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WATER CLARIFICATION BY FLOTATION - 2

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A laboratory study of the feasibility of floc flotation.

by

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THE WATER RESEARCH ASSOCIATION

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CONTENTS

1. INTRODUCTION

On the basis of a literature survey (1) it was concluded that the application of dissolved-air flotation to water clarification warranted more detailed investigation. Flotation has potential advantages over sedimentation, particularly for the clarification of waters prone to algal blooms. It is faster than sedimentation and its use could bring savings in the capital cost of new plant. There is also evidence that sludge resulting from flotation has a significantly higher solids content than that from settling tanks.

A number of different types of flotation process are available but dissolved-air flotation appears to be the most suitable for separating the kind of solids involved in water clarification. It can be accomplished without violent agitation which would break up delicate flocs and in contrast to dispersed-air flotation the addition of a surface-active agent (surfactant) is usually unnecessary. The latter is considered a crucial point in the application of flotation to the clarification of water for public supply. Apart from the high cost of surfactants, their addition to water is considered highly undesirable and their removal after treatment would involve further significant cost.

Although there is good evidence that flocculated algae may be separated by flotation, little work has been done previously on other types of floc encountered in water treatment. In the study described in this report a laboratory apparatus for batch dissolved-air flotation tests was constructed and used to demonstrate the feasibility of floating different types of water clarification floc. This work had the further objective of establishing some of the basic conditions necessary for the application of dissolved-air flotation to water clarification.

2. EXPERIMENTAL

2.1. Materials

2.1.1. Coagulants.

1% stock solutions of $Al_2(SO_4)_3\ 16\ H_2O$ and $FeCl_3$ analytical reagent quality, were prepared weekly. 0.05% solutions of the polyacrylamide LT25 (Allied Colloids Manufacturing Co.) were prepared by the method recommended by the manufacturer.

2.1.2. Water samples.

Water of constant composition was required for the preliminary experiments aimed at determining the main factors affecting flotation. For this purpose a 50 mg/litre suspension of kaolin (English Clays Lovering Pochin "Speswhite" grade) in tap water was used. An analysis of the tap water is given in Table 1.

For work on the flotation of different types of natural water, samples were obtained through the courtesy of a number of water undertakings. The tests were carried out as soon as possible after receipt of the samples although delay was inevitable in some cases; the results of analysis of these samples are given in Table 2. In some cases the analysis was limited by the quantity of sample available.

2.1.3. Algal culture.

In addition to samples of natural water containing algal blooms, some work was done on a culture of the green alga Scenedesmus prepared using a CHU 10 culture medium (2). The concentration of the culture was in excess of 10^6 cells/litre and it was diluted with tap water for the purpose of the experimental work.

2.2. Analytical measurements

All samples were well mixed before analysis, colour and turbidity were measured in terms of the optical density (40 mm light path) of samples at 400 and 580 nm respectively. The colour measurement was made after filtration through a 0.45μ pore size membrane filter. The turbidity reading was corrected for colour by deducting the optical density at 580 nm of the solution after filtration. Optical density measurements were made using a Hilger and Watts Spectrochem or Uvispek spectrophotometer. In some of the later work (test series 11 to 15, Table 7) a Hach turbidimeter Model 2100A was used for turbidity measurement. This instrument measures directly in Jackson Turbidity Units.

Algal counts were made using a modified Lund cell by a method developed at the Water Research Association (3). If there was to be any delay in measurement, the samples were treated with a few drops of 1% iodine in 2% potassium iodide (Lugols iodine) to inhibit algal growth.

2.3. Design of bench-scale flotation apparatus

For the purpose of the present work an apparatus was required in which water samples could be treated with a suitable coagulant and agitated gently for floc formation. Provision had to be made for the addition to the water sample of a controlled volume of water saturated under pressure with air, and facilities were required for the collection of samples from the middle and the bottom of the vessel in which flotation was to take place.

Preliminary experiments were made in which floc produced in beakers using a 'jar test' apparatus (4) was floated by the addition of water saturated under pressure with air and contained in a pressure vessel made from a short length of copper pipe. The water was injected into the beaker through a needle valve and a length of small-bore plastic tube. With this crude apparatus it was found that the floc produced by the addition of 30 mg/litre aluminium sulphate to 1 litre of Thames water could be floated by the addition of about 40 ml of distilled water saturated with air at 310 kN/m^2 (45 lb/in.^{2}). It was found to be very important to avoid undue turbulence during the injection of the pressurized water which tended to break up floc and lead to poor flotation. Satisfactory injection could be achieved by passing the pressurized water through a capillary tube directed at the bottom of the beaker.

On the basis of this preliminary work the apparatus illustrated in Fig. 1 was constructed. The flotation vessel was constructed from Perspex, with a capacity of 1.2 litre and a smaller diameter (75 mm) than a conventional coagulation beaker to allow increased retention of liberated air bubbles and good opportunity for bubble/particle contact. Two sampling points were provided, one at the base for sediment collection and one 150 mm from the base for sampling the clarified water. The vessel was provided with a stainless steel paddle driven by a variable-speed electric motor.

The stainless steel pressure vessel was of 1-litre capacity and was filled with 700 ml of distilled water and maintained at an air pressure of 340 kN/m^2 ± 21 kN/m^2 (50 lb/in.^{2} ± 3 lb/in.^{2}). In preliminary tests it was found that unless the water was agitated, a period of several hours was required for the water to become saturated with air at this pressure. The introduction of an electromagnetic stirrer enables saturation to be attained in 15 to 30 minutes. Discharge of the water from the pressure vessel was achieved by activating a timer-controlled, solenoid-operated valve. Air pressure then forced water through the stainless steel capillary tube and into the base of the flotation vessel where dissolved air was released from solution as very small bubbles. The internal diameter and length of the capillary tube, and the time interval for discharge determined the volume of water delivered to the flotation vessel. If the water had fallen below the end of the inlet tube during discharge, an electrical circuit would have been broken, closing the solenoid valve and preventing the delivery of air to the flotation vessel.

The steel capillary tube was connected to the solenoid-operated valve and the flotation vessel by 'Simplifix' fittings and was easily changed. Preliminary tests with a variety of capillaries showed that a bore diameter greater than 0.8 mm caused the pressurized water to enter too rapidly into the flotation vessel leading to floc rupture. A 100 mm length of 0.57 to 0.62 mm-bore tube (20 s.w.g.) was eventually selected because it gave a satisfactory rate of discharge without causing undue turbulence. It also allowed satisfactory control of the quantity of water discharged by means of a 0 to 30-second process timer. The volume of water discharged from the pressure vessel at 340 kN/m^2 (50 lb/in.^{2}) through such a tube for various settings of the timer was measured and a calibration graph plotted.

It was necessary in using this apparatus to assume that the quantity of air used in flotation was directly proportional to the volume of pressurized water discharged. Theoretically, 1 litre of distilled water saturated with air at 340 kN/m^2 (50 lb/in.^{2}) at 20°C should yield approximately 65 ml of air on reducing the pressure to atmospheric. However, the actual quantity of air released could be influenced by a number of factors. To minimize any variation, the conditions used for air saturation and air discharge were kept as constant as possible throughout the present work. Attempts to measure the volume of air released met with no success.

2.4. Test procedure adopted

The pressure vessel was two-thirds filled with distilled water, its lid replaced and securely clamped down. Air, pressurized to 340 kN/m^2 (50 lb/in.^{2}) was then admitted through the needle valve into the vessel, the pressure being maintained throughout the experiments. The magnetic stirrer was started and after a minimum of 15 minutes stirring, several 2 to 3 second discharges were made by activating the timer-controlled solenoid valve. This flooded the solenoid valve and capillary tube, replacing air which, if released after flocculation, would cause floc break-up and interfere with flotation.

800 ml of the water under test were poured into the flotation vessel and a 30-ml sample taken from the middle outlet. The coagulant was added and the solution well mixed by stirring for 1 minute at 100 rev/min. The stirrer speed was then reduced, 5 minutes at 60 rev/min being employed when using ferric chloride as a coagulant or 15 minutes at 25 rev/min when using aluminium sulphate. This difference in stirring conditions was necessary as aluminium sulphate floc systems are weaker and take longer to form than those of ferric chloride.

A controlled discharge of air-saturated water was then made by activating the solenoid valve for a preset time interval. On completion of the discharge, stirring was discontinued to allow flotation to take place. After 10 minutes, 30-ml samples of the clarified water were taken from the middle and base outlets and analyzed. The flotation vessel was then emptied and rinsed out with distilled water. Two further samples of the test water were subjected to the same procedure and a numerical average of the three sets of results calculated.

2.5. Sampling errors

The sampling tubes on the flotation vessel contained a small volume of water which could have been unaffected by the addition of coagulant and air-saturated water, and which could have led to sample contamination. When taking the middle sample this source of error was minimized by running a small volume (10 ml) of water to waste before the sample was collected. With the base sample, the purpose of which was to indicate the presence of sediment after flotation, this was not, however, possible. Further, it was possible that this sample could have included floc particles trapped under the stirrer blades during flotation and released during sampling. Such contamination would have led to high figures for the suspended solids or algal count of the base samples. Because of this, flotation effectiveness may in some cases have been better than indicated by the results presented in this report. The design of the flotation vessel was modified to overcome this defect towards the end of the investigation and the modified vessel was used in test series 11 to 15 (Table 8).

3. RESULTS

3.1. Main factors influencing flotation

Preliminary experiments, aimed at determining the main factors likely to influence flotation were made using suspensions of kaolin in tap water, coagulated with ferric chloride or aluminium sulphate. An analysis of the tap water is given in Table 1. It is a typical chalk borehole water of consistent quality and very low organic content (0.1 to 0.2 mg/litre organic carbon). Kaolin was used because the coagulation behaviour of this clay mineral has been shown to strongly resemble that of the suspended matter in natural waters (5).

In Table 3 the results are given of flotation tests in which the ferric chloride dose was varied. In the last column of the table, the results of an independent series of tests are given in which kaolin suspensions were coagulated under identical conditions to those employed in the flotation tests and then allowed to settle for 10 minutes (i.e. no air was introduced).

The floc produced with 10 mg/litre $FeCl_3$ could not be effectively floated and the turbidity after settling was rather high. With 20 mg/litre $FeCl_3$ a floc was obtained that could be floated, although the high turbidity of the base sample indicated that some settled out. Higher ferric chloride doses led to lower turbidities after flotation or settling. Thus dissolved-air flotation is probably at least as dependent on good floc formation as is settling. Suspensions treated with an inadequate coagulant dose cannot be floated effectively. A good degree of clarification is obtainable with flotation if coagulant doses are used that are sufficient to give good settling. With an adequate coagulant dose, flotation was often complete in about 30 seconds, whereas 10 to 15 minutes were required for a comparable degree of clarity to be achieved by sedimentation.

The results in Table 4 show that for $FeCl_3$/kaolin floc, flotation efficiency is not markedly affected by pH. Similar experiments in which aluminium sulphate was used as the coagulant gave markedly different results. Flotation at pH 7.5 was poor and at pH 6.5 and 8.5 was negligible. Floc formation under the conditions employed (kaolin 50 mg/litre, aluminium sulphate 50 mg/litre) was comparable, however, to that observed with ferric chloride. Flotation was not improved by the use of a polyelectrolyte coagulant aid (e.g. 0.3 mg/litre LT25).

In view of the fact that satisfactory flotation results with aluminium sulphate have been obtained on other waters (Sect. 3.2.) some effort was made to determine the reason for the apparent failure of this coagulant in flotation tests on kaolin suspensions in tap water.

Tests in which the composition of the tap water used in the preparation of the kaolin suspensions was modified by ion-exchange or by the addition of sodium chloride, indicated that the concentration of calcium, sodium and chloride ions in the water had no effect on flotation efficiency after aluminium sulphate coagulation. The addition of 0.3 mg/litre of sodium dodecyl benzene sulphonate however led to a marked improvement in the flotation results (optical density of middle sample 0.095, base sample 0.292) although these were not as good as those obtained using ferric chloride. It is likely, then, that the unsatisfactory results obtained with aluminium sulphate are related in some way to the very low organic content of the tap water used in this work, although this matter has certainly not been resolved completely.

The effect of increasing the clay concentration (Table 5) while the coagulant dose was held constant was a deterioration in flotation efficiency. The satisfactory result obtained with tap water containing no kaolin shows that ferric hydroxide floc itself is easily floated. Some deterioration in the results was evident with 200 mg/litre kaolin even when the quantity of dissolved air injected was doubled (i.e. by doubling the discharge time from 30 to 60 seconds). With 500 mg/litre kaolin the results were very poor indeed even with a 90-second injection of dissolved air.

In Table 6, the effect of the quantity of dissolved air injected (as determined by the discharge time) on the efficiency of flotation of 50 mg/litre and 200 mg/litre kaolin suspensions is shown. In this work it was observed in some experiments that a proportion of the floc settled slowly and then after a few minutes rose to the surface en masse. This 'delayed flotation' often produced good clarification although some sedimentation was evident from the base sample results. It seemed that this phenomenon was associated with the injection of marginally adequate quantities of air.

The results indicate an improvement in clarity as the quantity of dissolved air used is increased. Maximum clarity was obtained for a discharge time of 30 seconds (6.5% v/v) for the 50 mg/litre kaolin suspension and 90 seconds (17.5% v/v) for the 200 mg/litre kaolin suspension. Thus the floc resulting from the coagulation of the more concentrated clay suspension required considerably more air for efficient flotation to occur.

Preliminary experiments had indicated that the best results were obtained by injecting dissolved air after the formation of a good floc. Some further work was done to determine the effect of introducing air at the time of coagulant addition (Table 7). Van Vuuren (6) has emphasized the desirability of air introduction at this stage to ensure its incorporation into the floc structure. The results in Table 7 show however that inferior results were obtained by adding the air either just before or just after the coagulant. To achieve flotation at all under these conditions it was necessary to reduce the period of fast stirring after coagulant addition from 1 minute to 0.5 minutes and the period of slow stirring from 5 to 2 minutes. Very poor results were obtained using the standard conditions of stirring due to the loss of air during floc formation.

The apparent discrepancy between these results and those of van Vuuren is probably due to the fact that the latter based his conclusion on pilot plant continuously treating a very different type of water.

3.2. Flotation of various floc types

In Table 8 the results are summarized of laboratory flotation experiments on a variety of different types of water treated with aluminium and iron coagulants. The analysis of the natural waters studied is given in Table 2.

In test series 1, 2, 3, and 4 samples heavily laden with algae were treated with various coagulants and the floc floated with dissolved air. In all cases flotation was very rapid leading to efficient clarification of the sample. The results for separation of algae varied somewhat but in all cases removal was considerably better than 90%. In test series 1, the removal of algae ranged from 96.2 to 99.2% with aluminium sulphate and from 99.0 to 99.5% with ferric chloride.

In this work the sampling problems referred to in Sect. 2.5. were particularly acute and the results obtained for the base samples are probably not very meaningful although it is apparent that some settling took place. The quantity of sample available was insufficient to enable the coagulation conditions to be optimized, which almost certainly would have led to a considerable improvement of the results.

In test series 5, 6 and 7 samples of Thames river water, in some cases with added clay, were treated with a variety of coagulants. Good clarification was achieved in most cases, although again no attempt was made to optimize coagulation conditions. Flotation was rapid and very little sedimentation occurred. Experiments with soft coloured waters (test series 8, 9, 10, 12 and 15) showed that the flocs obtained could also be floated efficiently.

In Table 9 a comparison is made between the treated water quality obtained in laboratory flotation and laboratory settling experiments. The results taken were those for test series 11 to 15 in which the water was first subjected to a series of coagulation tests to determine the optimum coagulant dose. The optimum dose was used in the flotation tests and in a conventional coagulation test made under the same conditions as those used for flotation (Sect. 2. 4.), 10 minutes being allowed for settlement.

The table shows that the treated water quality after laboratory flotation is of the same order and in most cases better than that after laboratory sedimentation. It must be emphasised that the 10-minute period allowed for settlement corresponding to that allowed for flotation was rather short and better results would have been obtained after a longer period. The differences in the results do, however, at least reflect the differences in the rates of flotation and settling. In the case of algal separation, flotation may be expected to be inherently more efficient.

4. DISCUSSION

The work described in this report has demonstrated the technical feasibility of floating several different types of water clarification floc using the dissolved-air technique. The floc types studied included those resulting from the coagulation of water heavily laden with algae, coloured water and turbid water with a very low organic content. In all cases except one, flotation was achieved without the addition of any chemicals other than those normally used in coagulation. In one case (a suspension of kaolin in a chalk borehole water coagulated with aluminium sulphate) flotation was possible only after the addition of a small quantity of a surfactant, sodium dodecyl benzene sulphonate.

The attachment of air bubbles to the surface of hydrophilic substances such as the hydrous oxides of iron and aluminium is normally only possible if the surface is rendered hydrophobic by the addition of a suitable surfactant. It must therefore be assumed that in most natural waters a sufficient quantity of organic material capable of rendering the floc hydrophobic is present. Alternatively, some other mechanism of bubble attachment (e.g. physical entanglement) is involved in most cases. While this is of academic interest, the fact that the flotation of water clarification floc can be effected without the addition of surfactants would be of considerable practical importance if flotation were ever used as a water clarification process. The addition of surfactants to a water destined for public supply would be highly undesirable and expensive both to add and subsequently to remove.

This work has indicated that floc characteristics are as important in flotation as in sedimentation. In general, well-developed flocs were floated more effectively than small flocs resulting from the use of an inadequate coagulant dose. There was no general indication that one coagulant was better than another.

Better results were obtained by mixing dissolved air with a preformed floc than by adding it with the coagulant. Considerable care was necessary to prevent the breakup of floc at the point of dissolved air addition. It is considered that this is likely to be of great importance in the design of a continuous flow plant.

The quantity of dissolved air required to float floc was quite small: about 5% by volume of water saturated with air at 340 kN/m^2 (50 $lb/in.^2$). The efficiency of air utilization in the laboratory apparatus was very high and the release of microscopic air bubbles could only be discerned by careful inspection. It is quite possible that a larger proportion of dissolved air would be required on a continuous plant. The quantity of air required was certainly dependent on the quantity of solids to be floated but no attempt was made to determine a precise relationship.

The results of the present study provide ample justification for a pilot-scale investigation aimed at determining the main factors affecting the operation of a continuous flotation process and estimating the cost of flotation treatment. Further laboratory studies should be undertaken to obtain quantitative information on the influence of solids concentration on the quantity of dissolved air required. A more detailed study of the factors affecting the flotation of different types of floc is desirable.

5. CONCLUSIONS

- Floc formed by the treatment of widely different types of water with iron and aluminium coagulants can be separated by dissolved-air flotation without the addition of surface-active agents.

- In laboratory experiments efficient flotation can be achieved by the addition of 5% by volume, or less, of water saturated with air at 340 kN/m^2 (50 $lb/in.^2$).

- In laboratory experiments flotation is a considerably more rapid method of separation than sedimentation.

- Further studies should be undertaken of the factors affecting the operation of a continuous flotation process and to obtain an estimate of the cost of flotation treatment. A more comprehensive laboratory study of flotation is also required.

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TABLE 1

ANALYSIS OF TAP WATER USED IN FLOTATION EXPERIMENTS

pH	7.8	
Electrical conductivity (20 °C) μS/m	50200	
Colour (O.D. in 4-cm cell at 400 nm)*	0	
Turbidity (O.D. in 4-cm cell at 580 nm)**	0	
Total residue on drying at 105 °C	360	mg/litre
Hardness, total ($CaCO_3$)	285	" "
Hardness, carbonate ($CaCO_3$)	254	" "
Free CO_2 (CO_2)	11	" "
Nitrogen, ammoniacal (N)	<0.02	" "
Nitrogen, albuminoid (N)	Not determined	" "
Nitrogen, nitrite (N)	Not determined	" "
Nitrogen, nitrate (N)	4.74	" "
Sodium (Na)	6.4	" "
Potassium (K)	0.9	" "
Calcium (Ca)	113	" "
Magnesium (Mg)	0.8	" "
Iron (Fe)	0.01	" "
Manganese (Mn)	<0.02	" "
Chloride (Cl)	10.5	" "
Sulphate (SO_4)	8.2	" "
Silica (molybdate reactive) SiO_2.	23.1	" "
Phosphate, ortho (P)	0.041	" "
Permanganate value ½ hour 95 °C (O_2)	0.3	" "

* on filtered (0.5 μ) sample.

** difference between readings on unfiltered and filtered (0.5 μ) sample.

TABLE 2

ANALYSIS OF WATER SAMPLES USED IN FLOTATION EXPERIMENTS ON NATURAL WATERS

Test series	3	4	8	9	10	11	12	13	14	15
Turbidity (JTU)	-	11	0.9	2.5	1.8	4.8	3.2	5.4	10.2	3.2
Colour (O.D. 400 nm 40 mm)	-	-	0.103	0.123	0.420	0.008	0.390	0.052	0.024	0.036
Electrical conductivity (μS/m) 20 °C	425	508	118	-	-	14 700	5 000	97 100	18 400	54 300
pH	8.7	8.9	5.8	7.4	5.4	7.0	4.8	7.2	5.0	8.3
Alkalinity (mg/litre $CaCO_3$)	137	212	4.9	-	-	42	1.6	144	2.2	155
Total hardness (mg/litre $CaCO_3$)	205	280	27.5	-	-	64	10.4	357	40.6	264
Permanganate value (30 min 100 °C) mg/litre O_2	7.0	8.0	-	-	-	6.00	27.6	8.15	4.24	3.57
Chloride (mg/litre Cl)	-	-	52.9	-	-	16.3	7.24	107.4	30.6	32.3
Iron (mg/litre Fe)	<0.04	0.13	-	-	-	0.375	2.59	0.19	1.10	0.053
Algal count (cells/ml)	22 000	83 000	-	-	-	30 000	-	2 500	-	1 800

TABLE 3

FLOTATION OF $FeCl_3$/KAOLIN FLOC - EFFECT OF COAGULANT DOSE (KAOLIN 50 mg/litre IN TAP WATER, DISCHARGE TIME 30 Sec)

$FeCl_3$ dose (mg/litre)	Turbidity (O. D. 580 nm 40 nm)			
	Initial	After flotation		After settling
		Middle sample	Bottom sample	
10	0.393	Very poor flotation		0.068
20	0.393	0.023	0.497	0.015
30	0.384	0.012	0.075	0.010
40	0.394	0.011	0.050	0.005
50	0.395	0.012	0.074	0.005

TABLE 4

FLOTATION OF $FeCl_3$/KAOLIN FLOC - EFFECT OF pH (KAOLIN 30 mg/litre IN TAP WATER $FeCl_3$ 30 mg/litre. pH ADJUSTED WITH HCl OR NaOH. DISCHARGE TIME 15 Sec)

Final pH	Turbidity (O. D. 580 nm 40 nm)		
	Initial	After flotation	
		Middle sample	Bottom sample
6.0	0.234	0.036	0.089
7.1	0.238	0.022	0.046
8.5	0.271	0.027	0.118

TABLE 5

FLOTATION OF $FeCl_3$/KAOLIN FLOC - EFFECT OF CLAY CONCENTRATION ($FeCl_3$ 40 mg/litre)

Kaolin concentration in tap water (mg/litre)	Discharge time (sec)	Turbidity (O. D. 580 nm 40 nm)		
		Initial	After flotation	
			Middle sample	Bottom sample
0	30	0.000	0.000	0.002
50	30	0.406	0.013	0.059
100	30	0.751	0.020	0.078
200	60	1.32	0.019	0.223
500	90		Very poor flotation	

TABLE 6

EFFECT OF QUANTITY OF DISSOLVED AIR (DISCHARGE TIME) ON EFFICIENCY OF FLOTATION OF $FeCl_3$/KAOLIN FLOC ($FeCl_3$ 40 mg/litre) SAMPLE VOLUME 700 ml

Kaolin concentration (mg/litre)	Discharge time (sec.)	Turbidity (O. D. 580 nm 40 nm)		
		Initial	After flotation	
			Middle sample	Base sample
50	5	0.508	*0.025	0.655
50	10	0.503	*0.022	0.256
50	20	0.501	0.016	0.102
50	30	0.499	0.012	0.055
50	60	0.505	0.017	0.070
200	40	1.66	Very poor flotation	
200	50	1.66	*0.068	0.467
200	60	1.67	*0.053	0.810
200	90	1.67	*0.022	0.499
200	120	1.67	*0.027	0.271

* 'Delayed flotation' occurred to some extent (Sect. 3.1, p. 5)

TABLE 7

EFFECT OF TIME OF DISSOLVED-AIR INJECTION IN RELATION TO TIME OF COAGULANT ADDITION (KAOLIN CONCENTRATION 50 mg/litre)

FeCl$_3$ dose (mg/litre)	Time of dissolved air addition	Turbidity (O.D. 580 nm 40 nm)		
		Initial	After flotation	
			Middle sample	Base sample
+ 40	30 sec before coagulant	0.537	0.083	0.402
+ 40	immediately after coagulant	0.540	0.065	0.209
x 40	5 min after coagulant	0.499	0.012	0.055
+ 100	30 sec before coagulant	0.538	0.062	0.137
+ 100	immediately after coagulant	0.542	0.041	0.059
x 100	5 min after coagulant	0.511	0.008	0.018

+ Stirring conditions: 0.5 min fast stir after coagulant addition, 2 min slow stir.

x Stirring conditions 1 min fast stir after coagulant addition, 5 min slow stir.

TABLE 8

FLOTATION OF VARIOUS TYPES OF FLOC (PART 1)

A Test series no.	B Raw water samples	C Coagulant	D Coagulant dose (mg/litre)	E % v/v dissolved air	F Parameter	G Results for parameter in column F		
						Raw water	After flotation	
							Middle sample	Base sample
1	Culture of alga <u>Scenedesmus</u> diluted with tap water	$Al_2(SO_4)_3 16H_2O$	40	6.5	Algal count cells/ml	144 500	5 060	17 200
		"	50	6.5		203 000	1 580	11 400
		"	50	6.5		141 500	3 920	23 300
		$FeCl_3$	30	6.5		81 700	799	3 120
		"	40	6.5		236 000	1 275	9 160
		"	40	6.5		272 000	2 122	13 800
		"	40	6.5		114 000	810	5 950
		"	50	6.5		115 000	743	1 910
2	Culture of alga <u>Scenedesmus</u> diluted with Thames water	$FeCl_3$	20	6.5	Algal count cells/ml	37 500	2 330	2 030
		$Fe_2(SO_4)_3 9H_2O$	35	6.5		37 200	4 050	5 770
		$AlCl_3$	30	6.5		32 400	1 460	1 210
		$Al_2(SO_4)_3 16H_2O$	40	6.5		39 200	3 540	2 050
3	Sample from Farmoor reservoir (Oxford W. W.) with high count of alga <u>Aphanizomenon</u>	$Al_2(SO_4)_3 16H_2O$	20	6.5	Algal count cells/ml	21 900	6 340	3 640
		"	30	6.5		21 630	6 640	5 260
		"	50	6.5		17 500	2 590	2 120
		$FeCl_3$	10	6.5		23 700	2 440	5 360
			30	6.5		22 400	4 920	2 830
4	Thames sample with high count of <u>Stephanodiscus Hantzschii</u>	$FeCl_3$	30	3.3	Turbidity	0.140	0.022	0.013
		$Al_2(SO_4)_3 16H_2O$	30	3.3	O.D. 580 nm 40 nm	0.145	0.020	0.014

TABLE 8

FLOTATION OF VARIOUS TYPES OF FLOC (PART 2)

A Test series no.	B Raw water samples	C Coagulant	D Coagulant dose (mg/litre)	E % v/v dissolved air	F Parameter	G Results for parameter in column F		
						Raw water	After flotation	
							Middle sample	Base sample
5	Thames sample	$FeCl_3$	30	6.5	Turbidity O.D. 580 nm 40 nm	0.158	0.010	0.010
		$Al_2(SO_4)_3 16H_2O$	30	6.5		0.160	0.038	0.078
		$Al_2(SO_4)_3 16H_2O$	50	6.5		0.157	0.008	0.013
6	Thames sample with 50 mg/litre added kaolin	$FeCl_3$	30	6.5	Turbidity O.D. 580 nm 40 nm	0.650	0.080	0.093
		$FeCl_3$	50	6.5		0.652	0.060	0.067
		$Al_2(SO_4)16H_2O$	30	6.5		0.648	0.285	0.360
		$Al_2(SO_4)16H_2O$	50	6.5		0.655	0.033	0.133
7	Thames sample with 50 mg/litre added kaolin	$FeCl_3$	20	6.5	Turbidity O.D. 580 nm 40 nm	0.673	0.137	0.177
		$Fe_2(SO_4)_3 9H_2O$	35	6.5		0.690	0.233	0.600
		$AlCl_3$	30	6.5		0.693	0.050	0.109
		$Al_2(SO_4)_3 16H_2O$	40	6.5		0.720	0.052	0.243
8	Sample from Inverness-shire Water Board	$FeCl_3$	40	6.5	Colour O.D. 400 nm 40 nm	0.122	0.030	0.038
		$FeCl_3$ + LT25	40 + 0.3	6.5		0.122	0.025	0.028
9	Sample from South West of Scotland Water Board	$FeCl_3$	40	6.5	Colour O.D. 400 nm 40 nm	0.125	0.055	0.055
		$Al_2(SO_4)_3 16H_2O$	40	6.5		0.125	0.050	0.050
		$Al_2(SO_4)_3 16H_2O$	60	6.5		0.125	0.035	0.035
10	Sample from Ayrshire and Bute Water Board	$Al_2(SO_4)_3 16H_2O$	30	6.5	Colour O.D. 400 nm 40 nm	0.420	0.340	0.340
		$Al_2(SO_4)_3 16H_2O$	50	6.5		0.435	0.280	0.285
		$Al_2(SO_4)_3 16H_2O$	100	6.5		0.433	0.210	0.210
		$Al_2(SO_4)_3 16H_2O$ + LT25	50 +0.2	6.5	Colour O.D. 400 nm 40 nm	0.420	0.205	0.205
		$Al_2(SO_4)_3 16H_2O$ + LT25	100 +0.2	6.5		0.420	0.170	0.170

TABLE 8

FLOTATION OF VARIOUS TYPES OF FLOC (PART 3)

A Test series no.	B Raw water samples	C Coagulant	D Coagulant dose (mg/litre)	E % v/v dissolved air	Parameter	G Results for parameter in column F		
						Raw water	After flotation	
							Middle sample	Base sample
11	Mid Cheshire Water Board sample containing <u>melosira granulata</u> a filamentous diatom.	$Al_2(SO_4)_3 16H_2O$	30	6.5	Turbidity (JTU)	8.6	0.67	0.84
					Algal count (cells/ml)	30.870	232	650
		$FeCl_3$	25	6.5	Turbidity (JTU)	6.9	1.2	1.6
					Algal count (cells/ml)	31.500	0	303
12	Durham County Water Board	$Al_2(SO_4)_3 16H_2O$*	70	6.5	Turbidity (JTU)	3.2	0.70	0.77
					Colour O.D.400 nm	0.390	0.022	0.022
		$FeCl_3$*	40	6.5	Turbidity (JTU)	3.2	1.9	2.1
					Colour O.D.400 nm	0.390	0.004	0.004
13	River Trent at Colwick	$Al_2(SO_4)_3 16H_2O$	30	6.5	Turbidity (JTU)	5.8	1.1	1.1
					Algal count (cells/ml)	2310	312	607
		$FeCl_3$	25	6.5	Turbidity (JTU)	4.9	2.9	3.0
					Algal count (cells/ml)	2890	415	712
			35	6.5	Turbidity (JTU)	4.7	3.4	3.6
					Algal count (cells/ml)	2560	637	853

*NaOH added to give final pH approximately 6.0

TABLE 8

FLOTATION OF VARIOUS TYPES OF FLOC (PART 4)

A Test series no.	B Raw water samples	C Coagulant	D Coagulant dose (mg/litre)	E % v/v dissolved air	F Parameter	G Results for parameter in column F		
							After flotation	
						Raw water	Middle sample	Base sample
14	Wakefield and District Water Board	$Al_2(SO_4)_3\ 16H_2O$*	50	6.5	Turbidity (JTU)	10.9	2.1	2.2
					Colour O.D. 400 nm	0.024	0.003	0.003
		$FeCl_3$*	30	6.5	Turbidity (JTU)	10.9	2.9	3.1
					Colour O.D. 400 nm	0.024	0.002	0.002
15	Bucks Water Board Foscote Reservoir	$Al_2(SO_4)_3 16H_2O$	35	6.5	Turbidity (JTU)	3.1	2.4	2.5
					Algal count (count/ml)	1765	391	456
		$FeCl_3$	30	6.5	Turbidity (JTU)	3.0	1.4	1.4
					Algal count (count/ml)	1860	299	322

* NaOH added to give final pH approximately 6.0

TABLE 9

COMPARISON OF THE RESULTS OF LABORATORY FLOTATION EXPERIMENTS WITH THOSE OF LABORATORY SETTLING EXPERIMENTS

Test Series No.	Coagulant	Dose (mg/litre)	Treated water quality			
			Turbidity (JTU)		Algal count (cells/ml)	
			after flotation	after settling	after flotation	after settling
11	$Al_2(SO_4)_3 16\ H_2O$	30	0.67	0.77	232	1240
11	$Fe\ Cl_3$	25	1.2	1.3	0	1840
12	$Al_2(SO_4)_3 16\ H_2O$	70	0.70	2.2	-	-
12	$Fe\ Cl_3$*	40	1.9	1.9	-	-
13	$Al_2(SO_4)_3 16\ H_2O$	30	1.1	1.6	-	-
13	$Fe\ Cl_3$	25	2.9	2.1	-	-
13	$Fe\ Cl_3$	35	3.4	2.4	-	-
14	$Al_2(SO_4)_3 16\ H_2O$*	50	2.1	4.4	-	-
14	$Fe\ Cl_3$*	30	2.9	3.4	-	-
15	$Al_2(SO_4)_3 16\ H_2O$	35	2.4	2.2	391	710
15	$Fe\ Cl_3$	30	1.4	2.8	299	571

* Final pH adjusted with NaOH to 6.0 approximately

\- not determined

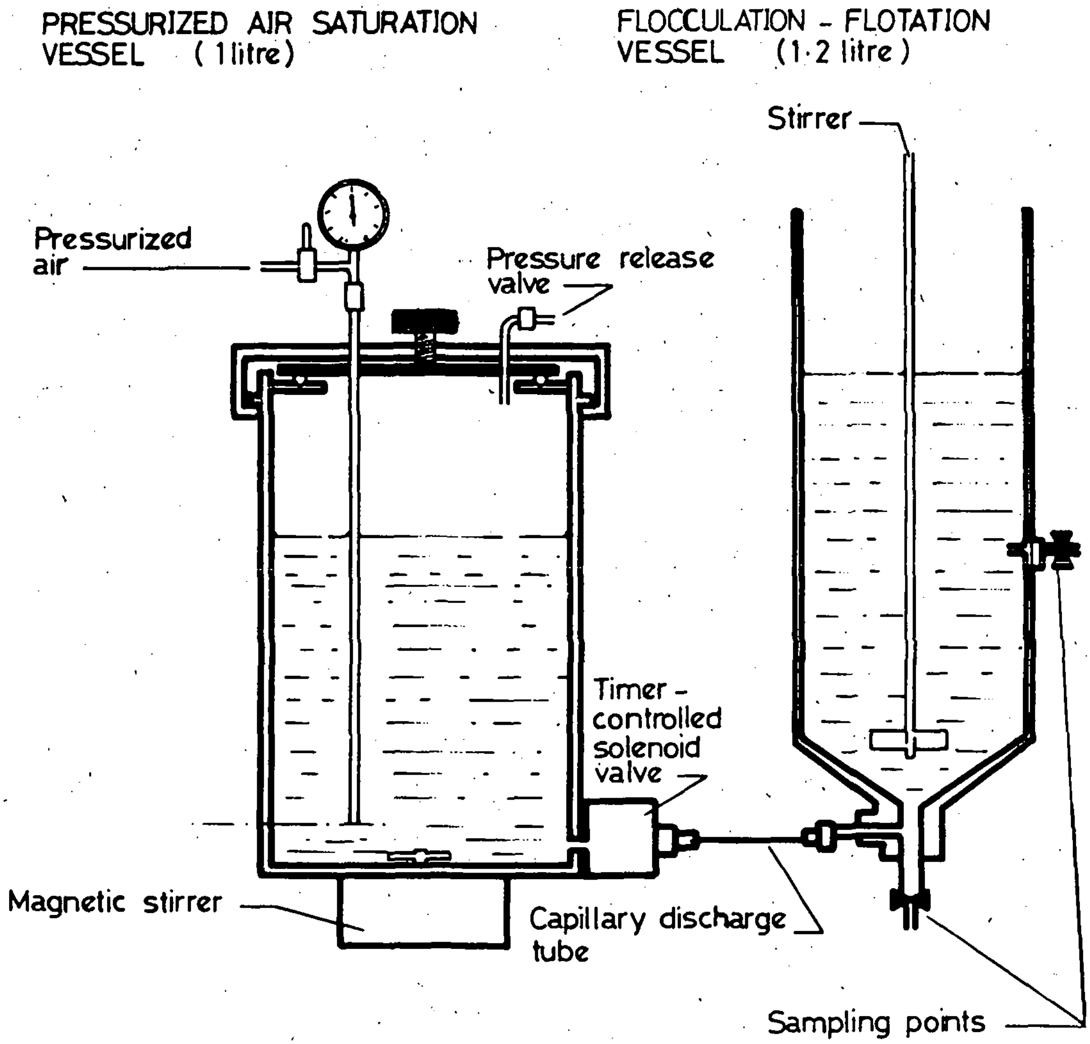

FIG. 1. LABORATORY FLOTATION APPARATUS.