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Removal of Powdered Activated Carbon from Water by Foam Separation

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Abstract

Foam separation was investigated as a possible method for removal of powdered activated carbon from aqueous suspension. Results obtained from the operation of a single stage, continuous flow system indicate that powdered carbon can be removed entirely from water using surfactant dosages as low as 30 mg/l with a hydraulic loading rate of about 1 gal/min/ft^2. Approximately 1% of the influent flow was lost as foam.

INTRODUCTION

An important development in water and wastewater treatment has been the increased interest in the use of activated carbon for removal of organics. The adsorptive properties of activated carbon have been well established for nearly a century; however, limitations have been placed on the use of powdered carbon forms due to the difficulty encountered in separating them from suspension for regeneration. Hence granular forms have been principally used to adsorb organic and inorganic materials, color, and toxic compounds. Powdered carbon is less costly to manufacture, offers more surface area for adsorption, and distributes more easily and uniformly in water, thereby providing greater removals and more rapid equilibrium, but it often cannot compete economically with granular carbon since it cannot be readily regenerated.

In order for powdered activated carbon to become more universally acceptable, better means for removal and regeneration will be necessary. This paper will consider foam separation as one method for recovery of the carbon.

Foam separation is a technique in which bubble adsorption is used as a means of separation. The contaminant in the liquid adsorbs to the surface of a bubble and rises to the surface with the bubble. In general, there are two types of solute systems which lend themselves to foam separation. The first is characterized by solutes which are inherently surface active. Examples of these are proteins, dyes, and detergents. The second class is comprised of those materials which are not naturally surface active, but which may be rendered so through the addition of a surfactant. Powdered activated carbon would be in this latter category.

Foam separation utilizing a surfactant has been used in water treatment. Grieves et al. (*1–5*) have investigated foam separation for clarification of water. Foam separation was initiated by addition of a cationic surfactant (quarternary ammonium salt) which adsorbed at the surfaces of the negatively charged colloidal particles. The particles were then floated to the water surface by use of aeration, with attachment of the particles to diffused or precipitated air bubbles. Using this procedure, the turbidity could be reduced from about 250 Jackson Turbidity Units (JTU) to about 4 JTU. Approximately 2% of the feed water was lost with the foam.

Foam separation of domestic wastewater has also been investigated (*6–9*). Removals of alkyl benzene sulfonate (ABS) and chemical oxygen demand (COD) were generally in the area of 50%.

Past efforts to separate activated carbon from water by foam separation have been limited to batch experiments (*10–12*). These studies did show promise, however. They indicated that at pH 7, carbon in suspension could be reduced from as much as 800 to 24 mg/l in 10 min with the addition of 0.37 m*M* EHDA-Br (ethylhexadecyldimethylammonium bromide), a cationic surfactant.

This report presents results of studies undertaken to determine the feasibility of foam separation for removal of powdered activated carbon from aqueous suspensions. The study was performed using a continuous flow reactor with varying flow rate, air rate, and surfactant feed rate. The principle variables monitored were foam volume, foam surfactant concentration, foam carbon concentration, effluent surfactant concentration, and effluent carbon concentration.

EXPERIMENTAL PROCEDURE

A single-stage, continuous flow foam separation reactor was used in this research. A schematic diagram of the apparatus can be seen in Fig. 1. Compressed air was delivered to the reactor through a pressure regulator, pressure gauge, filter, saturator, and rotameter before being released through a fritted glass sparger at the base of the 10-cm diameter column.

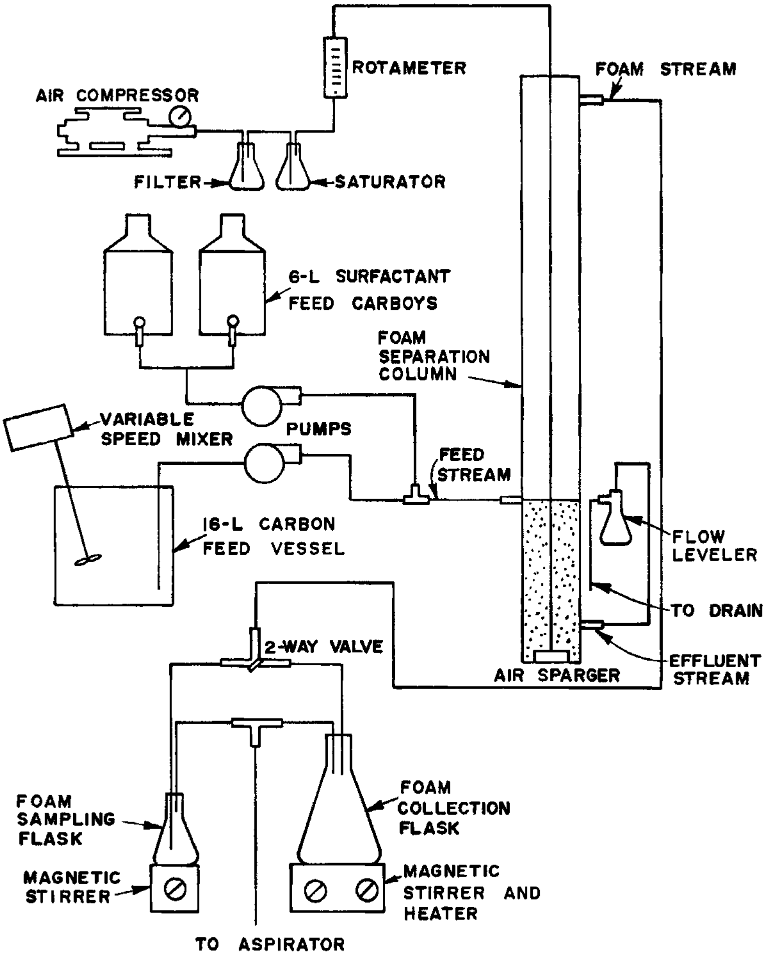

FIG. 1. Foam separation apparatus.

Surfactant was pumped from a 5-liter carboy to a glass T into which a suspension of powdered activated carbon was also pumped. Uniting the solutions in this manner allowed for mixing and a single feed at the foam–liquid interphase of the reactor, located 26 cm above the base. Carbon was kept in suspension prior to pumping by use of a variable speed mixer.

The generated foam was drawn from the column at a height of 100 cm with the aid of an aspirator and collected in an Erlenmeyer flask. Foam breakage was accomplished through stirring and heating. The sampling flask was stirred without heating so as not to alter the chemical nature of the surfactant. Effluent was drawn from the column 5 cm above the base.

DARCO grade S-51 powdered activated carbon was used in this study. Because the surface of powdered carbon is primarily negatively charged, a catonic surfactant, ethylhexadecyldimethylammonium bromide (EHDA-Br), was employed as the foaming agent. Deionized water was used to prevent possible ion interference.

During each of the foaming trials, feed was introduced at the foam–liquid interphase which was maintained at 26 cm from the base of column, and foam was drawn from the column's top port located 100 cm from the base. A carbon feed concentration of 50 mg/l was used in combination with liquid flow rates of 100, 200, and 300 ml/min; surfactant concentrations of 30, 50, and 70 mg/l; and air flow rates of 944, 1416, and 1888 ml/min at a pressure of 3.75 psig. The liquid flow rates correspond to loadings of approximately 0.3, 0.6, and 0.9 gal/min/ft^2, while the air flow rates corresponded to loadings of 0.4, 0.6, and 0.8 scfm/ft^2. Each trial was repeated three times. A more complete description of the experimental procedure can be found elsewhere (*13*).

The reactors were operated for a period of 2 hr to secure equilibrium conditions, after which material from the foam stream and effluent stream were collected. Both samples were then filtered through a glass filter, with the filtrate analyzed by a two-phase titration technique for EHDA-Br developed by Cullum (*14*). The filtered material was placed in a 325°C oven to insure that both surfactant and moisture were driven off. The residue was then weighed to determine the amount of carbon collected.

RESULTS

Table 1 is a compilation of the results obtained. The data presented depict average values for the three replicates performed with each combination of variables. All trials were performed at a carbon feed concentration of 50 mg/l, while surfactant feed concentration (30, 50, and 70 mg/l),

TABLE 1

Foam Separation Data[a]

Influent surfactant (mg/l)	Liquid flow rate (gal/min/ft^2)	Air flow rate (scfm/ft^2)	Effluent carbon (mg/l)	Foam carbon (mg/l)	Effluent surfactant (mg/l)	Foam surfactant (mg/l)	Foam fraction[b] (%)
30	0.3	0.4	0	2610	9.2	1430	1.0
30	0.3	0.6	0	2110	8.6	1150	1.0
30	0.3	0.8	0	1293	12.1	1140	1.0
30	0.6	0.4	0	2758	10.3	1000	1.0
30	0.6	0.6	7	1410	10.4	854	1.3
30	0.6	0.8	0	1160	9.4	720	1.5
30	0.9	0.4	3	1571	13.6	610	1.1
30	0.9	0.6	3	2311	16.6	580	1.9
30	0.9	0.8	3	1350	13.9	540	1.7
50	0.3	0.4	0	990	19.2	696	3.1
50	0.3	0.6	0	356	15.2	532	4.7
50	0.3	0.8	0	490	15.8	535	6.2
50	0.6	0.4	0	1390	26.8	626	1.8
50	0.6	0.6	3	561	22.8	533	2.4
50	0.6	0.8	0	472	18.9	331	6.3
50	0.9	0.4	0	536	30.6	507	2.6
50	0.9	0.6	0	540	25.4	326	4.2
50	0.9	0.8	0	300	26.7	258	5.5
70	0.3	0.4	0	916	28.5	480	6.7
70	0.3	0.6	4	574	27.5	370	6.4
70	0.3	0.8	0	468	26.7	387	12.0
70	0.6	0.4	0	423	44.5	530	3.8
70	0.6	0.6	0	740	38.3	444	4.8
70	0.6	0.8	0	437	39.5	360	5.3
70	0.9	0.4	3	632	49.0	334	3.8
70	0.9	0.6	0	429	44.0	286	5.7
70	0.9	0.8	4	345	44.5	252	6.6

[a] Carbon feed concentration = 50 mg/l.

[b] Foam production expressed as a percentage of influent flow rate.

hydraulic loading rate (0.3, 0.6, and 0.9 gal/min/ft^2) and aeration rate (0.4, 0.6, and 0.8 scfm/ft^2) were varied.

In nearly all cases, no detectable amount of activated carbon could be found in the effluent, indicating that foam separation was very effective in stripping powdered activated carbon from the water.

Statistical analysis of the data indicates that the concentration of surfactant in the effluent is related to the hydraulic loading rate and influent surfactant concentration (multiple correlation coefficient, $r^2 = 0.96$). Figure 2 graphically shows this relationship. It can be seen that the effluent surfactant concentration increases with increasing surfactant feed con-

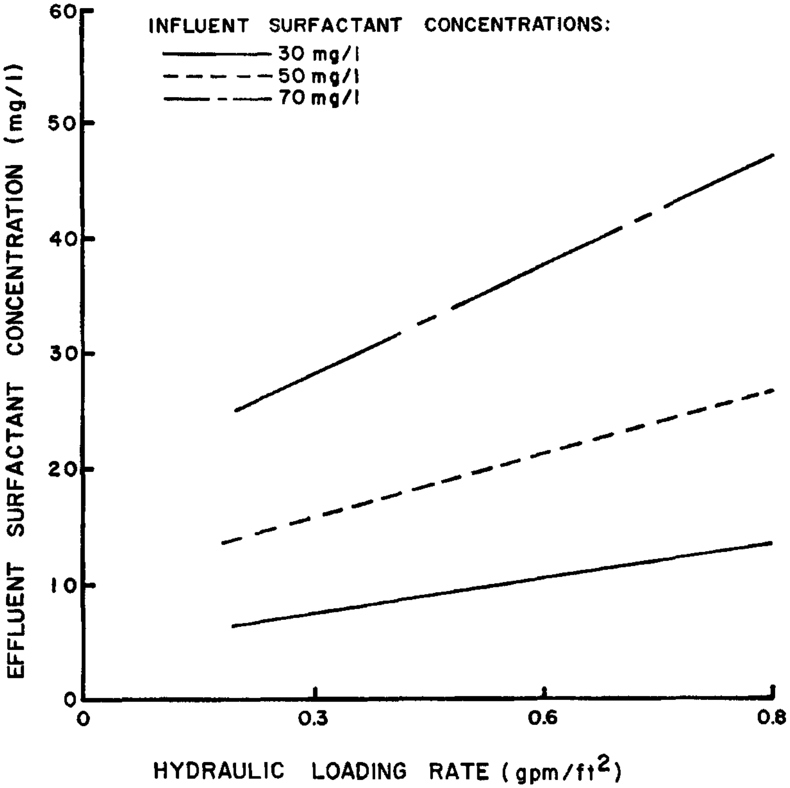

Fig. 2. Effects of hydraulic loading rate and influent surfactant concentration on effluent surfactant concentration.

centration and increasing hydraulic loading rate. Of the variables evaluated, aeration rate had the least effect on effluent surfactant concentration.

Figure 3 illustrates the effect of increasing aeration rate and influent surfactant concentrations on the amount of foam produced ($r^2 = 0.84$). Foam volume produced is expressed as a percentage of the influent flow rate. The percentage of influent flow leaving the reactor as foam increased markedly with increased aeration rate. Obviously, it is desirable to keep the foamate volume to a minimum since this material must be handled further. Lower aeration rates would, therefore, be best with respect to foam volume. Foam volume also increased with increasing surfactant dosage.

The effect of aeration rate on foam surfactant concentration is shown in Fig. 4. This shows that the concentration of surfactant in the foam decreased with increasing aeration rate, while increasing with an increase

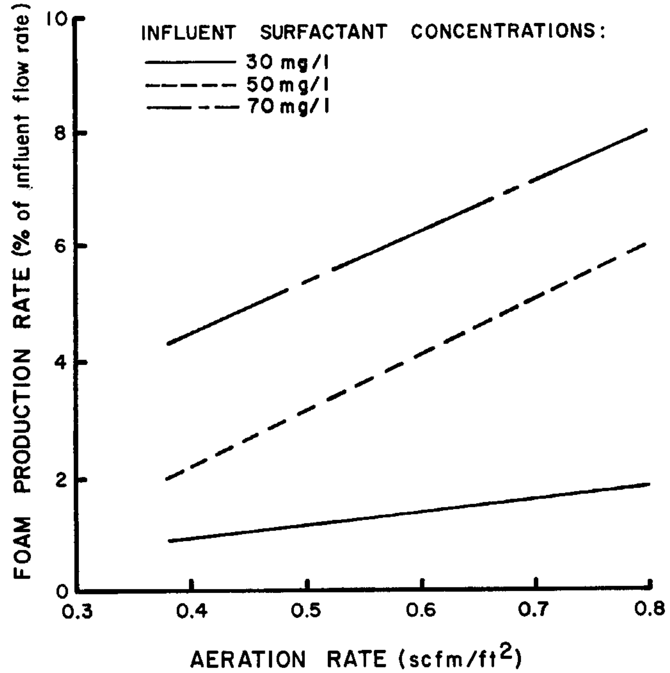

Fig. 3. Effect of aeration rate and influent surfactant concentration on foam production rate.

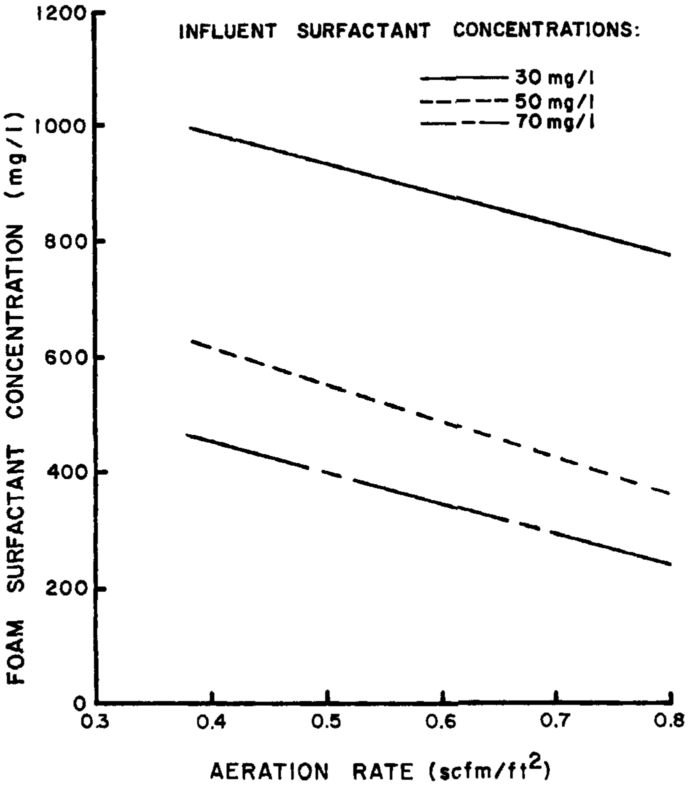

FIG. 4. Effect of aeration rate and influent surfactant concentration on foam surfactant concentration.

in influent surfactant concentration ($r^2 = 0.92$). Figure 5 illustrates that the concentration of activated carbon in the foam also decreased with increasing aeration rate ($r^2 = 0.83$). This is to be expected since the foam volume also increased with increasing aeration rate, thus diluting the surfactant and carbon in the foam.

In essentially all cases, no detectable amount of powdered activated carbon was found in the column effluent. This raised the question of whether a surfactant was even needed. To determine this, an air flotation study was performed. A carbon suspension of 50 mg/l was fed to the column at a loading rate of 0.6 gal/min/ft^2 with an aeration rate of 0.6 scfm/ft^2. Fluid was collected from a port 40 cm from the base (the highest the

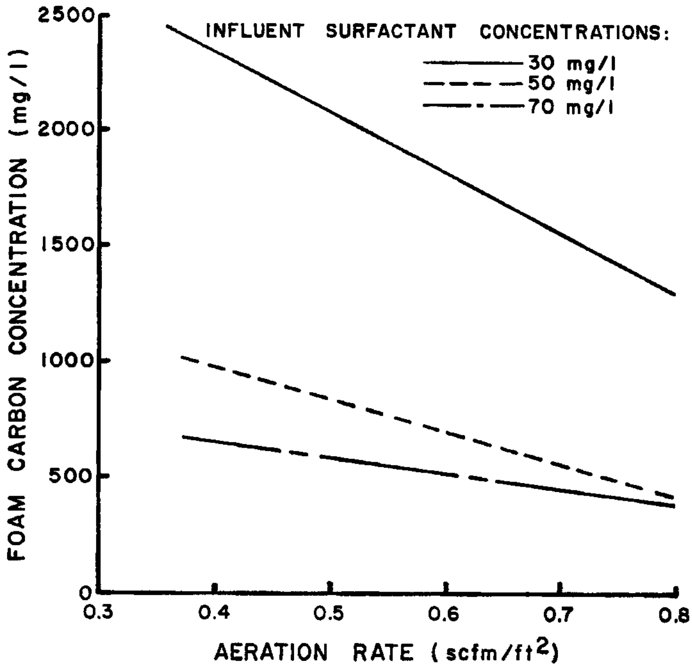

FIG. 5. Effect of aeration rate and influent surfactant concentration on foam carbon concentration.

TABLE 2

Air Flotation Study[a]

Test period (min)	Effluent carbon (mg/l)	Overflow carbon (mg/l)
30	26	34
60	64	28
90	40	38
120	40	26

[a] Hydraulic loading rate = 0.6 gal/min/ft^2
Aeration rate = 0.6 scfm/ft^2 at 3.75 psig
Carbon feed concentration = 50 mg/l
Overflow collected from port 40 cm above base of the column

foam would rise) and at the effluent port. The results of this study are shown in Table 2. Most of the activated carbon remained in the liquid, leaving the reactor with the effluent. The results indicate that a surface-active agent is necessary for satisfactory removal of the activated carbon.

DISCUSSION

Foam separation represents a promising unit operation for removal of powdered activated carbon from water. The process was very efficient with the effluent from the column essentially free of any carbon, even at low surfactant dosage rates. The little carbon that might remain could easily be removed by sand filtration.

As expected, higher aeration rates were more effective in removing surfactant from solution. However, this resulted in a greater amount of foam which would require further treatment. An increase in the surfactant dosage would also result in an increase of the amount of foam recovered. The hydraulic loading rate had little effect on foam formation. By increasing the foamate volume, concentrations of surfactant and carbon in the foam are decreased, thereby making recovery more difficult.

A column height of 100 cm was used in all the studies. A higher foam port could have been used with the higher flow rates and would probably have reduced the volume of foam since there would be a larger degree of foam drainage.

The amount of foam recovered was generally about 1 % of the incoming flow. This is less than the amount of water generally used to backwash a rapid sand filter. Foam carbon concentrations varied depending on operating conditions, but were usually high enough to make recovery feasible. The surfactant should not pose a problem to activated carbon regeneration since it is volatilized at temperatures much below that used for regeneration.

One problem which did arise was the higher than expected concentration of surfactant in the effluent. Concentrations ranged from as low as 6 mg/l to as high as 48 mg/l depending on the hydraulic loading rate and surfactant concentration. Better design of the column should improve the effluent quality considerably. For example, the air sparger did not cover the entire column bottom, resulting in little or no aeration in some areas at the bottom of the column. The effluent port was located in this region so that fluid was collected from a region through which bubbles were not passing. Enlarging the aerator would overcome this problem and probably reduce the effluent surfactant concentration.

Depending on the primary objective of foam separation, different operating conditions would prevail. For example, if activated carbon recovery is the main objective, it would be desirable to have a small foam volume and a high activated carbon concentration. This would require a lower aeration rate and surfactant dosage. However, if the quality of the effluent is the main criteria, it would be desirable to have a higher aeration rate, a lower hydraulic loading rate, and lower surfactant dosage.

CONCLUSIONS

Foam separation processes hold promise for removal of powdered activated carbon from aqueous suspension. Results obtained from operation of a single stage, continuous flow system indicate that powdered carbon is entirely removed from water at surfactant dosages as low as 30 mg/l with detention times as low as 5.9 min and a hydraulic loading of approximately 1 gal/min/ft^2. Under these conditions the ratio of foam volume to incoming flow was approximately 1%. Effluent surfactant concentrations averaged about 6 mg/l.

It was found that foam volume increased and foam carbon concentration decreased with increasing aeration rate and surfactant dosage. Effluent surfactant concentration increased with increasing hydraulic loading rate and influent surfactant dosage.

Addition of a surface-active agent was necessary for adequate removal of carbon from the water. Air flotation alone had little effect on the activated carbon.

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