period.

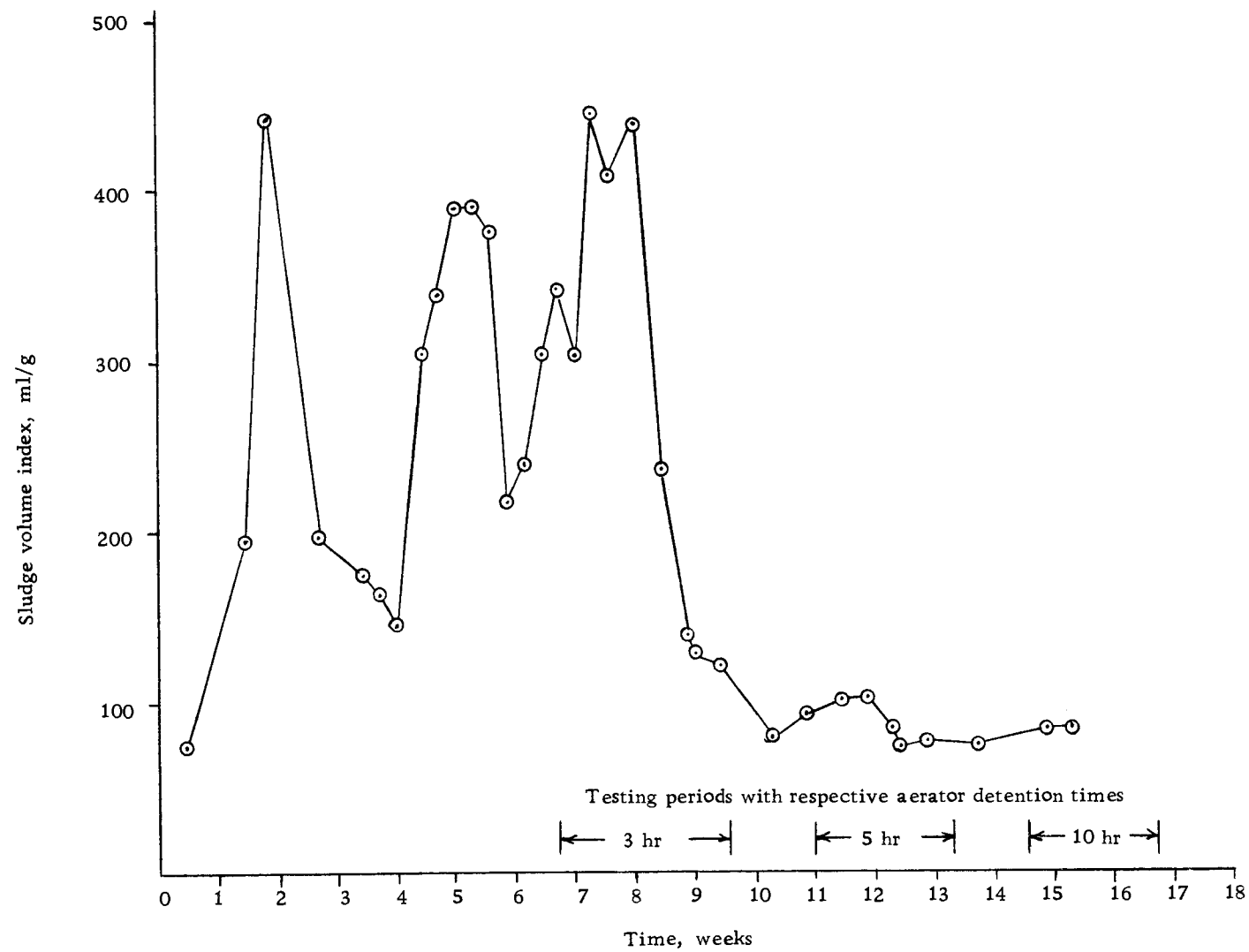


Figure 4. Sludge volume index during test period.

at a detention time of five or ten hours except that the sludge return ratio was adjusted to 0.50 to prevent anaerobic conditions from developing in the settling tank.

### Sand Filtration

The physical process of sand filtration was used to remove suspended solids from the activated sludge process effluent in order to prevent fouling of the activated carbon bed. When the head loss increase through the sand filter caused the variable head standpipe to overflow backwashing of the filter was necessary. A head loss of about eight feet was required to cause the standpipe to overflow. Backwashing of the sand filter was necessary approximately every 12 hours. A positive displacement pump fed activated sludge process effluent to the standpipe; therefore, the hydraulic loading to the sand filter did not vary until head loss buildup caused water to overflow the standpipe.

### Carbon Adsorption

The activated carbon adsorption column was operated at a hydraulic loading of  $4.0 \text{ gpm/ft}^2$ . A flow rate of 0.12 gpm provided this loading for the column used in this study. After every backwashing of the sand filter the flow rate was adjusted to 0.12 gpm. Occasionally the flow rate was also checked before backwashing and in no



case was the flow rate more than ten percent less than that desired.

The time the waste water was in contact with the activated carbon was determined using a salt tracer technique. A sample of sodium chloride salt solution was injected at the top of the carbon column. Samples of the carbon column effluent were analyzed for the chloride concentration by the Mohr titration method (1). The time between injection of the sample of sodium chloride solution and the appearance of the maximum chloride concentration in the carbon column effluent is termed as the contact time. At a hydraulic loading of  $4.0 \text{ gpm/ft}^2$  a maximum chloride concentration of 545 mg/l appeared seven minutes after the injection of the sodium chloride solution into the carbon adsorption column as shown in Figure 5.

### Treatment Results

The treatment of domestic waste has been separated into three process units in this study. Biological treatment is carried out in an activated sludge process. Following biological treatment a sand filtration process removes suspended material. Finally carbon adsorption removes dissolved organic compounds from the waste. The analytical data obtained and relationships developed for each process will be discussed in the order of treatment. Analytical data for 24 hour composite samples are presented in Table 2. Table 3 presents a summary of the treatment efficiencies for each process at

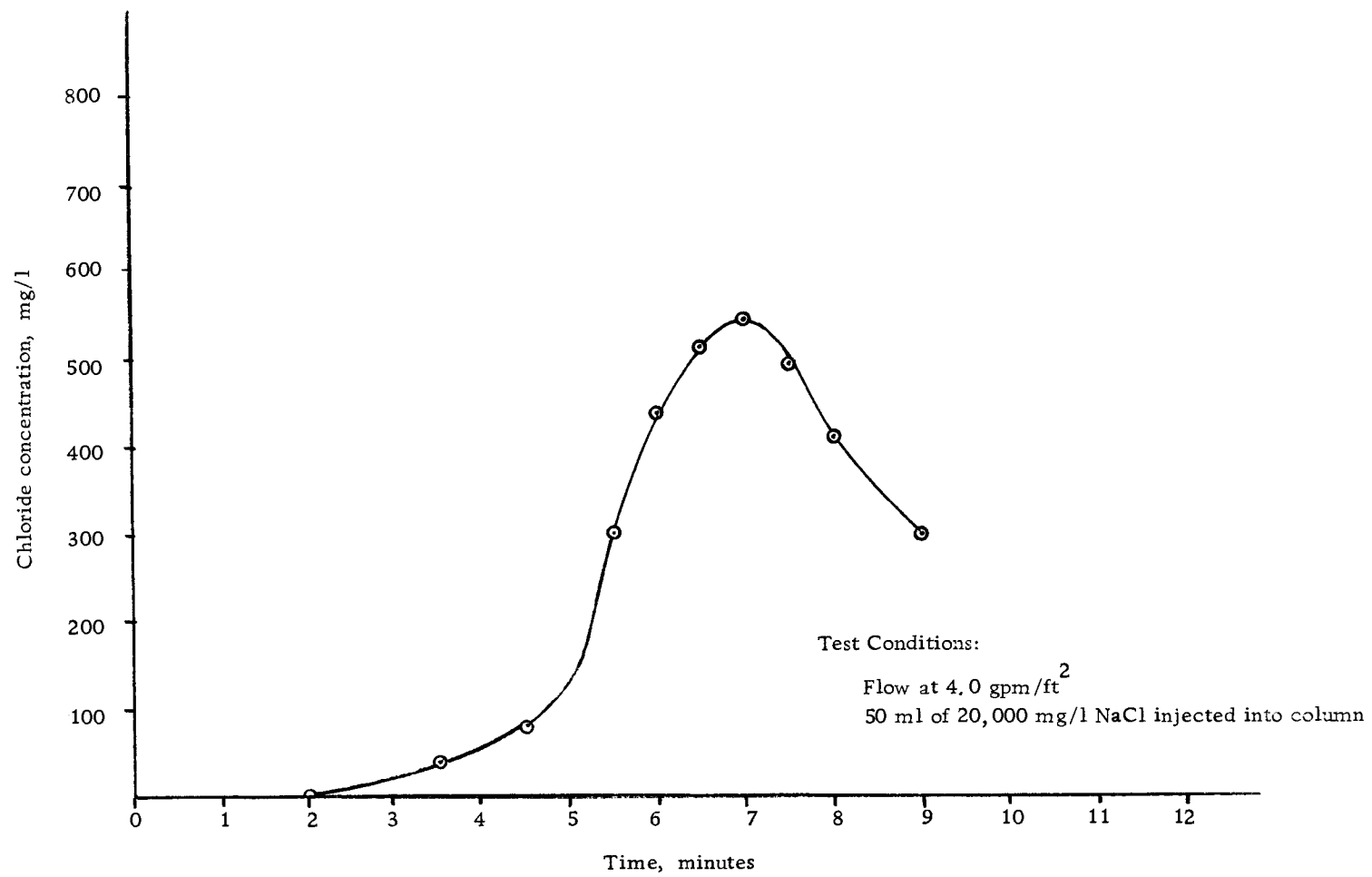


Figure 5. Carbon column contact time.

Table 2. 24 hour composite sample data. All values recorded in mg/l.

Sample number	A. S. Influent			A. S. Effluent				Sand Effluent					Carbon Column Effluent				
	BOD	COD	TOC	BOD	COD	TOC	SS	BOD	COD	TOC	SS	COLOR	BOD	COD	TOC	SS	COLOR
<u>3 hour detention time</u>																	
1	36	110	16	6	26	5	9	2	19	4	6	-	1	11	2	6	-
2	30	105	13	13	67	8	0	5	54	8	0	15	3	20	5	0	0
3	50	140	23	8	41	7	0	4	34	7	0	10	3	14	2	0	1
4	10	63	8	5	44	7	0	2	39	7	0	10	1	39	5	0	5
<u>5 hour detention time</u>																	
5	-	-	9	-	-	7	-	-	-	6	-	-	-	-	2	-	-
6	55	134	35	20	45	8	50	4	33	8	1	10	3	22	4	1	0
7	20	88	26	8	55	8	13	3	33	8	3	10	2	22	5	1	0
8	62	110	21	17	55	6	28	3	33	6	14	10	2	22	4	5	0
<u>10 hour detention time</u>																	
9	60	127	14	18	63	9	23	4	42	9	1	10	2	16	4	1	0
10	45	69	10	14	37	5	18	1	21	5	2	10	1	11	2	1	0
11	69	180	31	10	37	6	16	2	27	5	2	10	1	11	3	1	0
12	30	80	10	13	48	6	15	2	37	6	2	5	1	5	3	1	0

Table 3. Summary of treatment efficiency. All values recorded in percent.

Sample number	Activated Sludge			Sand Filtration			Activated Carbon			Total Removal		
	BOD	COD	TOC	BOD	COD	TOC	BOD	COD	TOC	BOD	COD	TOC
<u>3 hour detention time</u>												
1	83	78	69	67	27	20	50	50	50	97	90	88
2	57	36	38	61	19	0	40	63	37	87	81	61
3	84	71	69	50	17	0	25	59	71	94	90	91
4	50	30	12	60	11	0	50	0	29	90	38	37
<u>5 hour detention time</u>												
5	-	-	22	-	-	14	-	-	66	-	-	78
6	64	66	80	80	27	0	25	33	50	94	84	89
7	60	37	69	62	40	0	33	33	37	90	75	81
8	72	50	71	82	40	0	33	33	17	97	80	81
<u>10 hour detention time</u>												
9	70	50	28	78	33	0	50	62	55	97	87	72
10	69	47	30	93	43	0	0	48	60	98	84	80
11	85	79	80	80	27	17	50	59	40	98	94	90
12	57	40	40	85	23	0	50	86	50	98	94	70

the three detention times investigated.

### Activated Sludge

The BOD removal efficiency for the activated sludge process varied from 50 to 85 percent and COD removal ranged from 30 to 79 percent for the three detention times investigated. The TOC removal varied from 12 to 80 percent for the various detention times studied. Table 4 presents supporting BOD data obtained from the Corvallis Sewage Treatment Plant operating data. From this data the variable nature of the organic loading to the activated sludge process can be appreciated because the primary clarifier effluent BOD ranges from a low of 10 mg/l to a high of 120 mg/l.

The BOD-COD relationship for the activated sludge process influent and effluent is shown in Figure 6. The curves were fit to the data using a least squares analysis. The intersection of the curve with the ordinate indicates the presence of some non-biodegradable material. If the presence of the non-biodegradable material is neglected and attention is given to the slope of the two curves a difference in slope between the activated sludge influent and effluent curves is noted. The slope of the activated sludge influent curve is 1.43 and the slope of the effluent curve is 1.11. The biological treatment process has changed the characteristics of the waste material and the presence of biological solids in the activated sludge process

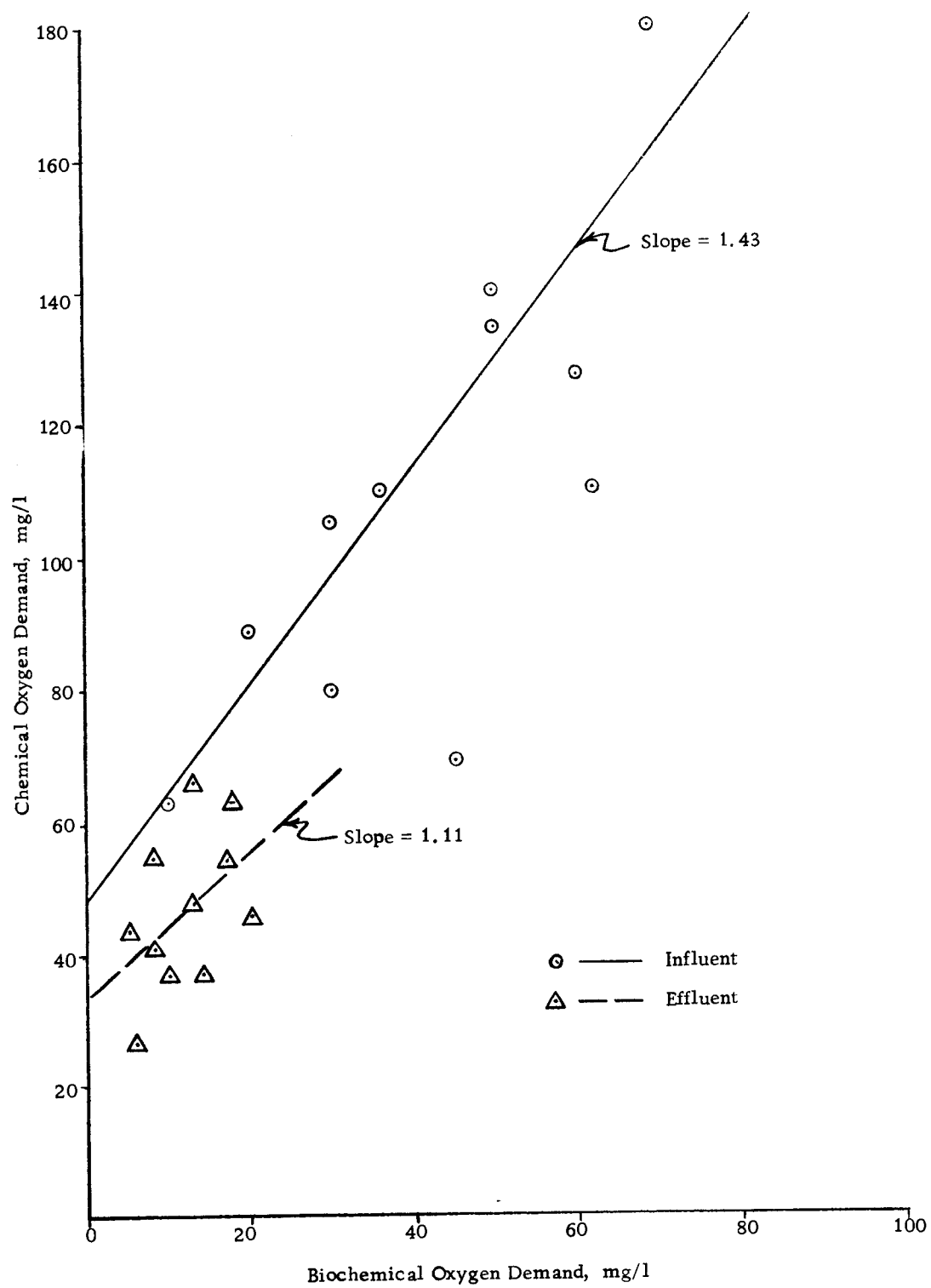


Figure 6. Comparison of BOD with COD for activated sludge process.

effluent explains the decrease in the slope of the curve. These biological solids exert a considerable BOD if they are not effectively removed in the sedimentation process.

Table 4. Corvallis sewage treatment plant data.

Sample week	Primary clarifier effluent BOD, mg/l
2	65
2	56
3	30
3	42
4	18
4	55
5	113
6	18
7	-
8	56
9	30
9	10
10	78
11	98
12	72
12	54
13	42
13	54
14	69
14	80
15	120
15	70

#### Sand Filtration

Sand filtration of the activated sludge process effluent removed the suspended solids prior to carbon adsorption. The BOD removal

efficiency for the sand filtration process varied from 50 to 93 percent and COD removal ranged from 11 to 43 percent for the detention times investigated. A negligible amount of TOC was removed by the sand filtration process. Figure 7 compares the BOD-COD relationship for the activated sludge process effluent and the sand filter effluent. The slope of the sand filter influent curve is 1.11 and the slope of the sand filter effluent curve is 6.49. This increase in the slope is due to the removal of biodegradable suspended solids by the sand filtration process.

#### Carbon Adsorption

The dissolved organic materials which were removed by the carbon adsorption column caused a BOD reduction which varied from 25 to 50 percent and the COD removal efficiency ranged from 33 to 86 percent for the detention times studied. In one case no BOD removal was noted and in another instance no COD removal was determined. The BOD values were very low at this time and the sensitivity of the BOD test was not great enough at this level to detect any reduction. For the sample in which no COD reduction was noted a very turbid water was being treated as a result of stormwater in the sewers at that time. A comparison of the BOD-COD relationship is shown in Figure 8 for the activated carbon column. The slope of the carbon column influent curve is 6.49 and the slope of the activated



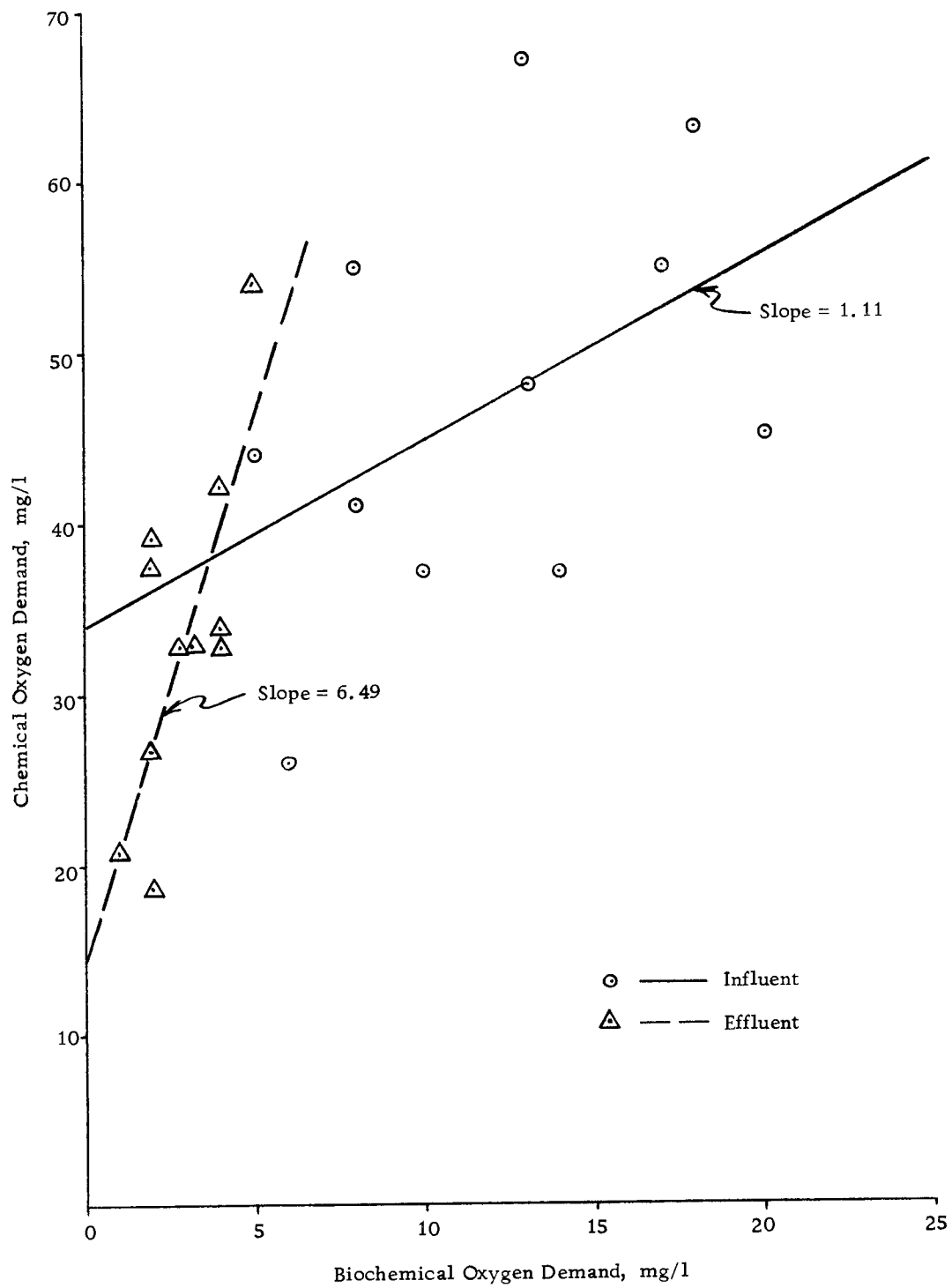


Figure 7. Comparison of BOD with COD for sand filtration process.

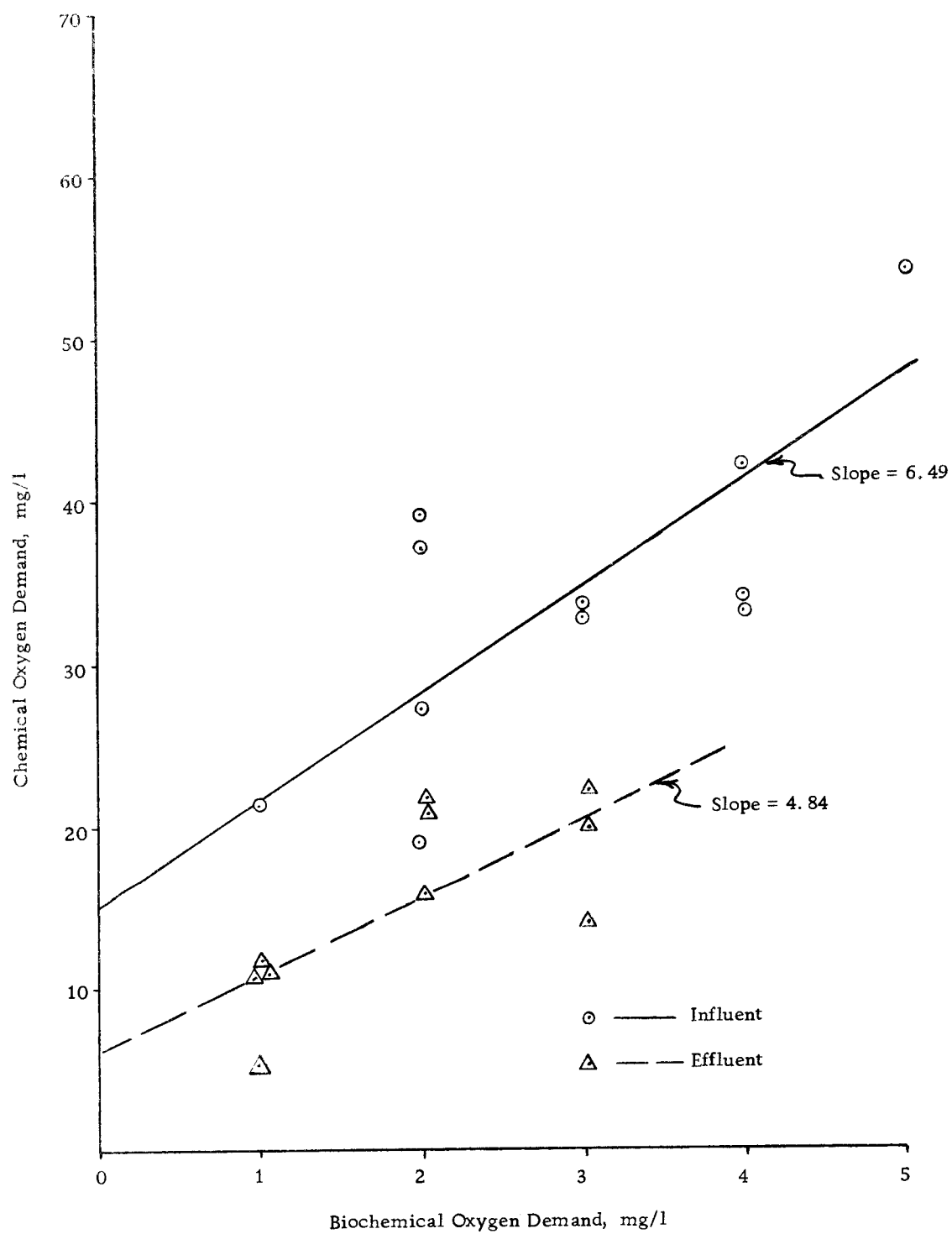


Figure 8. Comparison of BOD with COD for carbon adsorption column.

carbon effluent curve is 4.84. The reduction in the slope in this case is probably due to a greater portion of the non-biodegradable material rather than biodegradable material being adsorbed by the activated carbon adsorption bed.

As additional information on the characteristics of the carbon column was desired ultimate BOD values were determined for samples collected from the sample ports of the carbon column. Table 5 presents these values obtained for samples taken at three and five hours detention time in the aeration tank. The ultimate BOD is approximated by the biochemical oxygen demand exerted in 20 days. The ultimate BOD values were determined using the direct method because the oxygen demand was very low. The procedure followed was to wash the BOD bottles in chromic acid cleaning solution to remove any organic material clinging to the sides of the bottles. The bottles were thoroughly rinsed in distilled water and air dried before filling with a sample of waste water. Duplicate initial dissolved oxygen values were determined on the samples. Throughout the 20 day period dissolved oxygen values on single samples were recorded.

A decrease in the ultimate BOD value was observed with increasing depth of the carbon bed. The minimum BOD value was obtained at the last sample port, a depth of 46 inches. An increase of BOD was noted between the last sample port and the carbon column

Table 5. Ultimate BOD for carbon column sample ports.

Port number	BOD exerted on day given, mg/l								
	1	2	3	4	5	7	10	15	20
<u>3 hour detention time</u>									
1	0.90	1.10	1.20	1.55	1.65	2.10	2.80	3.80	4.35
3	1.00	1.20	1.50	1.60	1.80	2.20	2.80	3.60	4.30
5	1.00	1.20	1.35	1.55	1.75	2.20	2.50	3.10	3.85
7	0.20	0.60	0.90	1.05	1.25	1.30	2.00	2.60	3.70
9	0.20	0.30	0.50	0.70	0.70	1.10	1.50	2.20	2.30
Eff.	0.30	0.80	0.95	1.35	1.35	1.80	2.30	3.10	3.75
<u>5 hour detention time</u>									
1	1.50	2.35	2.90	3.45	4.20	5.70	-	-	-
3	0.45	1.00	1.70	1.90	2.30	3.70	6.10	-	-
5	0.20	0.60	1.30	1.90	2.60	4.20	5.95	-	-
7	0.35	0.80	1.45	2.00	3.20	4.20	5.75	-	-
9	0.30	0.85	0.95	0.95	1.10	2.15	4.40	-	-
Eff.	0.40	1.65	2.15	2.30	3.00	3.90	5.90	-	-

effluent port. The column was constructed with a single 5/16 inch effluent port in the center of the column rather than with a porous underdrain system. The increase of BOD is probably due to a space around the effluent port which does not have continuous flow through the carbon. Organic material may be trapped in this dead space and subsequently leached into the effluent stream; thus causing an increase in BOD values.

To evaluate the service time of an activated carbon adsorption bed requires the collection of samples throughout the depth of the carbon column after given times of operation. These samples are analyzed for TOC in order to determine the location of the adsorption wave within the carbon column. Table 6 presents the results of these analyses for carbon column operation at the three detention times. The adsorption wave was assumed to be located directly opposite the sample port just above a reduction in TOC. For example, take sample number four. At a carbon depth of 16 inches the TOC was 7 mg/l and at a depth of 22 inches the TOC was 6 mg/l. In this case the adsorption wave was assumed to be 16 inches below the surface of the carbon.

The service time relationship for three, five, and ten hours aerator detention time is shown in Figure 9. A decrease in carbon service time with increasing aerator detention time is readily apparent. The explanation for this phenomenon is not known but the author

Table 6. 1968 total organic carbon data for carbon column, mg/l.

Detention time, hrs	3				5				10			
Sample number	1	2	3	4	5	6	7	8	9	10	11	12
A. S. Inf.	16	13	23	8	9	35	26	21	14	10	31	10
A. S. Eff.	5	8	7	8	7	8	8	6	9	5	6	6
Sand Eff.	4	8	7	7	6	8	8	6	9	5	5	6
<u>Carbon depth</u>												
0 in	2	9	6	7	6	8	8	6	9	5	5	6
4 in	1	8	6	7	5	8	8	6	9	5	5	6
10 in	1	7	6	7	4	7	8	6	7	5	5	6
16 in	-	7	5	7	4	6	7	6	6	5	5	6
22 in	-	7	5	6	3	6	5	5	4	3	5	6
28 in	-	-	4	6	3	6	5	4	4	3	3	4
34 in	-	-	4	6	3	4	5	4	4	3	3	4
40 in	-	-	4	6	2	4	5	4	4	2	3	4
52 in	-	5	2	5	2	4	5	4	4	2	3	4
Service time, hrs	34	193	330	412	45	115	275	345	41	203	292	355

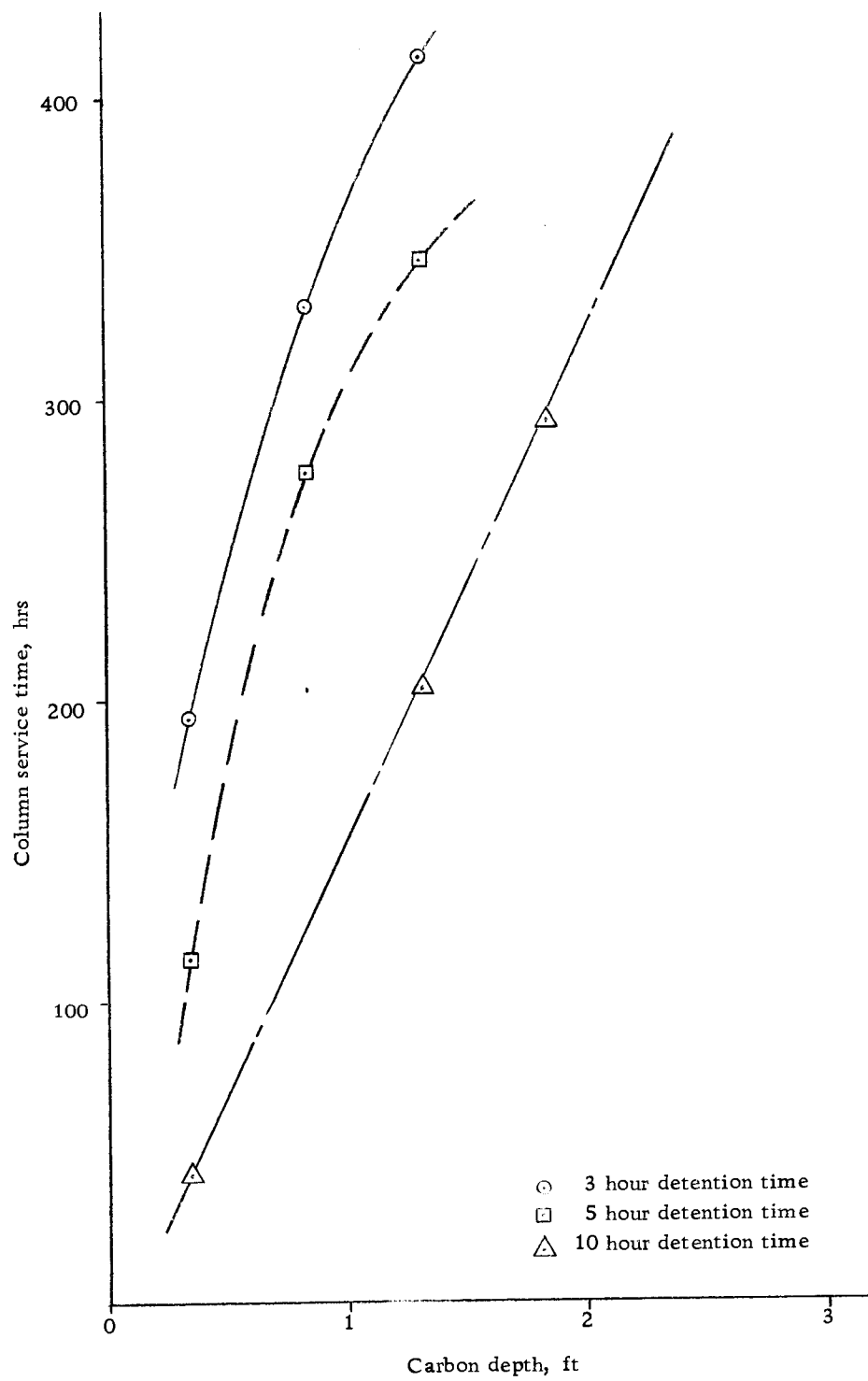


Figure 9. Carbon service time vs. carbon depth.

proposes the following theory which may partially explain this observed characteristic of the activated carbon adsorption bed. Upon biological treatment the large organic molecules are degraded to smaller organic molecules. In some instances several small organic molecules may be formed from a single large organic molecule, especially as the detention time is increased (because more time is thereby allowed for biological degradation of the waste materials). Due to increasing numbers of molecules and perhaps greater adsorptive qualities of the smaller molecules the available adsorption sites may become filled more rapidly when long detention times are used in the activated sludge process rather than when short detention times are employed.



## DISCUSSION

The increasing needs of our growing population for clean water coupled with new water quality standards have placed greater demands on the treatment of waste water. To meet these requirements advanced waste treatment technology must be introduced which will produce water of the desired quality from waste water. The activated sludge process followed by sand filtration and carbon adsorption is an effective method of removing oxygen demanding compounds as well as the color imparted to domestic sewage by organic materials. In this study the BOD removal for the entire process ranged from 87 to 98 percent as the detention time was varied from three to ten hours. The color was reduced by activated carbon adsorption from about ten color units to zero during a contact time of only seven minutes.

The service time relationship obtained from an analysis of the data indicates a general reduction in service time of the activated carbon adsorption bed for increasing detention time in the activated sludge process aeration tank. This suggests carbon adsorption treatment of activated sludge process effluent is most efficient at short detention times.

The TOC remaining in the activated carbon adsorption column effluent shows no significant difference for the three detention times investigated in this research study. TOC values for the activated

carbon column effluent are shown in Table 6 and are listed as the sample taken at a carbon depth of 52 inches. From this consideration alone no particular advantage in the carbon adsorption column operation is gained by operating the activated sludge process at any certain detention time.

## CONCLUSIONS

As a result of this research study the following conclusions are made:

1. Direct filtration of an activated sludge process effluent at low hydraulic loadings provides adequate particulate matter removal to prevent fouling of the activated carbon beds.
2. The BOD removal by sand filtration-activated carbon adsorption varies between 75 and 92 percent when aerator detention time is varied from three to ten hours.
3. The service time of an activated carbon adsorption bed is decreased as the activated sludge process aerator detention time is increased.

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