WATER RESEARCH CENTRE

TECHNICAL REPORT TR114

WATER CLARIFICATION BY FLOTATION – 5

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April 1979

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ERRATA

TR 114 WATER CLARIFICATION BY FLOTATION - 5

Page 15. Section 3.1.3, line 3. *Should read* from 10 000 cells/ml to 4000 cells/ml.
Page 30. *Correct* Figure 17 as indicated:

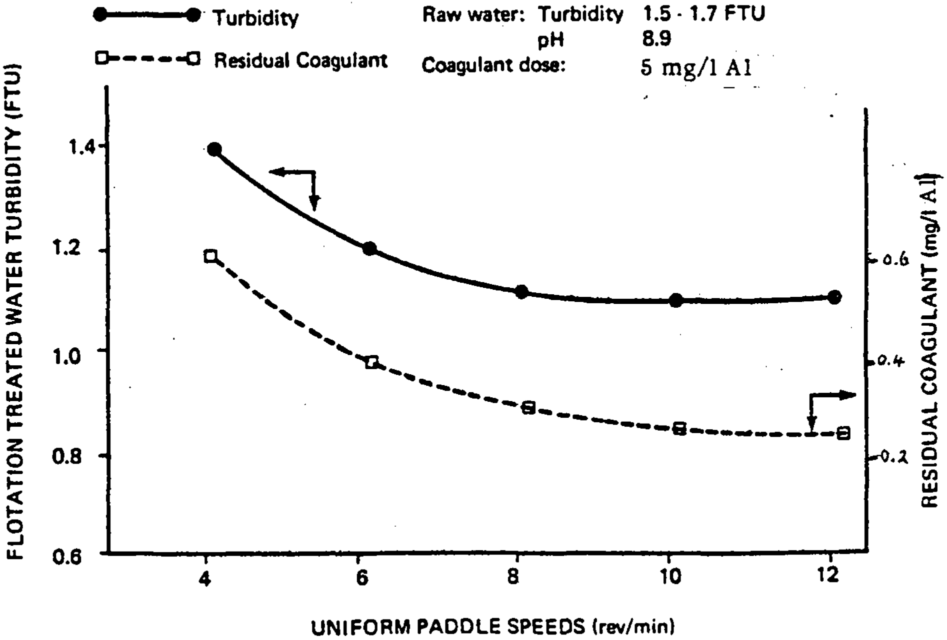

Fig. 17. Effect of varying uniform paddle speeds on flotation treated water quality - Ardleigh

Page 43. Table 18. Under the heading 'Algal count, cells/ml' *add* (x 10^{-3}).
Page 46. Table 22. Under the heading 'Rate of headloss development' *unit should read* mm/h.
Page 55. References. Ref.No.4, line 3. *For* TR 14 *please substitute* TR 13.

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Results from five 95 m^3/h plants operating on different raw waters

by

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SUMMARY

The objectives of this study were to assess the effectiveness of dissolved air flotation for treating different types of water, to establish design criteria for full-scale plants and to investigate methods of sludge removal.

Five 95 m^3/h plants were constructed and operated at different water undertakings. The types of water treated were:

+ river water with algal problems (3-day storage)
+ turbid river water
+ low-turbidity, highly-coloured, stored water
+ nutrient-rich water with algal problems (long-term storage)
+ hard water from a flashy stream

Flotation was found to be particularly effective for the treatment of stored water containing heavy algal loads and for stored, low-turbidity, highly-coloured water. Treating turbid river water by flotation produced generally slightly poorer water quality than sedimentation. However, the final water quality after filtration was the same. During periods of rapidly changing raw water quality control of the flotation plant was difficult and therefore if flotation is used for this application raw water storage should be provided.

The following process advantages have been found for flotation plants:

+ They can be operated at high upflow rates (up to 12 m/h) independently of the type of water being treated.

+ Rapid start-up is possible, treated water of steady quality being achieved after only 45 minutes.

+ They are relatively small and shallow (1.2 to 1.6 m deep) so that they can be easily housed and do not need excavation. However, protection of the flotation tank from wind and rain is essential to avoid break-up of the floated sludge layer.

+ The solids content of the sludge produced was generally higher than with sedimentation and was suitable for filter pressing without intermediate thickening.

+ The capital cost of flotation is less than for floc blanket sedimentation but its operating cost is higher. The overall cost is very similar to that of sedimentation.

Several full-scale flotation plants are being constructed in the UK and the results of their evaluation will be used to optimise the design and performance of the flotation process.

CONTENTS

1. INTRODUCTION

A literature survey(1) and laboratory investigations using a flotation jar test apparatus(2) showed that dissolved air flotation was a feasible process for the clarification of a wide variety of raw waters. Following this initial work two pilot plants were evaluated on River Thames water treating 1.8 m^3/h(3) and 8.2 m^3/h(4) respectively, to obtain operating and scale-up data for continuous plants. The pilot plant tests showed that flotation could produce treated water of similar quality to upflow sedimentation whilst offering several process advantages, such as rapid start-up, short retention time, and sludge with a high solids content (up to 10%). The chemical requirements for flotation were found to be the same as those for sedimentation.

To evaluate the process further, information was required on the effectiveness of flotation on a variety of different raw waters, the best method of sludge removal, and factors influencing scale-up to full-size plants. Several water undertakings were interested in evaluating dissolved air flotation and it was therefore decided to obtain the information by a joint investigation. Five 95 m^3/h pilot plants were constructed according to a design supplied by the WRC, and operated by the water undertakings taking part in the project. To co-ordinate these studies a WRC Flotation Working Group comprising representatives of the water undertakings operating the plants and WRC staff was set up. The Group provided a forum for discussions of technical problems and for the exchange of information between the parties concerned.

Development funds covering 75% of the construction and operating costs were provided for four of the five plants with the intention that information from these plants would become available to all Members of the WRC.

The selection of the treatment plants was based on the raw water types required for the study:

(a) three-day stored river water with algal problems (Langham Treatment Works, Essex Water Company)
(b) water from a flashy, hard stream (Bucklesham Pumping Station, Anglian Water Authority)
(c) turbid river water (Strensham Treatment Works, Severn-Trent Water Authority)
(d) low turbidity, highly coloured water (Arnfield Treatment Works, North West Water Authority)
(e) nutrient-rich, long-term stored water with algal problems (Ardleigh Treatment works, Ardleigh Reservoir Committee).

The locations of these plants are shown in Fig. 1. The plants were operated over a two-year period to investigate the effects of seasonal changes in raw water quality on plant performance. This report gives the results of these studies.

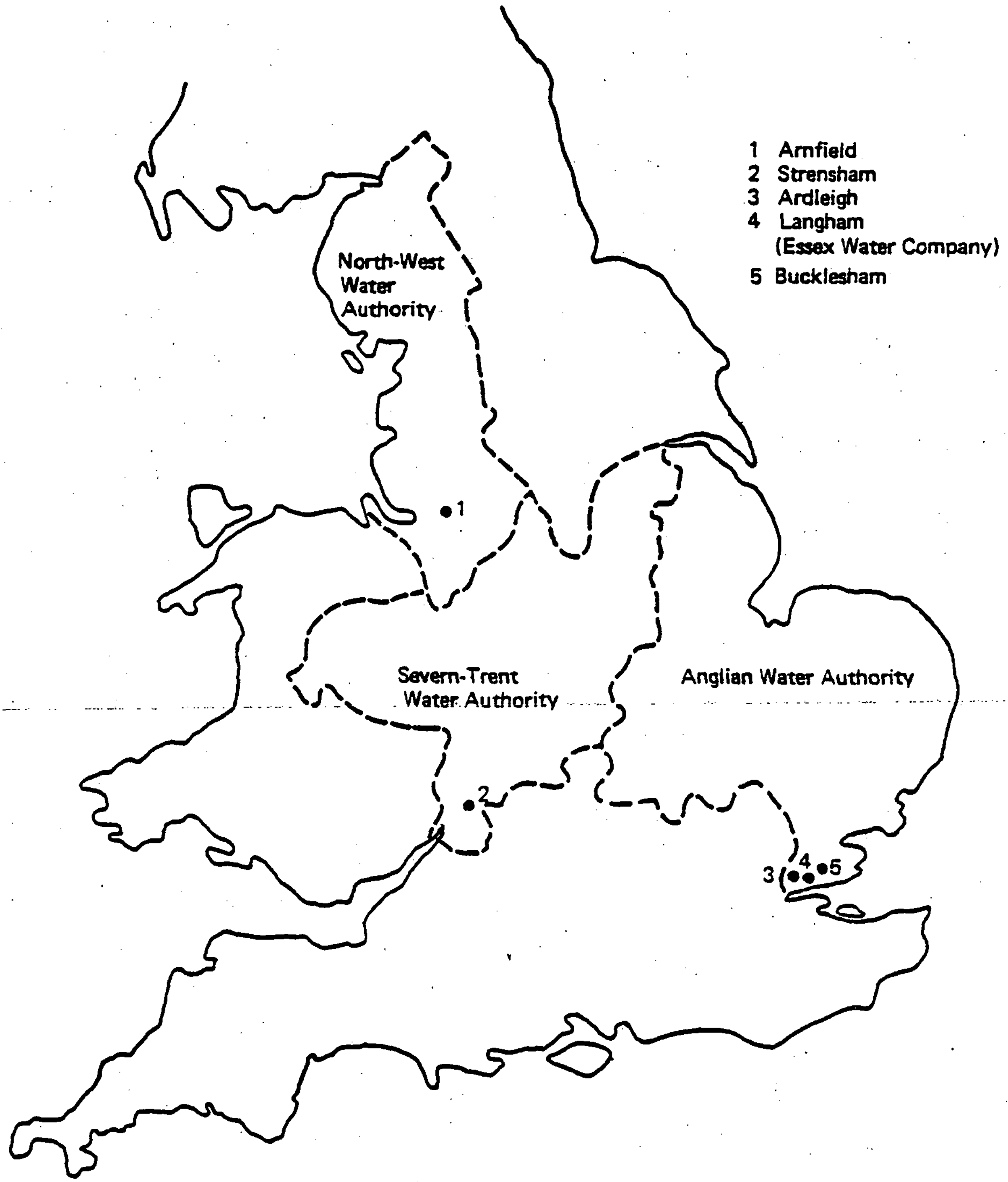


Fig. 1. Locations of the 95 m^3/h pilot plants

2. DESCRIPTION OF THE FLOTATION PILOT PLANTS

The five plants were of similar design, based on results obtained from the 8.2 m^3/h pilot plant operated at Medmenham(4). Each plant comprised a flash mixer, a three-stage mechanical flocculator and a flotation tank with its associated recycle system (Fig. 2). Three of the plants were equipped with mechanical sludge removal devices and provision was made at all the sites to filter the flotation treated water. Photographs of the five pilot plants are shown in Fig. 3.

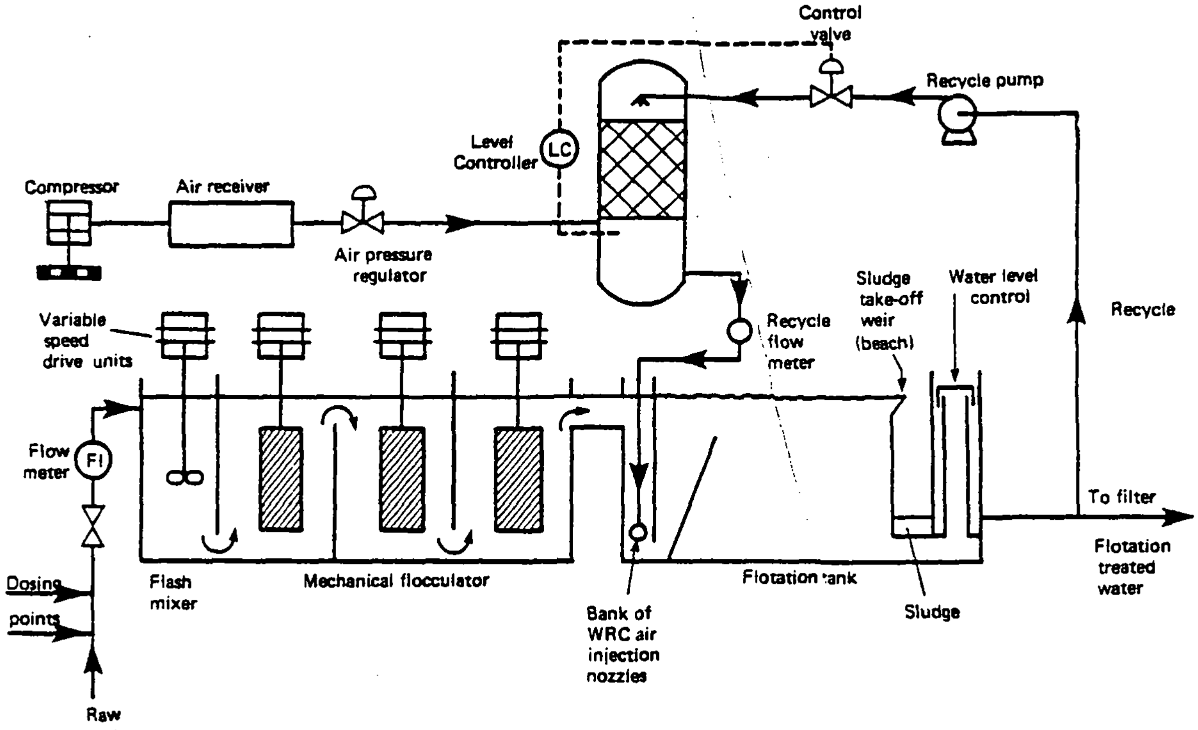


Fig. 2. Flow diagram of a 95 m^3/h flotation pilot plant

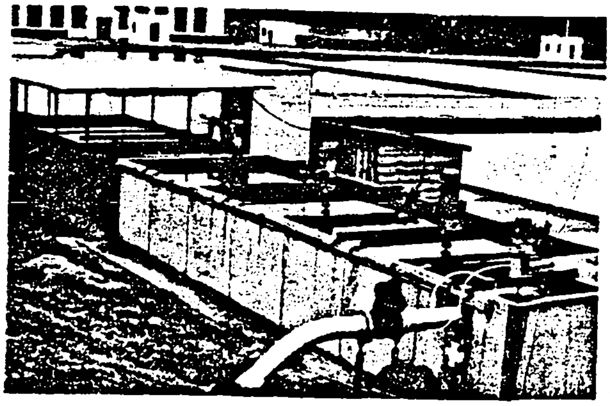
2.1. FLASH MIXER AND FLOCCULATOR

The flash mixer was a 1.2 m wide × 1.2 m long × 1.2 m deep tank and mixing was achieved by a marine propeller. The flocculator consisted of a rectangular shaped tank, 2.4 m wide × 7.2 m long × 1.2 m deep, divided into three equal compartments by partial baffles. On the Arnfield plant the flash mixer was later replaced by a fourth flocculator compartment, 2.4 m wide × 2.4 m long × 1.2 m deep. Agitation in the flocculator was provided by variable-speed gate paddles. Each paddle consisted of 4 blades 0.76 m high and 0.25 m wide and the diameter of the paddle was 1.22 m.

2.2. FLOTATION TANK

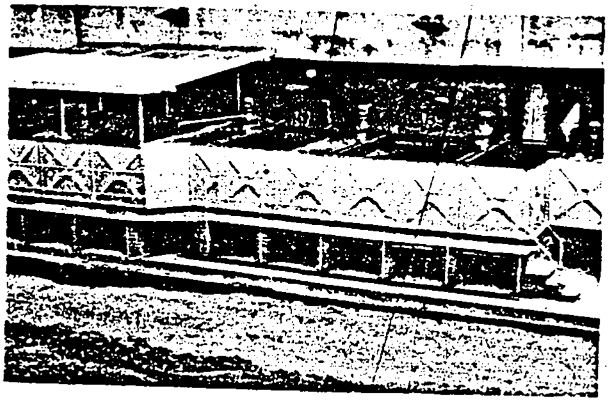
At Langham the flotation tank was 2.4 m wide, 3.6 m long and 1.8 m deep whereas the flotation tanks of the other four plants were 3.6 m wide, 2.4 m long and 1.2 m deep.

All plants were fitted with an inclined baffle in the flotation tank to direct the flow of air and flocs towards the surface and to minimise short-circuiting. With the exception of the Bucklesham plant, the recycle was introduced close to the bottom of the flotation tank on the upstream side of the inclined baffle. In the Bucklesham

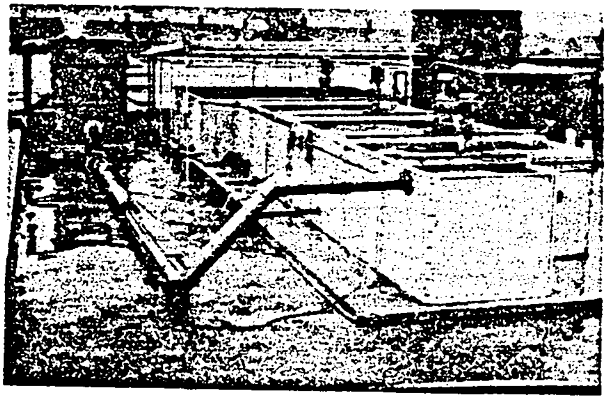


Langham – Essex Water Company

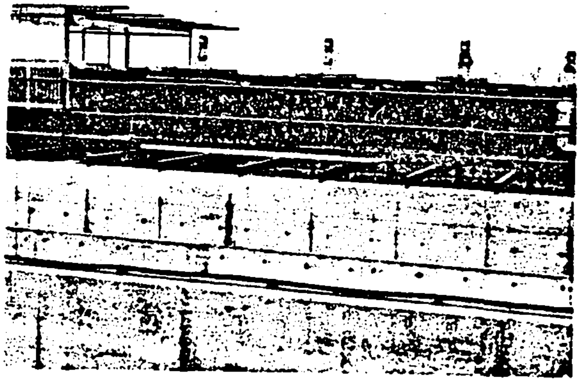
Bucklesham – Anglian Water Authority



Strensham – Severn-Trent Water Authority



Arnfield – North West Water Authority



Ardleigh – Ardleigh Reservoir Committee

Fig. 3. The five 95 m^3/h flotation pilot plants

plant the recycle was injected in the preceding downflow section. Occasionally some flotation occurred in the last flocculator compartment when the flow through the plant was reduced substantially below the design flow rate, or when the paddle speed in the last flocculator compartment was below 4 rev/min. The water level in the plants was controlled by adjustable weirs at the outlet of the flotation tank. Roofs were provided for all the flotation tanks to eliminate sludge break-up due to rain and wind.

2.3. SATURATOR SYSTEM

The pressure vessel used for saturating the recycle water with air was made of mild steel with an anti-corrosion coating and was 0.75 m in diameter and 2.25 m high. The vessel was filled with 1.2 m depth of packing above a 0.45 m deep saturated water reservoir.

The saturator system is shown in Fig. 2. Part of the treated water was pumped to the top of the saturator vessel by a multi-stage centrifugal pump. Compressed air was introduced above the saturated water reservoir. The pressure in the saturator was adjusted by an air pressure regulator and the liquid level was controlled by an automatic control valve on the inlet to the saturator. The pressurised saturated water was recycled through a variable area flowmeter into the flotation tank via a bank of WRC air injection nozzles fitted to a manifold. The nozzles were equipped with drilled plates which controlled the amount of recycle. At four of the plants twelve nozzles were used on a 300 mm spacing, but at Langham only eight nozzles were used on a 300 mm spacing because of the narrower flotation tank.

The system was designed to give 8% recycle at a saturator pressure of 450 kPa. At Strensham an additional pump was later installed to increase the available recycle.

The recycle system was lagged to prevent freezing of the water in the lines and in the saturator.

2.4. SLUDGE REMOVAL

The Arnfield plant was equipped with a mechanical scraper consisting of a chain drive and two blades which enabled most of the surface area of the tank to be scraped. The scraper speed was adjustable from zero to 3.5 m/min. At Strensham and Ardleigh a sludge beach scraper ('sludge roll') was installed. This system comprised a number of blades, fixed to a shaft, which only scraped the sludge layer above the beach. The speed of the scraper was adjustable from 0.9 to 3.7 rev/min. Figure 4 shows the sludge beach scraper installed at Strensham. On the other two plants the sludge could only be removed by raising the water level in the flotation tank and flooding the sludge off.

2.5. FILTER

Pilot-scale sand or anthracite/sand filters (0.3 m diameter) were installed at all the plants except Bucklesham where the flotation treated water could be passed to two of the works' rapid gravity filters.

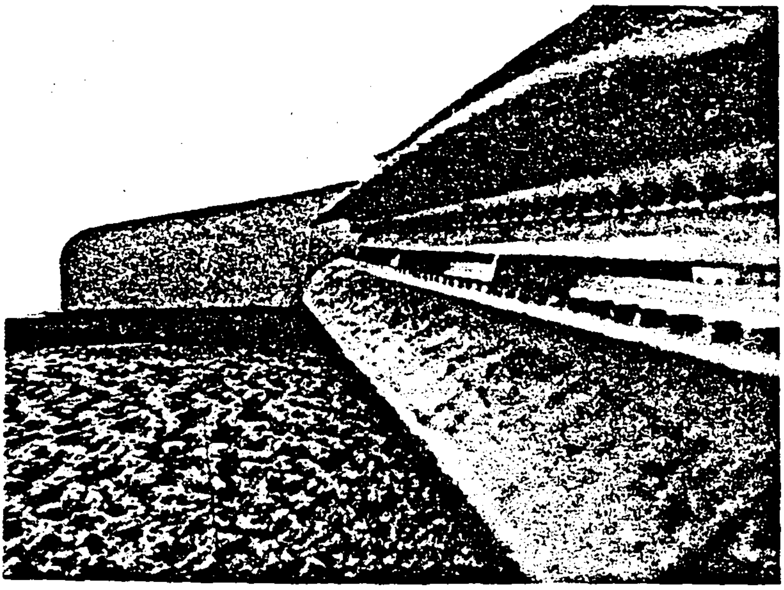


Fig.4. Sludge beach scraper - Strensham

3. INFLUENCE OF THE RAW WATER QUALITY ON THE FLOTATION TREATED WATER QUALITY

As the raw water supplied to the various plants was so different, the effect of the raw-water quality on the performance of each flotation plant will be discussed separately.

3.1. TREATMENT OF THREE-DAY STORED RIVER WATER WITH ALGAL PROBLEMS - LANGHAM

The raw water for the plant at Langham was abstracted from a reservoir with a three-day storage capacity. The reservoir received its water from the River Stour and was occasionally supplemented with water from Abberton Reservoir. The River Stour water quality could vary considerably, but these variations were evened out by the three-day storage. The turbidity in the raw water was caused by either clay suspensions, particularly during spate conditions in the river, or by algal growth. The heaviest algal growth encountered (up to 80 000 cells/ml, mainly small centric diatoms) occurred in the spring months. The range of raw water conditions experienced during the pilot plant trials is shown in Table 1.

Table 1. Raw water quality data for the period January 1976 to January 1978 - Langham (River Stour)

		Minimum	Maximum	Average	
Temperature (1977)	°C	2.0	21.0	10.8	
Turbidity (HACH)*	FTU	0.7	94	5.3	(For 1977)
Colour (0.45 µm filtered)	°Hazen	9	38	17	(Lovibond)
pH		7.4	9.1	8.1	
Permanganate value	mg/l as O_2	1.3	8.9	3.3	
Alkalinity	mg/l as $CaCO_3$	166	286	227	
Total hardness	mg/l as $CaCO_3$	258	470	362	
Total phosphate	mg/l as P	0.07	4.3	1.53	
Reactive silica	mg/l as SiO_2	0.06	18.0	9.9	
Algal species					
1. *Stephanodiscus*	cells/ml	5	80 000	10 200	
2. *Navicula*	cells/ml	ND	1500	190	
3. *Scenedesmus quadricauda*	cells/ml	ND	1300	170	

* The maximum turbidity of the raw water entering the pilot plant was less than 25 FTU because of the buffering capacity of the storage reservoir.

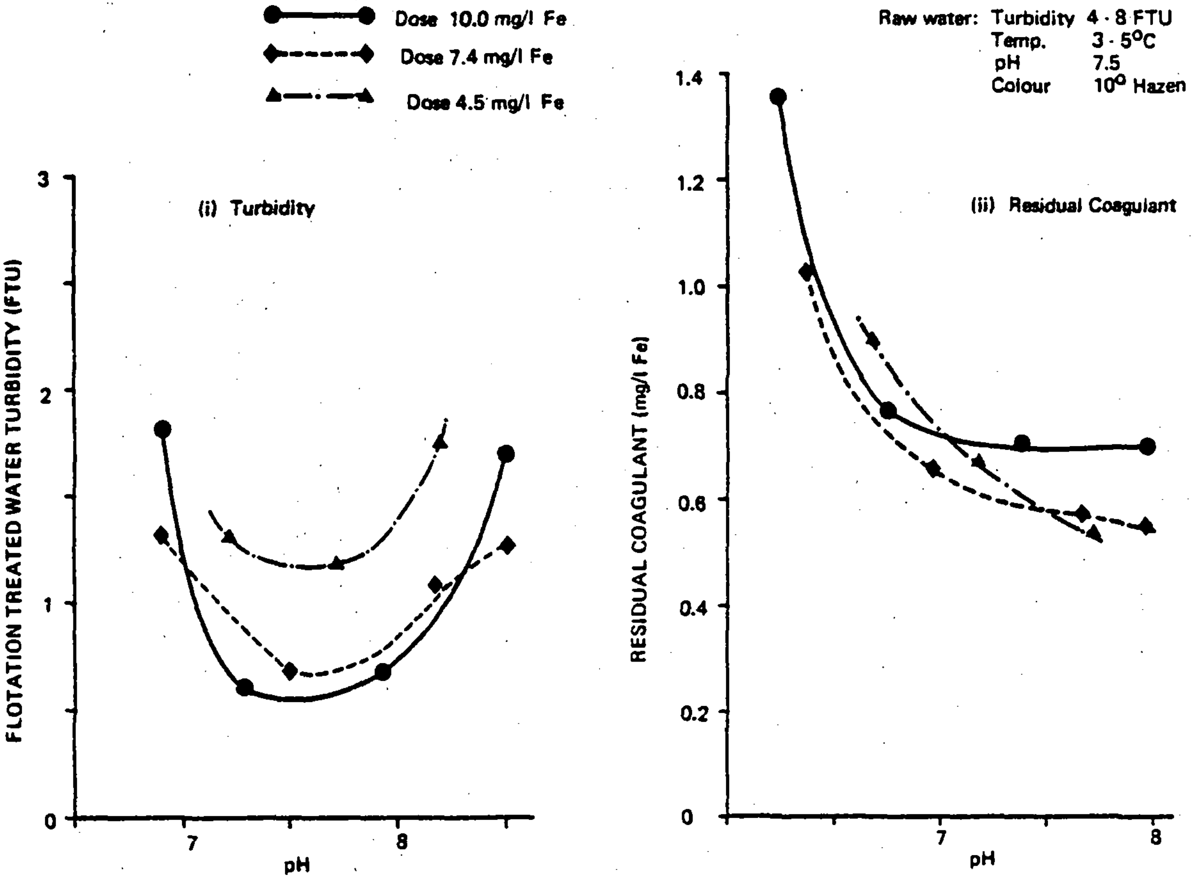
The Main Treatment Works consisted of horizontal sedimentation and rapid gravity sand filtration followed by slow sand filtration. As a general rule coagulant dosing on the main plant was only used when the raw water turbidity exceeded 10 FTU or when high numbers of algae were present. During periods of heavy algal growth the output of the works was reduced by up to 40% because of clogging of the slow sand filters by algae passing through the primary filters.

3.1.1. Effect of coagulant dose and pH on clay turbidity removal

During the experiments the raw water turbidity varied between 4 and 8 FTU and the temperature between 2.5 and 5 °C. Figure 5 shows that improved turbidity removal could be achieved by increasing the coagulant dose; however, exceeding the optimum dose resulted in an increase in residual coagulant. The optimum pH for ferric sulphate was found to be between 7.5 and 8.0.

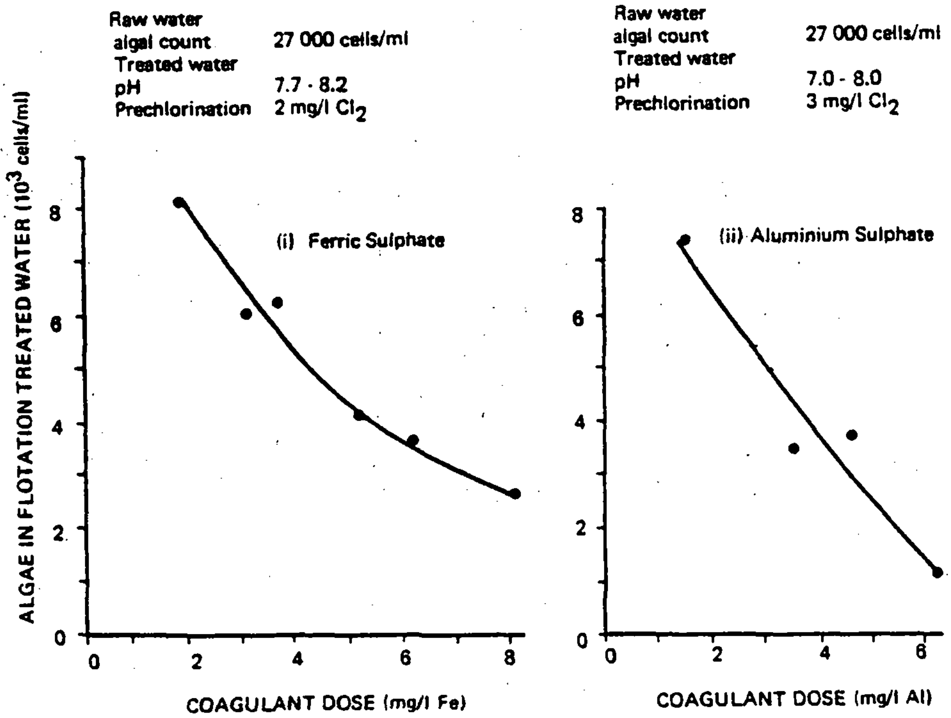
3.1.2. Effect of coagulant dose and pH on algal removal

Figure 6 shows the effect of coagulant dose on algal removal for both ferric sulphate and aluminium sulphate. The raw water algal count was approximately 30 000 cells/ml (mainly *Stephanodiscus*) and the results indicate that increasing the coagulant dose resulted in an improvement in algal removal. The algal removal was not affected by a change of pH in the range 6.5 to 8.0. However, the optimum pH in terms of residual coagulant and treated water turbidity was between 7.5 and 8.0 for ferric sulphate, and between 6.5 and 7.5 for aluminium sulphate. When polyaluminium chloride (PAC) was used as the coagulant, optimum algal removal and lowest residual coagulant levels were achieved in the pH range 6.3 to 7.0. Similar algal removal was achieved with approximately half the dose of PAC compared with aluminium sulphate (both expressed as Al). Increasing the coagulant dose again improved the algal removal.



Raw water: Turbidity 4 - 8 FTU
Temp. 3 - 5°C
pH 7.5
Colour 10° Hazen

Fig. 5. Effects of coagulant dose and pH on flotation treated water quality - Langham



Raw water
algal count 27 000 cells/ml
Treated water
pH 7.7 - 8.2
Prechlorination 2 mg/l Cl_2

Raw water
algal count 27 000 cells/ml
Treated water
pH 7.0 - 8.0
Prechlorination 3 mg/l Cl_2

Fig. 6. Effect of coagulant dose on algal removal - Langham

3.1.3. Effect of chlorine on algal removal

The addition of chlorine enhanced algal removal. For a raw water containing about 45 000 cells/ml, prechlorination with 4 mg/l of chlorine reduced the algal count in the flotation treated water significantly from 10 000 cells/ml to 400 cells/ml.

3.1.4. Effect of Wisprofloc 20 on algal removal

Up to 1.67 mg/l of Wisprofloc 20 (starch based polyelectrolyte) was used in combination with either aluminium sulphate or ferric sulphate as the primary coagulant. No improvement in algal removal, treated water turbidity or residual coagulant was observed.

3.2. TREATMENT OF WATER FROM A FLASHY, HARD STREAM - BUCKLESHAM

Most of the raw water for the Bucklesham treatment works was abstracted from a small stream (Mill River). The raw water was hard and usually of low turbidity and colour. However, when the stream was in spate the turbidity could rise very rapidly to values exceeding 100 FTU. Table 2 shows the range of raw water quality experienced during the course of the investigation. The Main Works treatment comprised aluminium sulphate dosing, horizontal sedimentation and rapid gravity sand filtration.

Insufficient information was obtained of the plant performance during river flood conditions as these occurred very infrequently. Most of the work was therefore concentrated on the treatment of low turbidity raw water (2 to 6 FTU).

Table 2. Raw water quality data for the period April 1975 to April 1977 - Bucklesham (Mill River)

		Minimum	Maximum	Average
Temperature	°C	1.0	16.0	9.1
Turbidity	FTU	1.4	240	5.2
Colour (0.45 µm filtered)	°Hazen	< 5	105	19
pH (1975 - 1976)		7.5	8.5	7.9
Permanganate value	mg/l as O_2	0.6	9.7	1.9
Alkalinity	mg/l as $CaCO_3$	116	162	148
Total hardness	mg/l as $CaCO_3$	220	290	267
Total phosphate	mg/l as P	0.01	0.24	0.06
Reactive silica	mg/l as SiO_2	6.3	13.0	9.6
Manganese	mg/l Mn	0.02	0.06	0.03
Iron	mg/l Fe	0.09	1.13	0.30

3.2.1. Effect of different primary coagulants on the treated water quality

During periods of low raw water turbidity it proved difficult to flocculate the water using aluminium sulphate as the primary coagulant, and in general flotation treated water of poor quality was produced. Extensive flotation jar test experiments were carried out to investigate the poor performance. Surprisingly, all samples tested in the flotation jar test apparatus exhibited good flotation although for optimum results it was occasionally necessary to increase the pH of the coagulated water by adding sodium hydroxide.

Using aluminium sulphate as the coagulant, trials were carried out on the pilot plant to investigate the influence of increasing the pH with sodium hydroxide on the treated water quality. In parallel with these trials, the effect of varying the pH on the treated water quality was also investigated in the flotation jar tester. Figure 7 shows a comparison of the results achieved on the plant and with the jar tester. Although the treated water quality produced by the flotation pilot plant was improved by increasing the pH to an optimum of approximately 8.0 the same results as obtained in the jar tester could not be achieved; in addition the treated water turbidity produced in the jar test equipment during these tests was independent of the pH.

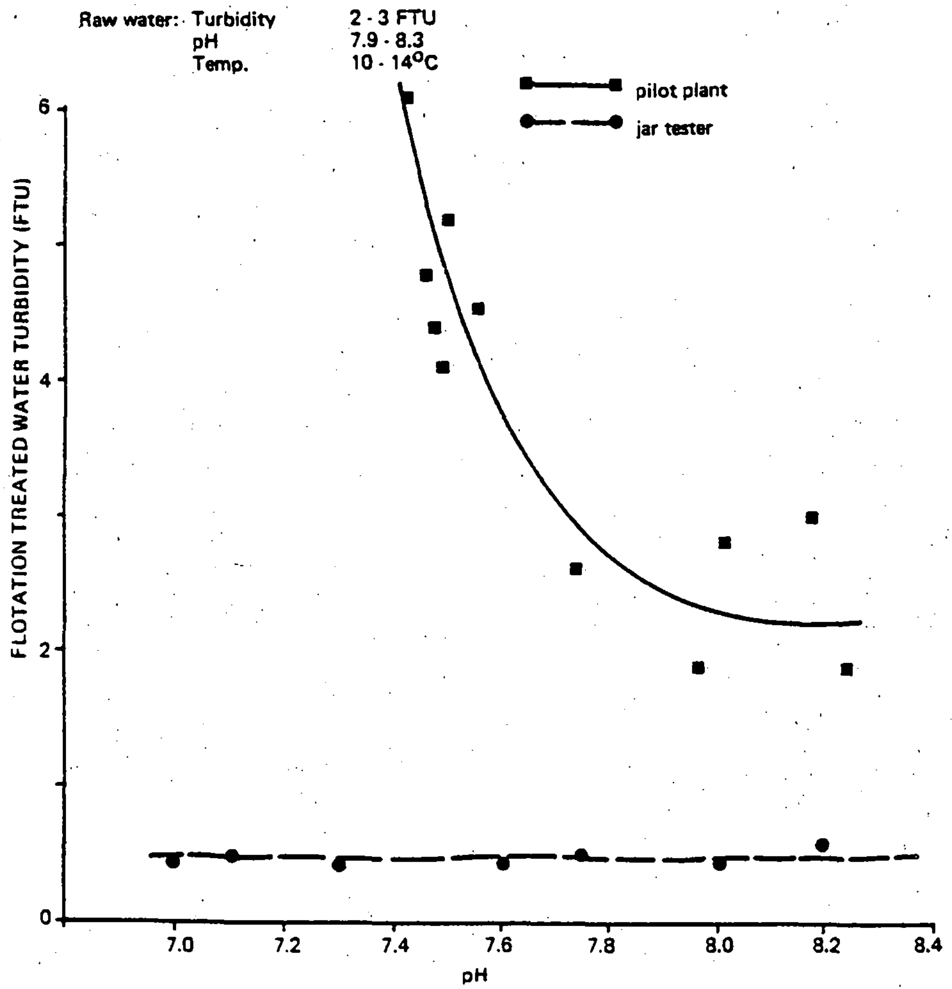


Fig. 7. Effect of pH on flotation treated water quality from 95 m^3/h pilot plant and from jar tester - Bucklesham

As the treated water quality produced by the plant using aluminium sulphate coagulant was not satisfactory, the use of alternative coagulants, ferric sulphate and polyaluminium chloride (PAC), was investigated and compared with aluminium sulphate. The optimum dose for the raw water conditions during the period of this test was found to be for PAC about 2.5 mg/l Al, for ferric sulphate 6 mg/l Fe and for aluminium sulphate 1.5 mg/l Al.

Figure 8 shows the effect of the pH on the treated water quality for the three coagulants. The results show that only PAC gave effective treatment. Visual observation confirmed that good flocculation occurred only with PAC.

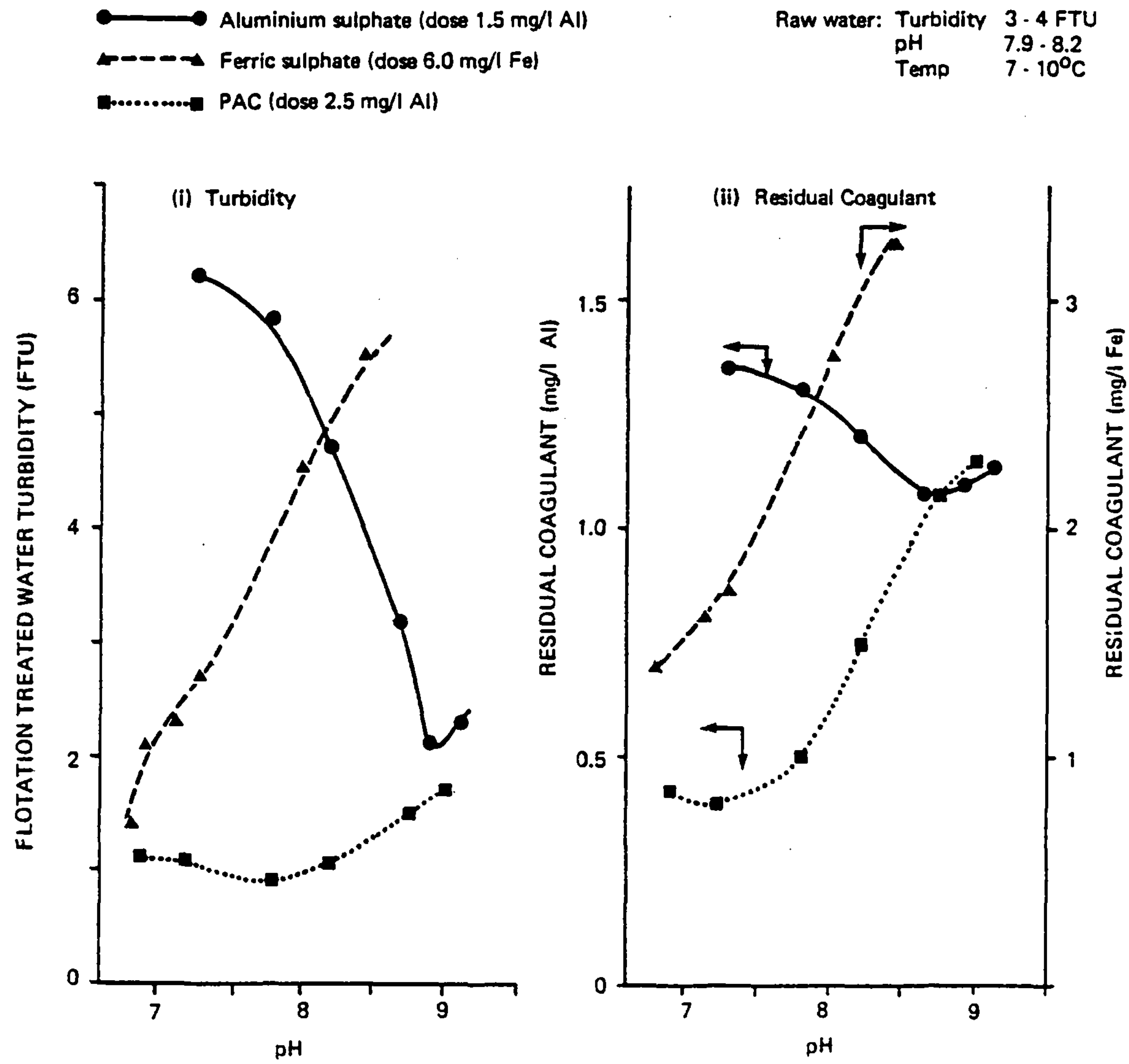


Fig. 8. Effect of pH on flotation treated water quality - Bucklesham

3.2.2. Effect of using coagulant aids on the treated water quality

Flotation jar test experiments had indicated that the polyacrylamide Magnafloc LT24 (cationic) gave an improvement in treated water quality when dosed in conjunction with aluminium sulphate or ferric sulphate as the primary coagulant. Tests carried out on the pilot plant showed some improvement in treated water quality (Fig. 9), but the results were still not satisfactory. A similar improvement was achieved when dosing LT24 in conjunction with ferric sulphate.

As the best treated water quality was achieved at pH values between 8.0 and 8.5 it was thought that this might be caused by partial softening of the water, giving rise to nuclei of calcium carbonate which promoted flocculation. Dosing of fuller's earth was therefore tried to provide more turbid material for flocculation, but no improvement in treated water quality was observed.

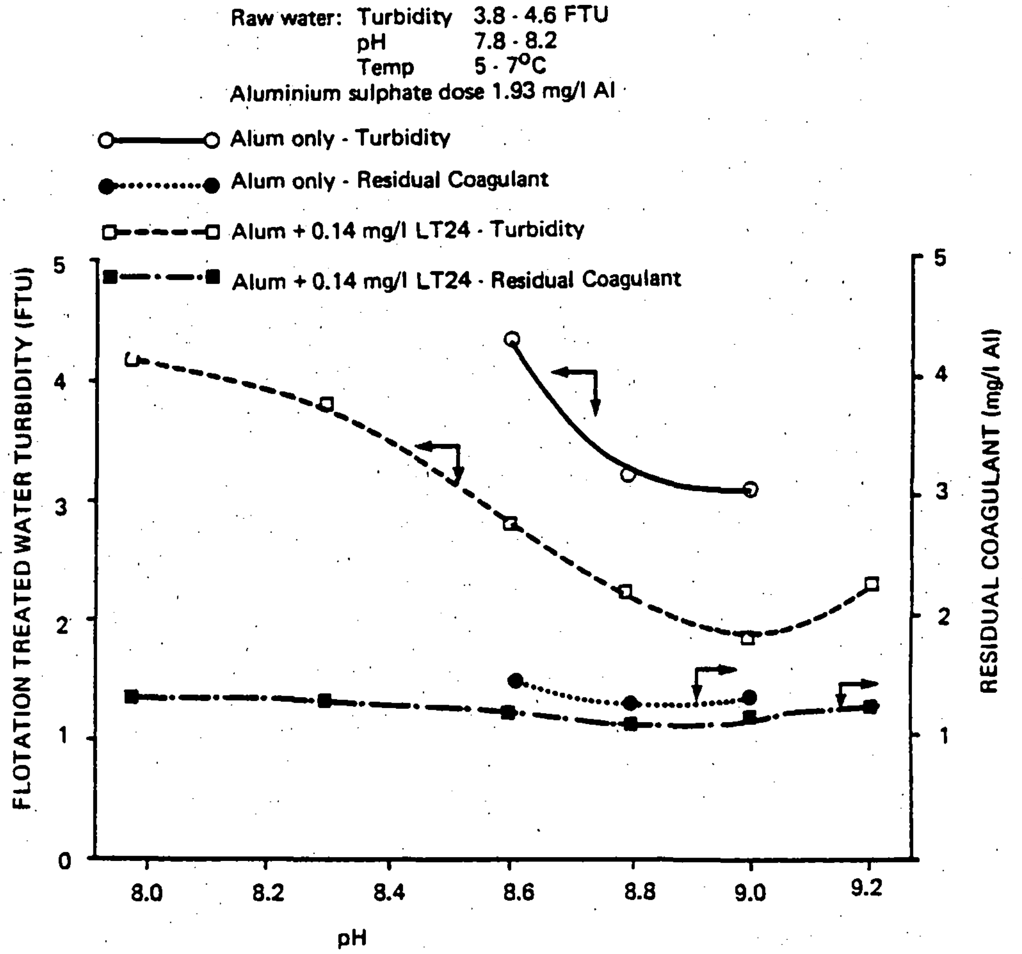


Fig. 9. Effect of using the polyelectrolyte LT24 with aluminium sulphate on the flotation treated water quality - Bucklesham

3.3. TREATMENT OF TURBID RIVER WATER - STRENSHAM

The raw water for the Strensham plant was abstracted from the River Severn at Upton-upon-Severn and pumped directly to the head of the works. The Main Treatment Works consisted of a biological pretreatment stage for ammonia removal, upflow sedimentation, and anthracite/sand rapid gravity filtration. After the biological sedimentation stage, break-point chlorination was applied. Usually a small proportion of the coagulant dose was added to the flash mixer of the biological stage and the main amount was dosed to the flash mixer of the upflow sedimentation stage. Originally the water for the flotation pilot plant was taken from the flash mixer of the biological stage but at a later date provision was made to abstract the water for the pilot unit from the outlet channel of the biological sedimentation stage so as to study the influence of this pretreatment stage on the performance of the flotation plant.

River Severn water quality changed considerably during the year and changes could be very rapid (within hours). As no raw water storage was provided, the flotation plant had to cope with these rapid changes. Table 3 gives the range of the raw water conditions experienced during the pilot plant trials. The raw water turbidity was usually below 10 FTU; however, during flood conditions it could rise to as high as 160 FTU with corresponding suspended solids concentrations of up to

750 mg/l. The colour was generally between 10 and 20 °Hazen, but again during flood conditions this could increase to 70 °Hazen. During the period of investigation several algal blooms occurred with counts of up to 88 000 cells/ml - mainly *Stephanodiscus*, *Cyclotella* and unicell coccoid.

3.3.1. Effect of dosing aluminium sulphate on the flotation treated water quality

Provided the optimum operating conditions were used, the flotation plant could cope with turbidities of up to 60 FTU resulting in treated water turbidities similar to those produced by sedimentation (Fig. 10).

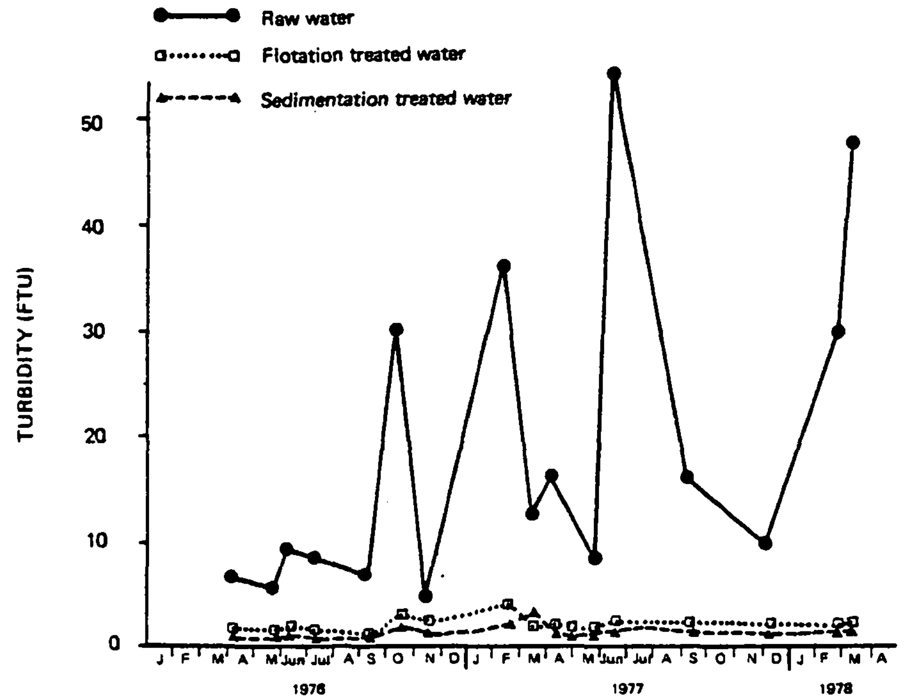


Fig. 10. Spot values of raw, flotation treated, and sedimentation treated water turbidity - Strensham

Table 3. Raw water quality data for the period January 1976 to January 1978 - Strensham (River Severn)

		Minimum	Maximum	Average
Temperature	°C	1.0	26.0	11.0
Turbidity	FTU	3.5	160	14
Colour (0.45 µm filtered)	°Hazen	5	70	14
pH		7.1	9.4	7.8
Permanganate value	mg/l as O_2	1.5	9.5	3.6
Alkalinity	mg/l as $CaCO_3$	30	178	107
Total hardness	mg/l as $CaCO_3$	62	288	183
Total phosphate	mg/l as P	0.1	1.5	0.38
Reactive silica	mg/l as SiO_2	0.1	10	5
Manganese	mg/l Mn	0.01	0.27	0.06
Iron	mg/l Fe	0.05	1.0	0.23
Suspended solids	mg/l	8	750	30
Total algal count (mostly centric diatoms)	cells/ml	80	88 000	11 000

The treated water turbidity rarely exceeded 3 FTU, the colour was reduced to below 5 °Hazen and the residual coagulant levels were in the range from 0.25 to 0.6 mg/l Al. However, the floc-blanket sedimentation plant (operated at an upflow rate of 2 m/h compared with the 12 m/h for flotation) produced a treated water with usually lower residual coagulant levels ranging from 0.15 to 0.4 mg/l Al. When the raw water turbidity exceeded 60 FTU, the performance of the flotation plant could be improved by reducing the flow rate through the plant by about 10 to 20%, giving a longer flocculation time and increased percentage recycle. This is shown in Table 4.

Table 4. Effect of reduced flowrate on flotation treated water quality - Strensham

Raw water turbidity FTU	Flowrate m^3/h	Flotation treated water turbidity FTU
140-155	95	5.2
	85.5	3.6
72-73	92	5.3
	83	3.8

The coagulant dose on the Main Works was adjusted at two-hourly intervals according to an empirical dose equation based on the raw water turbidity and colour. The dose needed for the optimum operation of the flotation plant was found to be 5 to 10 mg/l of alum (as $Al_2(SO_4)_3.21H_2O$) higher than predicted by the equation. The coagulation pH was critical for efficient operation of the pilot plant and the optimum pH was between 6.8 and 7.0 (Fig. 11). During rapid raw water quality changes constant monitoring and adjustment of the dose were required because of the short detention time in the plant.

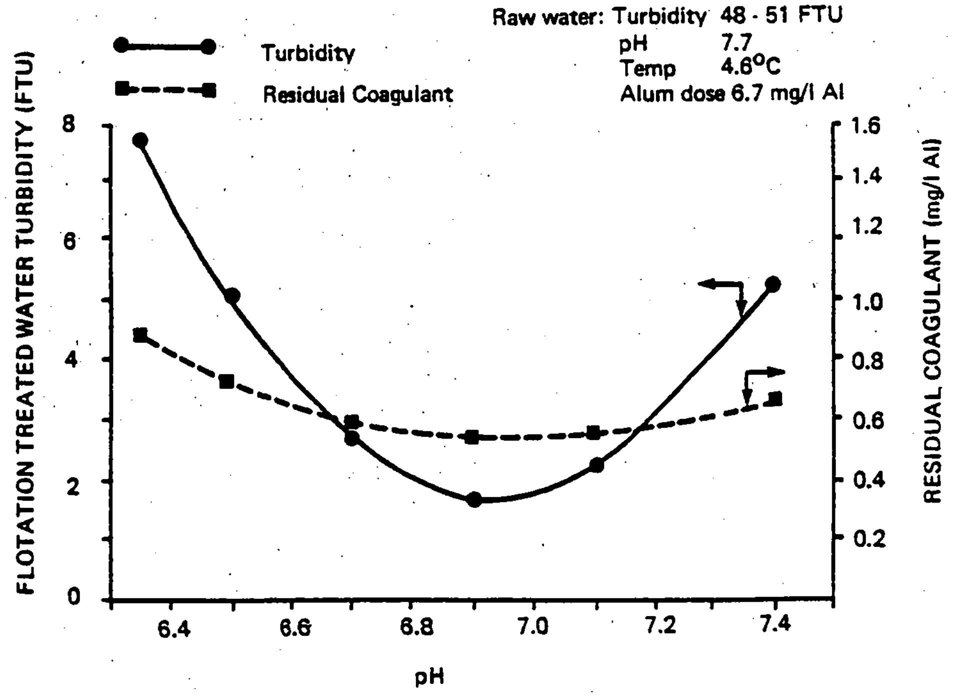


Fig. 11. Effect of pH on flotation treated water quality - Strensham

3.3.2. Effect of dosing polyaluminium chloride (PAC) on the flotation treated water quality

The use of polyaluminium chloride as the primary coagulant on the flotation plant was investigated and compared with aluminium sulphate dosing on the Main Works. The results (Table 5) indicate that approximately half the dose as mg/l Al is required for PAC compared with aluminium sulphate to obtain equivalent treated water quality.

Table 5. Comparison of dosing PAC on the flotation plant with dosing aluminium sulphate on the Main Plant sedimentation unit - Strensham

Raw Water		Flotation	Sedimentation	Flotation treated water		Main Plant treated water	
Turbidity FTU	pH	PAC dose mg/l Al	Aluminium sulphate dose mg/l Al	Turbidity FTU	Residual coag. mg/l Al	Turbidity FTU	Residual coag. mg/l Al
10	7.65	0.85	1.95	1.0	0.14	1.6	0.18
36	7.55	1.8	2.5	1.3	0.24	1.4	0.28
42	7.5	1.9	3.4	1.3	-	1.8	-
55	7.55	2.1	4.2	1.8	0.24	1.5	0.18
23	7.3	0.75 alum* + 0.9 PAC	2.7	1.8	0.1	1.8	0.26
23	7.3	0.75 alum* + 0.75 PAC	2.7	1.9	-	1.6	-
22	7.4	0.35 alum* + 1.0 PAC	3.3	1.0	0.16	1.6	0.12

* Alum dose mg/l Al applied to the biological pre-treatment stage

By increasing the PAC dose, better treated water quality could be produced than that in the sedimentation plant. The low residual coagulant levels remaining in the flotation treated water when using PAC indicate that a shorter flocculation time is required for PAC than for aluminium sulphate. Similarly only a slight deterioration in flotation treated water quality was observed when the flowrate was increased from 95 to 104 m^3/h (Table 6).

Table 6. Effect of increasing the flowrate through the plant on the treated water quality using PAC - Strensham

Flowrate m^3/h	Raw water turbidity FTU	PAC-dose mg/l Al	Treated water turbidity FTU	Residual coag. mg/l Al
95	30	3.39	0.9	0.26
104	30	3.37	1.1	0.35

The optimum coagulation pH for PAC was not so critical as for aluminium sulphate and was in the range 6.2 to 7.2. In addition, as smaller coagulant doses were required when dosing PAC, the pH of the water was reduced less with PAC than with aluminium sulphate.

3.4. TREATMENT OF STORED, LOW-TURBIDITY, HIGHLY-COLOURED WATER - ARNFIELD

The raw water for the Arnfield Treatment Works originated from an upland catchment area and was taken from a chain of reservoirs in the Longdendale valley. The raw water was soft, of low alkalinity and turbidity, and the colour of the water could rise to moderately high levels (Table 7).

Table 7. Raw water quality data for the period January 1976 to January 1978 - Arnfield (Longdendale Reservoirs)

		Minimum	Maximum	Average
Temperature	°C	3	17	9
Turbidity	FTU	1.0	10.0	3.0
Colour (0.45 µm filtered)	°Hazen	10	60	35
pH		3.4	7.3	5.4
Permanganate value	mg/l as O_2	0.8	5.6	2.3
Alkalinity	mg/l as $CaCO_3$	2	8	4
Total hardness	mg/l as $CaCO_3$	24	35	30
Manganese	mg/l Mn	0.03	0.38	0.12
Iron	mg/l Fe	0.10	1.64	0.42
Aluminium	mg/l Al	0.10	0.15	0.14

Chemical treatment at the Main Works comprised pH adjustment with lime dosing with chlorinated ferrous sulphate as the primary coagulant and addition of a starch-based polyelectrolyte to improve the settling velocity of the flocs. This was followed by single stage mechanical flocculation and upflow floc blanket sedimentation. Before filtration the pH of the water was raised to approximately 9.0 for efficient manganese removal.

On the flotation pilot plant it was found to be more convenient to use ferric sulphate as the primary coagulant and caustic soda for pH adjustment. Experiments showed that similar treated water quality could be achieved when using chlorinated ferrous sulphate as the coagulant and lime for pH adjustment.

3.4.1. Effect of coagulant dose and pH on the flotation treated water quality

Provided the coagulant dose was above a certain low value (approximately 2 mg/l Fe) and the coagulation pH was within the optimum range, no residual colour remained in the flotation treated water, independent of the initial raw water colour. The higher dose levels used on the plant were required for the effective removal of the turbidity in the water (Fig. 12). For good coagulation the pH of the coagulated water had to be kept within a narrow range (Fig. 13) which varied according to the season. In the winter the optimum pH lay between 4.3 and 4.7 while in the summer the optimum pH increased and was between 4.8 and 6.2.

3.4.2. Comparison of the performance of the flotation plant with the Main Works sedimentation plant

Table 8 shows a comparison of the flotation and sedimentation treated water quality during operation of the plants at their respective design ratings (12 m/h upflow for flotation and 0.9 m/h for sedimentation).

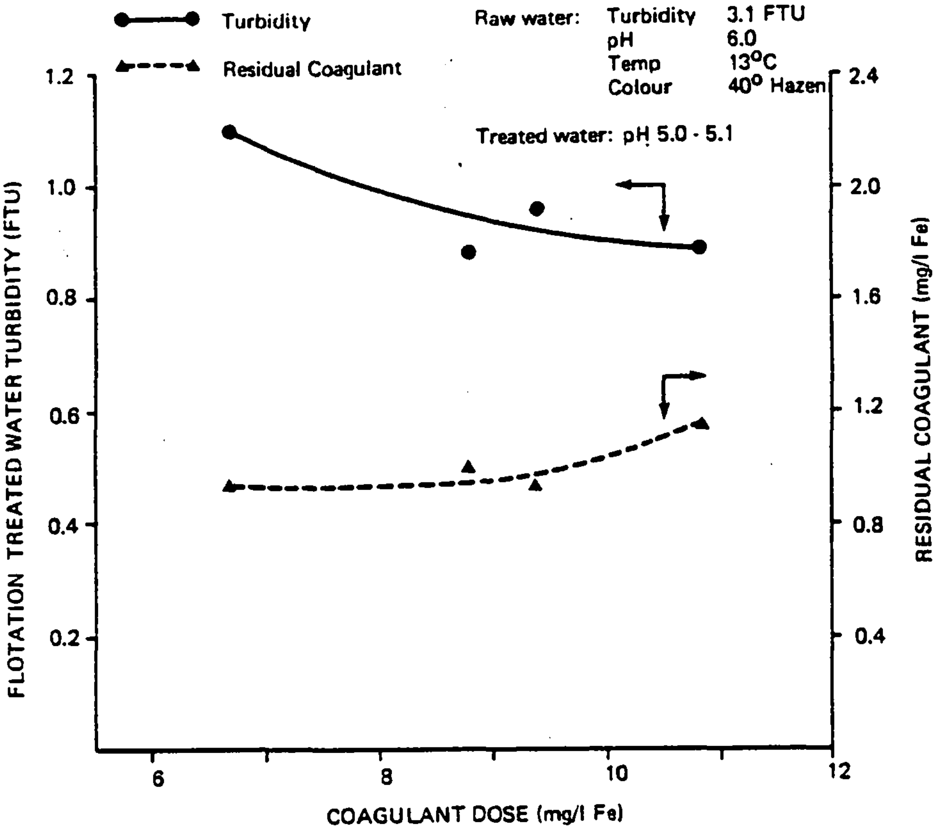


Fig. 12. Effect of coagulant dose on flotation treated water quality - Arnfield

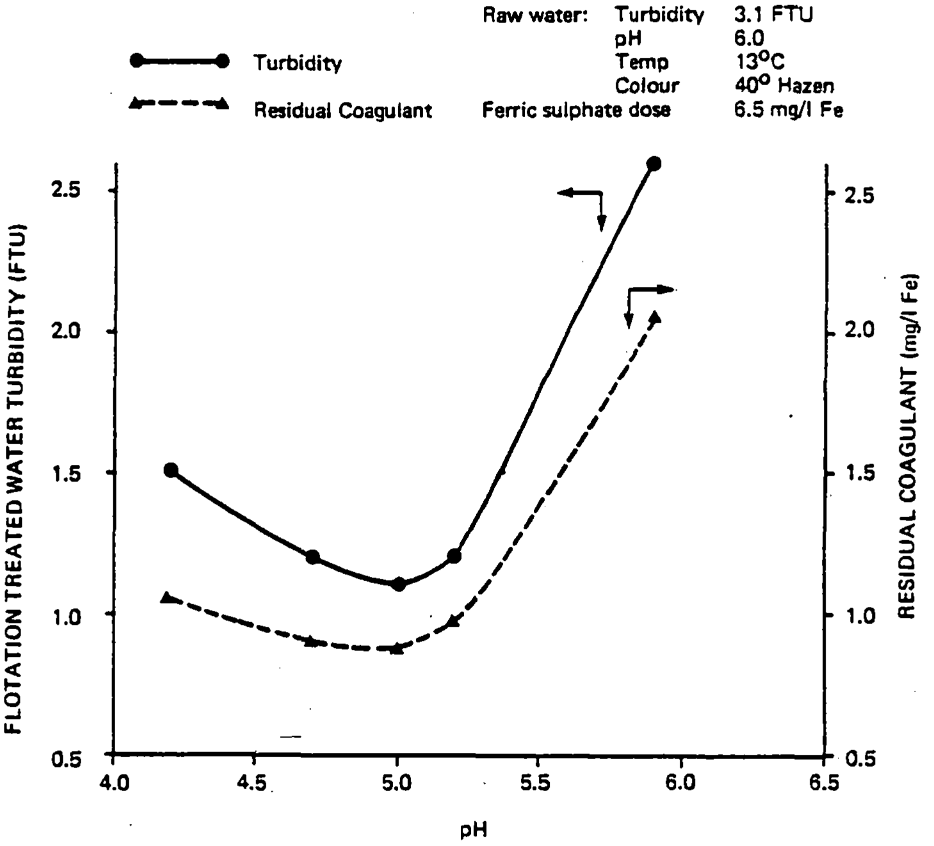


Fig. 13. Effect of pH on flotation treated water quality - Arnfield

Table 8. Comparison of flotation and sedimentation treated water quality - Arnfield

Sample	Dose mg/l Fe	pH	Turbidity FTU	Colour °Hazen	Iron mg/l Fe	Manganese mg/l Mn
Raw	-	6.2	3.2	45	0.70	0.11
Flotation treated	8.5	4.8	0.72	2	0.58	0.16
Flotation filtered	-	9.0	0.19	0	0.04	<0.02
Sedimentation treated	6.0 + 0.8 mg/l polyelectrolyte	5.05	0.50	0	0.36	0.14
Sedimentation filtered	-	10.5	0.29	0	0.01	<0.02

The Main Works coagulant dose and coagulation pH were determined by sedimentation jar test experiments. Trials on the flotation pilot plant showed that the optimum pH required for flotation was similar to that for sedimentation. Although reasonable flotation treated water quality could be obtained with the same primary coagulant dose as used on the Main Works, the flotation treated water quality could be improved further by increasing the dose. Therefore, for most of the work the dose used for flotation was about 2 mg/l Fe higher than for sedimentation. However, in addition to the primary coagulant, 0.8 mg/l of starch-based polyelectrolyte was needed in the Main Plant sedimentation unit. Generally, the sedimentation plant produced slightly better treated water quality than the flotation plant. In order to achieve the same performance it was necessary to increase the flocculation time by decreasing the flowrate through the flotation plant. This is discussed in Section 4.5.

3.4.3. Performance of aluminium sulphate and polyaluminium chloride (PAC) as primary coagulants in comparison with ferric sulphate

Table 9 shows that similar treated water quality could be achieved with aluminium sulphate and ferric sulphate at approximately equivalent relative doses.

Table 9. Comparison of ferric sulphate and aluminium sulphate as primary coagulants - Arnfield

Coagulant	Dose	Treated Water Quality			
		pH	Turbidity FTU	Residual coagulant	Colour °Hazen
Aluminium sulphate	3.25 mg/l Al	6.1	1.5	0.47 mg/l Al	<5
Ferric sulphate	7.85 mg/l Fe	4.85	1.5	0.90 mg/l Fe	<5

Flotation jar tests were carried out to compare PAC with aluminium sulphate, which indicated that for PAC the same treated water quality could be obtained at half the dose (expressed as mg/l Al) required for aluminium sulphate. Further improvement in treated water quality could be obtained by increasing the dose of PAC and the optimum dose required for PAC was found to be the same as for aluminium sulphate. A comparison of dosing ferric sulphate and PAC on the pilot plant at the optimum doses established in the flotation jar test is given in Table 10. Better turbidity removal was achieved, but the residual coagulant level for PAC was relatively high.

Table 10. Comparison of ferric sulphate and polyaluminium chloride as primary coagulants - Arnfield

Coagulant	Dose	Treated Water Quality			
		pH	Turbidity FTU	Residual coagulant	Colour °Hazen
Ferric sulphate	7.34 mg/l Fe	5.80	0.90	0.82 mg/l Fe	<5
PAC	3.74 mg/l Al	6.20	0.53	0.42 mg/l Al	<5

3.4.4. Effect of using polyelectrolytes as coagulant aids on the flotation treated water quality

Several polyacrylamides - Magnafloc LT22 and 24 (both cationic) and 25, 26 and 27 (all anionic) - were investigated as coagulant aids. No significant improvement in treated water quality was observed for any of the products. The starch-based polymer Perfectamyl, which was successfully used on the Main Works, was also tried. The dose level and the place of addition were varied but no significant improvement in treated water quality was obtained with this polyelectrolyte either.

3.5. TREATMENT OF NUTRIENT-RICH, LONG-TERM STORED WATER WITH ALGAL PROBLEMS - ARDLEIGH

The work at Ardleigh concentrated on evaluating the potential of flotation for algal removal. The raw water for the Ardleigh treatment works was abstracted from a 2.3×10^6 m^3 capacity reservoir yielding a moderately hard water of low turbidity. During the summer severe blue-green algal blooms occurred. The raw water quality experienced during the period of investigation is given in Table 11.

The treatment at the Main Works consisted of cascade aeration, coagulation with chlorinated ferrous sulphate, and pH adjustment with caustic soda, followed by upflow floc blanket sedimentation in Precipitators and rapid gravity anthracite/sand filtration. Facilities for polyelectrolyte and aluminium sulphate dosing were available.

3.5.1. Comparison of algal removal efficiency of flotation and sedimentation

During the experimental period, blooms of four different predominant algal species were experienced: *Microcystis aeruginosa*, *Aphanizomenon*, *Stephanodiscus hantzschii* and *Chlorella* sp. Table 12 shows that for all the algal species investigated flotation gave more efficient removal than upflow sedimentation.

3.5.2. Effect of different primary coagulants on the algal removal efficiency

The effectiveness of three different primary coagulants (chlorinated ferrous sulphate, aluminium sulphate and polyaluminium chloride (PAC)) for algal removal was investigated. Initial work concentrated on optimising the pH: this showed that for aluminium sulphate the coagulation pH should be between 6.8 and 7.2 for optimum residual coagulant, treated water turbidity and algal removal. For chlorinated ferrous sulphate the optimum pH for algal removal and treated water turbidity was approximately 7.5, but the best residual coagulant levels were obtained for pH values above 8.2. For PAC a wide pH range of 6.8 to 7.8 could be used without deterioration in treated water quality.

Table 11. Raw water quality data for the period January 1976 to December 1977 - Ardleigh

		Minimum	Maximum	Mean
Temperature	°C	2.0	22.5	11.3
Turbidity	FTU	1.1	12.0	2.6
Colour (GF/A filtered)	°Hazen	6	26	12
pH		8.0	9.4	8.7
Permanganate (GF/A filtered)	mg/l as O_2	1.2	2.8	2.2
value (unfiltered)	mg/l as O_2	1.3	3.4	2.4
Alkalinity	mg/l as $CaCO_3$	104	180	146
Total hardness	mg/l as $CaCO_3$	272	324	297
Orthophosphate (soluble)	mg/l as P	0.01	0.75	0.25
Silica	mg/l as SiO_2	0.36	9.30	4.6
Algal species - 1976				
Aphanizomenon June - August (filaments/ml)		ND	1 960	550
Microcystis February - April (cells/ml)		ND	340 000	205 000
Stephanodiscus (small type) March - April (cells/ml)		ND	55 500	18 000
Microcystis August - December (cells/ml)		ND	34 200	7 600
Algal species - 1977				
Anabaena May - June (filaments/ml)		ND	770	520
Aphanizomenon May - July (cells/ml)		ND	462 000	168 000
Microcystis July - November (cells/ml)		ND	205 000	77 000
Stephanodiscus (small type) January - May (cells/ml)		ND	11 600	5 800
Unicells March - April (cells/ml)		ND	54 400	34 200

Table 12. Comparison of the algal removal efficiency of flotation and sedimentation using chlorinated ferrous sulphate as coagulant - Ardleigh

Algal type	Raw water cells/ml	Sedimentation treated water cells/ml	Flotation treated water cells/ml
Aphanizomenon	179 000	23 000	2 800
Microcystis[*]	102 000	24 000	2 000
Stephanodiscus	53 000	21 900	9 100
Chlorella	23 000	3 600	2 200

[*] Aluminium sulphate was used as the coagulant.

During an algal bloom of *Microcystis* a comparison was made of the effectiveness of the three primary coagulants for algal removal at their optimum pH for lowest residual coagulant values. The raw water algal counts during the experiment with PAC were substantially higher (120 000 cells/ml) than for the other two coagulants (50 000 cells/ml). However, one value for aluminium sulphate at the same high algal counts as experienced during the PAC investigation (120 000 cells/ml) is available and has been included in the comparison. Figures 14 and 15 indicate that aluminium sulphate was the most effective coagulant in terms of turbidity, residual coagulant and algal removal, and that for PAC equivalent dosages in terms of aluminium were required to achieve similar algal removal efficiency. The poorest treated water quality was achieved with chlorinated ferrous sulphate.

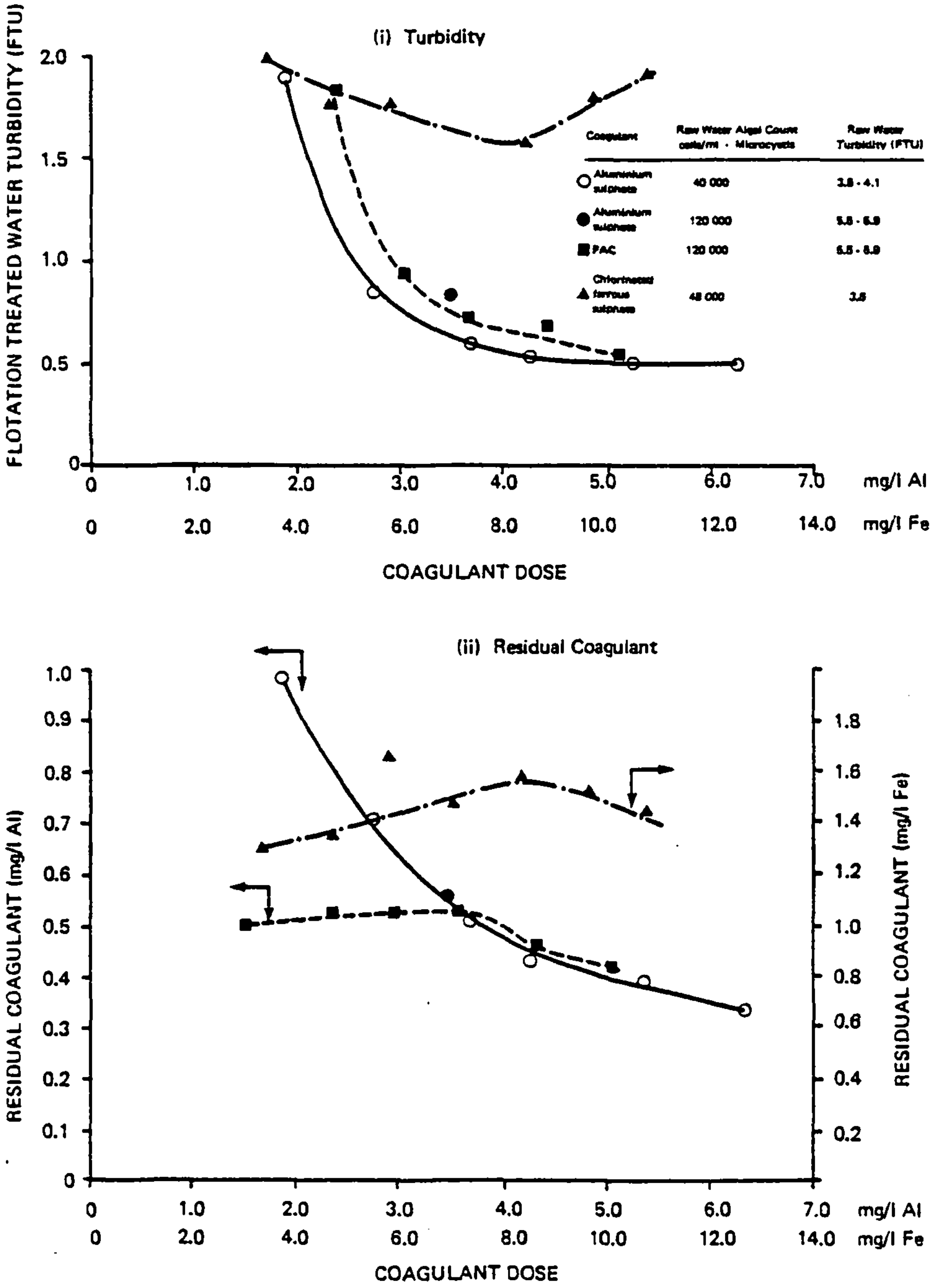


Fig. 14. Comparison of three different coagulants - Ardleigh

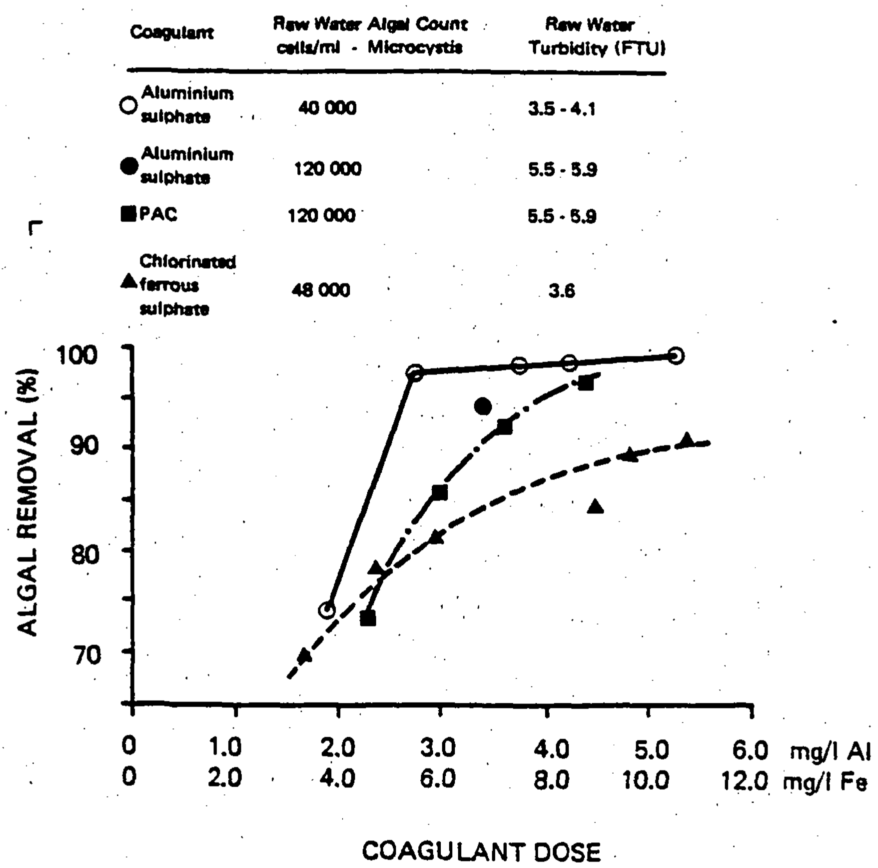


Fig. 15. Comparison of the effectiveness of three coagulants on algal removal - Ardleigh

3.5.3. Effect of polyelectrolytes on the algal removal efficiency

Using chlorinated ferrous sulphate as the primary coagulant, the influence of different polyacrylamides - Magnafloc LT20 (non ionic), LT24 (cationic) and LT25 (anionic) - on the algal removal was investigated. During an algal bloom of *Microcystis* (100 000 cells/ml), concentrations of 0 to 0.2 mg/l of polyelectrolyte were added, but no improvement in algal removal, treated water turbidity, or residual coagulant was noticed.

On the Main Works sedimentation plant the starch-based polyelectrolyte Wisprofloc 20 was used as a coagulant aid. During an algal bloom of *Stephanodiscus* (32 000 cells/ml), this polyelectrolyte was dosed on the flotation plant at a concentration of 0.5 mg/l with chlorinated ferrous sulphate as primary coagulant: again no improvement in treated water quality was found compared with using chlorinated ferrous sulphate alone.

Tests were also carried out using no coagulant on the flotation plant which showed that only approximately 20% of the algae were removed. The results show that for effective algal removal efficient coagulation is required.

4. FLOCCULATION

At all the plants it was found that efficient flocculation was essential for overall plant performance. Some of the factors affecting flocculation are discussed below.

4.1. COAGULANT DOSE AND pH

Good flocculation depended on the correct coagulant dose and pH. This has been discussed in detail in Section 3 for the different raw waters investigated.

4.2. POSITION AND ORDER OF DOSING THE COAGULANT AND ACID/CAUSTIC FOR pH CONTROL

Initially the chemicals were added to the flash mixer, but tests carried out at Langham (3-day stored river water) showed that dosing the chemicals directly into the raw water feed pipe gave improved results (Table 13).

Table 13. Effect of varying the points of addition of the treatment chemicals - Langham

Points of addition		Flotation treated water quality	
Ferric sulphate	Caustic soda	Turbidity FTU	Residual coagulant mg/l Fe
Into flash mixer	Into pipe	1.7	0.97
Into pipe	Into pipe	0.87	0.74

The better results achieved can be explained by the improved mixing efficiency in the pipe compared with that in the flash mixer. Experiments were also carried out on the other plants, and in all cases better treated water quality was obtained when dosing the chemicals directly into the feed pipe. The order of chemical addition had little influence on the treated water quality - either equal or slightly better results were obtained dosing the pH adjustment chemical first.

At Arnfield (low-turbidity, highly-coloured water) the distance along the feed pipe separating the points of addition of the chemicals could be varied. Figure 16 indicates that provided the distance between the points used for the caustic soda and ferric sulphate dosing was more than 2 m, the treated water quality was not influenced. However, when the points were separated by less than 2 m a deterioration in treated water quality occurred, which indicates that good mixing of the first chemical should be completed before the next chemical is added. (During the investigation, the flotation plant was operated at a reduced flow of 57 m^3/h giving a pipe flow velocity of 1 m/s.)

4.3. EFFECT OF PADDLE SPEEDS

Figure 17 shows the effect of varying the paddle speeds at the Ardleigh plant (nutrient-rich, long-term stored water). Using uniform paddle speeds (all three paddles operating at the same speed) it was found that a minimum of 8 rev/min was required (corresponding to a mean velocity gradient of $G = 75\ s^{-1}$). Similar results were found with the other plants, with a deterioration in treated water quality

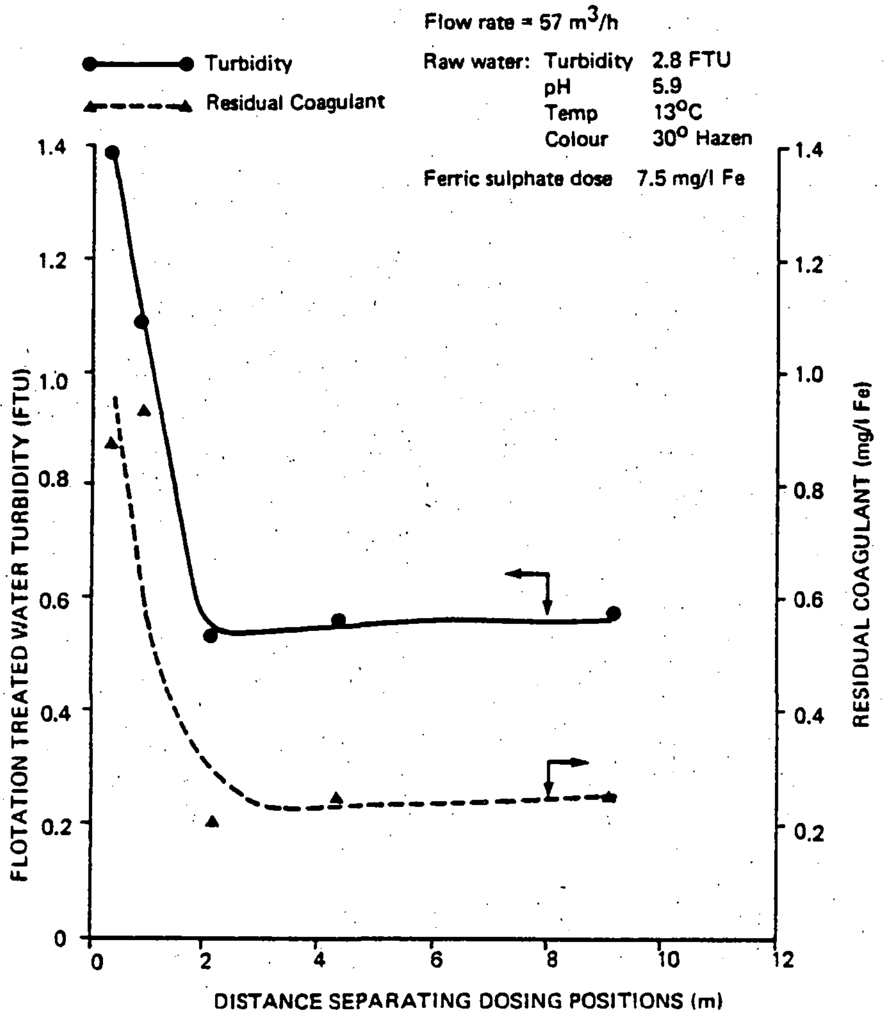


Fig. 16. Effect of distance separating dosing positions on flotation treated water quality - Arnfield

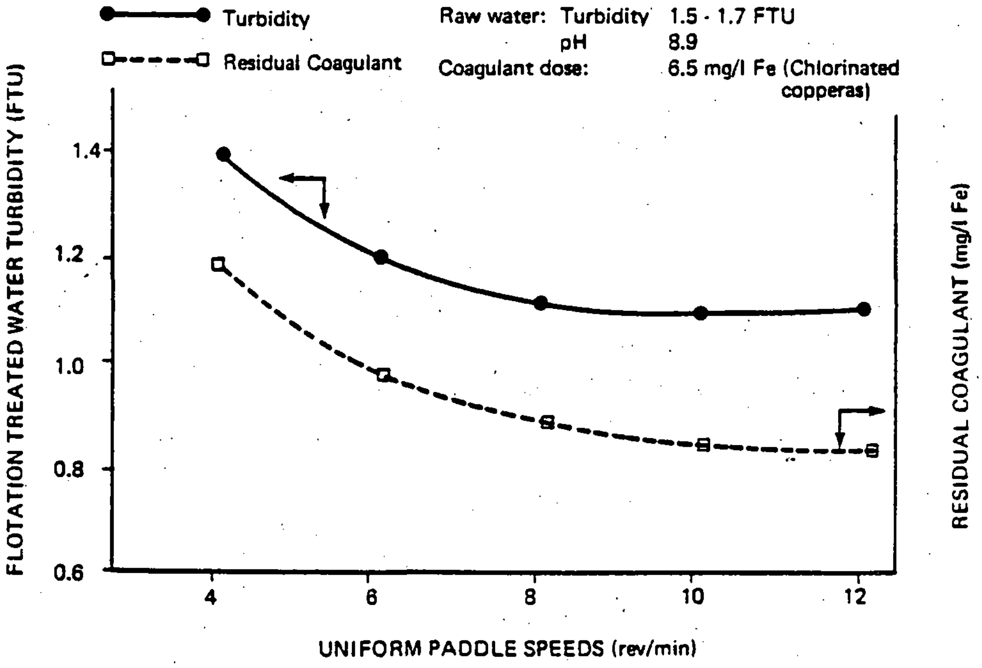


Fig. 17. Effect of varying uniform paddle speeds on flotation treated water quality - Ardleigh

generally occurring at speeds above 12 rev/min. The optimum paddle speeds resulted in floc sizes of about 0.5 to 1.0 mm, with the larger flocs occurring when treating high turbidity water. Tapering the paddle speeds gave no improvement except at Strensham (turbid river water) where tapering the paddle speeds to 10:7:5 rev/min was occasionally beneficial.

4.4. EFFECT OF THE NUMBER OF FLOCCULATION STAGES

At Arnfield (low-turbidity, highly-coloured water) flotation jar test experiments indicated that improved water quality could be achieved by increasing the flocculation time. The flash mixer of the plant was therefore replaced by a fourth flocculator stage, increasing the flocculation time from 12 to 16 minutes at the design flowrate of 95 m^3/h. Improved treated water quality both in respect to turbidity and residual coagulant was obtained (Fig. 18).

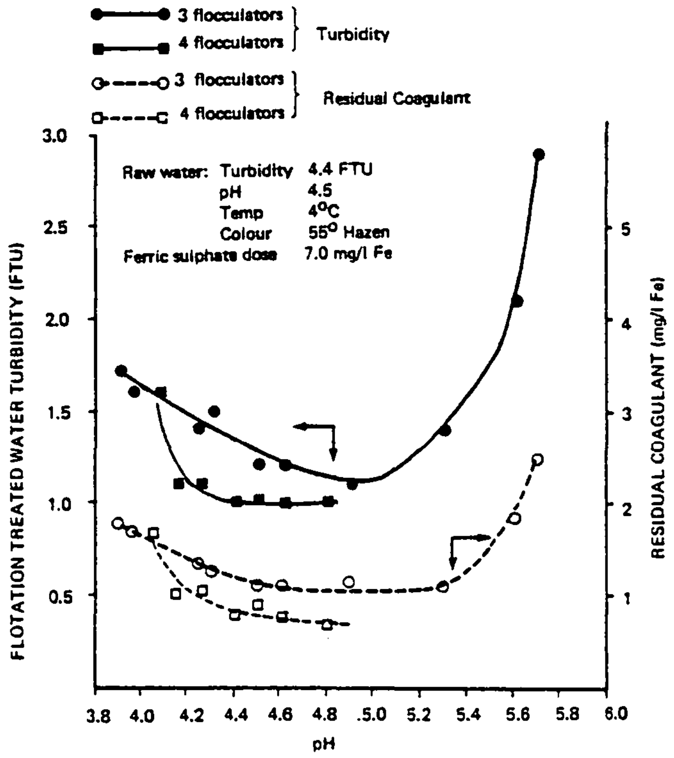


Fig. 18. Effect of varying pH using 3 and 4 flocculators - Arnfield

To investigate whether the improvement was due to using four instead of three flocculation stages, the flowrate through the plant was adjusted to give equal flocculation times in the two experiments. The results shown in Table 14 indicate that no benefit was gained by using four flocculator stages instead of three, provided the flocculation time was the same. In both tests excess air (Section 5) was supplied to the flotation tank and the effect observed can therefore be attributed to the flocculation rather than the flotation.

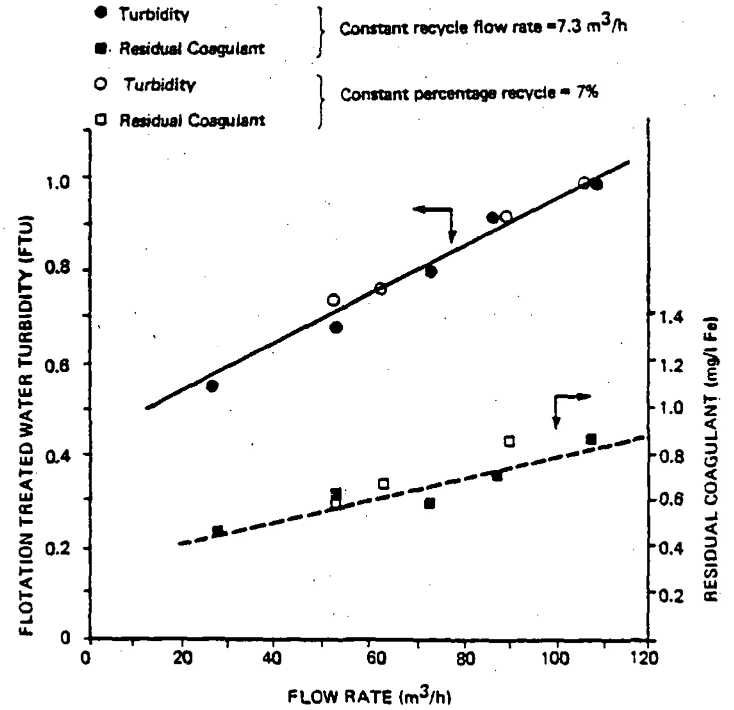
4.5. EFFECT OF FLOWRATE

Again at the Arnfield plant (low-turbidity, highly-coloured water) the effect of the flowrate through the plant on the treated water quality was investigated. Two experiments were carried out: in the first the recycle flowrate was kept constant at 7.3 m^3/h resulting in varying percentage recycle for the different plant flowrates; in the second the amount of recycle was adjusted with the plant flowrate to give a constant percentage recycle of 7% (Fig. 19). As in both experiments similar treated water quality was obtained for a given throughput, the improvement in the quality with reduction in flowrate can be attributed to the increased flocculation time. It can also be concluded that provided sufficient air is supplied to the flotation tank in the form of recycle, the excess air results in no improvement in treated water quality.

At Strensham (turbid river water) a reduction in flowrate also gave improved treated water quality, especially during high turbidity raw water conditions. However no significant improvement in treated water quality was found at Langham (3-day stored water) when the flowrate was reduced to 50% of the 95 m^3/h design rate. Similarly at Ardleigh (nutrient-rich, long-term stored water) no benefit was obtained when reducing the flowrate.

Table 14. Effect of the number of flocculator compartments on the treated water quality - Arnfield

No. of flocculator stages	Flowrate m^3/h	Flocculation time min	Treated water quality Turbidity FTU	 Residual coagulant mg/l Fe
3	66	17.3	0.82	0.80
4	90	16.9	0.86	0.80



Raw water: Turbidity 3.6 FTU
pH 4.7
Temp 3.5°C
Colour 30 - 40° Hazen

Coagulant dose 6.5 - 7.5 mg/l Fe
Treated pH 4.6 - 4.8

Fig. 19. Effect of varying flowrate on flotation treated water quality - Arnfield

5. QUANTITY OF AIR REQUIRED FOR FLOTATION

5.1. SATURATION SYSTEM

Previous work(4) had shown that the level of saturation achieved in an unpacked saturator was only 60 to 70% of that obtained in a packed saturator and therefore the unpacked saturator had to be operated at pressures 100 to 200 kPa above those for a packed saturator for equal performance. Measurements had also shown that 100% air saturation could be achieved in a packed saturator. Although some deposition on the packing occurred, no blocking was observed. Because of these advantages, all plants were equipped with packed saturators.

The pressure vessels were designed for a loading of 410 m^3/m^2 d. Higher surface loadings have been reported(5) but a conservative loading was chosen for the flotation trials to ensure that the saturator performance was not the limiting factor in evaluating the potential of the flotation process. Using an apparatus similar to that described elsewhere(5) tests were carried out on the saturator vessels of the Langham and Strensham plants, which showed that 100% saturation was being obtained up to the maximum pressure of 550 kPa investigated (based on saturation data quoted in(5)).

5.2. EFFECT OF VARYING THE PRESSURE AND RECYCLE ON THE FLOTATION TREATED WATER QUALITY

The quantity of air supplied to the flotation tank could be varied by altering the saturator pressure and/or the recycle. Altering the saturator pressure was associated with a slight change in recycle. To obtain a variation in recycle at constant pressure, the nozzle sizes had to be changed (Fig. 20). In all the plants flotation treated water was used as recycle.

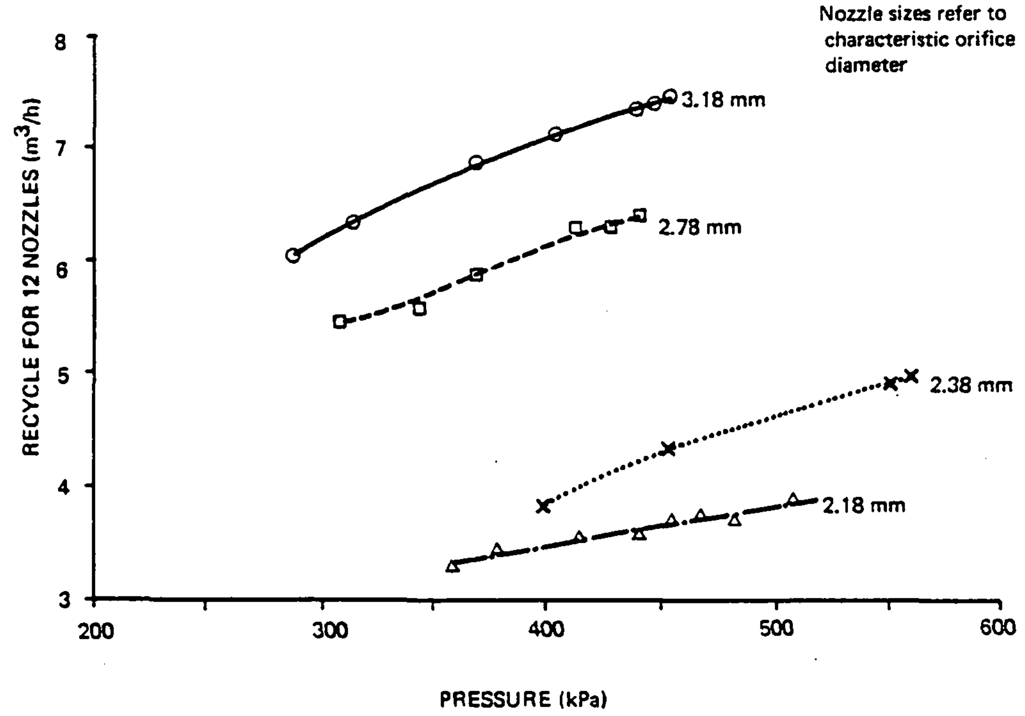


Fig. 20. Effect of pressure on recycle for different nozzles - Arnfield

Tests were carried out on the Arnfield pilot plant (low-turbidity, highly-coloured water) to study the effect of varying the recycle at different pressures (Fig. 21). The results indicate that with increasing saturator pressure a lower rate of recycle is required to achieve the same treated water quality. For the particular raw water conditions experienced during the test, the optimum operating conditions were found to be a recycle of 6.5% at a pressure of approximately 350 to 400 kPa.

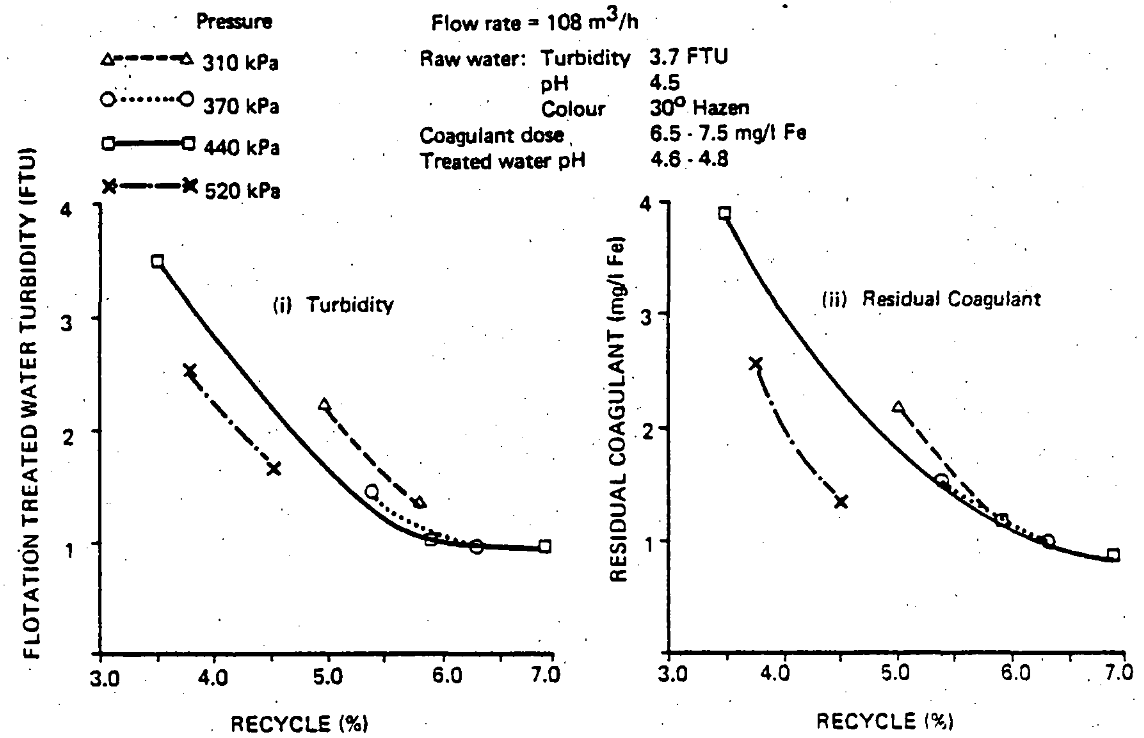


Fig. 21. Effect of pressure and recycle on flotation treated water quality - Arnfield

By assuming 100% saturation at the temperature of the recycle stream (4 °C) during tests, the quantity of air released can be calculated for the different recycles and pressures. Figure 22 shows that approximately 8 g of air/m^3 of treated water were required for optimum operation of the plant for the raw water conditions prevailing during the course of the experiments. It can be concluded that it is the quantity of air added to the water that is important and not the individual values of the pressure or recycle. The results confirm data obtained from the 8.2 m^3/h pilot plant treating River Thames water which indicated that approximately 7 g air/m^3 raw water was required for optimum operation(6).

On the other four pilot plants it was found that there was generally little benefit in terms of treated water quality from increasing the pressure and recycle above 480 kPa and 8% respectively. However, at Strensham (turbid river water) during flood conditions an improvement in treated water quality was obtained by raising the recycle to 11% at a pressure of 480 kPa, corresponding to 15 g air/m^3 raw water. The higher amount of air was required to cope with the very high solids loadings experienced during these periods of river floods.

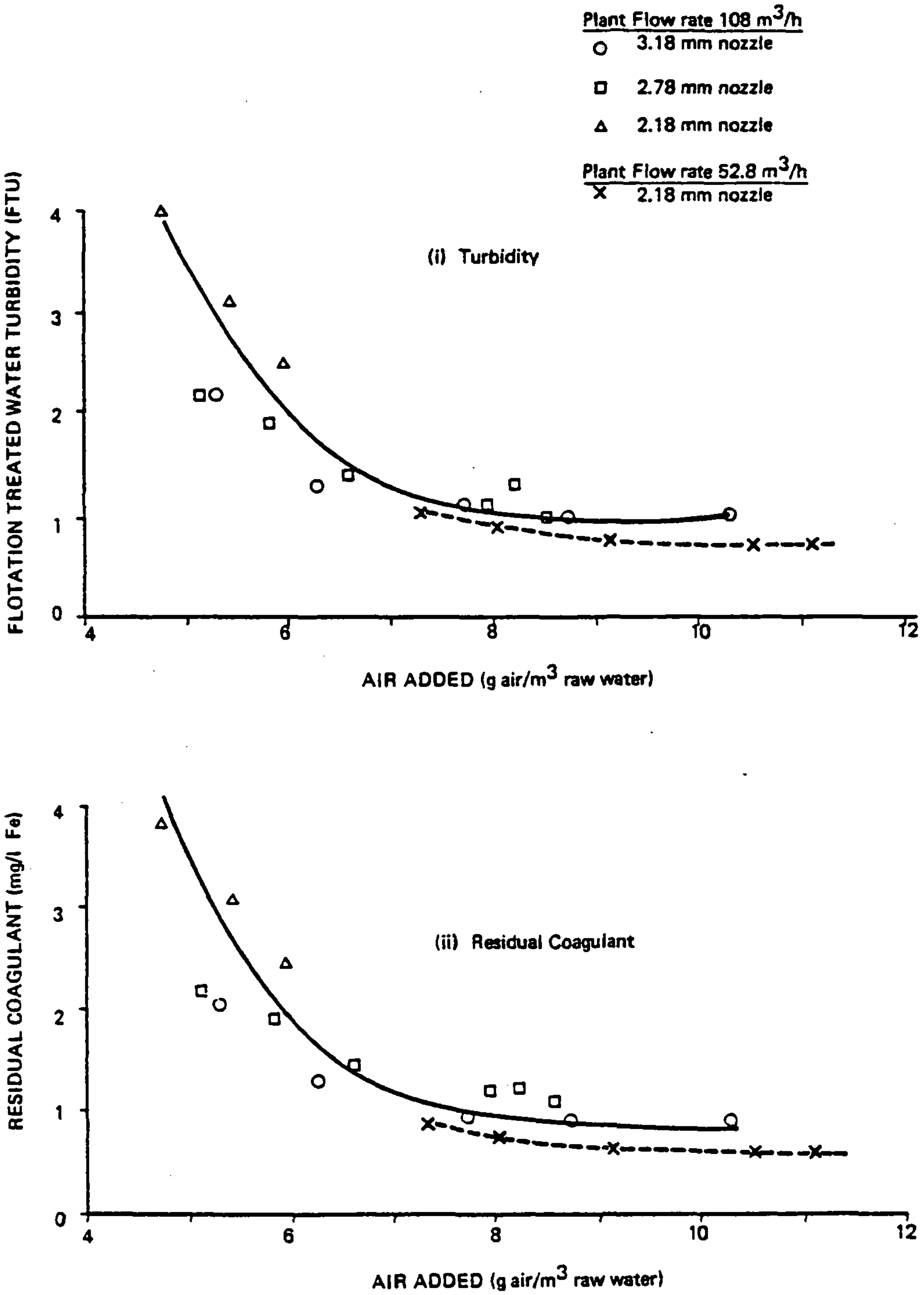


Fig. 22. Effect of quantity of air added on flotation treated water quality - Arnfield

5.3. NUMBER OF AIR INJECTION NOZZLES USED

To ensure adequate mixing between the flocculated water and the air released from the recycle stream, twelve WRC nozzles on a 300 mm spacing supplied from a common manifold were used for introducing the recycle to the flotation tank. On the Langham plant, which had a narrower flotation tank, the nozzle spacing was maintained at 300 mm by reducing the number of nozzles to eight. At Strensham a bank of eighteen nozzles was compared with twelve nozzles at equal recycle, which produced similar treated water qualities. Again, at the Langham plant, increasing the number of nozzles from eight to twelve did not result in an improvement in treated water quality.

6. SLUDGE PRODUCED BY FLOTATION

Initially, continuous or intermittent flooding was used on all plants for the removal of the sludge. Continuous flooding required some water to be continuously drawn over the sludge take-off weir with the sludge. For intermittent flooding the sludge was allowed to accumulate on the flotation tank surface for a prolonged period. The sludge was subsequently removed by closing off the treated water outlet completely and passing the total flow together with the sludge over the sludge take-off weir. Both methods produced sludge of only low solids content.

The initial work indicated that the characteristics of the sludges obtained from the treatment of different raw waters varied considerably. Therefore three plants producing sludges representative of the different types encountered during the investigation were selected and equipped with mechanical sludge removal devices. The results obtained for the different types of sludges will be discussed separately.

6.1. SLUDGE PRODUCED FROM THE TREATMENT OF TURBID RIVER WATER - STRENSHAM

6.1.1. Sludge removal and its effect on the treated water quality

Figure 23 shows the build-up of the sludge layer over a 30-hour period and its effect on the treated water quality. A rapid build-up of sludge occurred with only a slight deterioration in treated water quality. However, if the sludge was allowed to accumulate for too long, sludge particles tended to be sheared off the floated sludge. These particles did not refloat and resulted in a deterioration in treated water quality. These experiments were carried out during a period of low raw water turbidity and more frequent removal of the sludge was required when the raw water turbidity was high.

Removal of the accumulated sludge by flooding took approximately 10 minutes. Desludging every 12 hours resulted in a water loss of approximately 1.4% and in addition the solids content of the removed sludge decreased rapidly (Fig. 24). Installation of water sprays on the tank walls prevented the sludge adhering to the walls and shortened the removal time to about 2.5 minutes.

Removal of the accumulated sludge by manually scraping the total flotation tank surface resulted in a deterioration in treated water quality which returned to its original value after approximately 15 minutes. The degree of deterioration increased with the amount of sludge which had to be removed. Sludge solids concentrations of 6 to 8% were achieved. The sludge could also be removed by allowing it to trickle slowly over the weir. This, however, required that the flowrate through the plant remained constant, which was difficult to achieve. Once the sludge stopped flowing over the weir, it started to consolidate and a different sludge removal method had to be employed. Sludge solids concentrations of up to 11% were achieved by continuous trickling during high raw water turbidity periods (> 50 FTU).

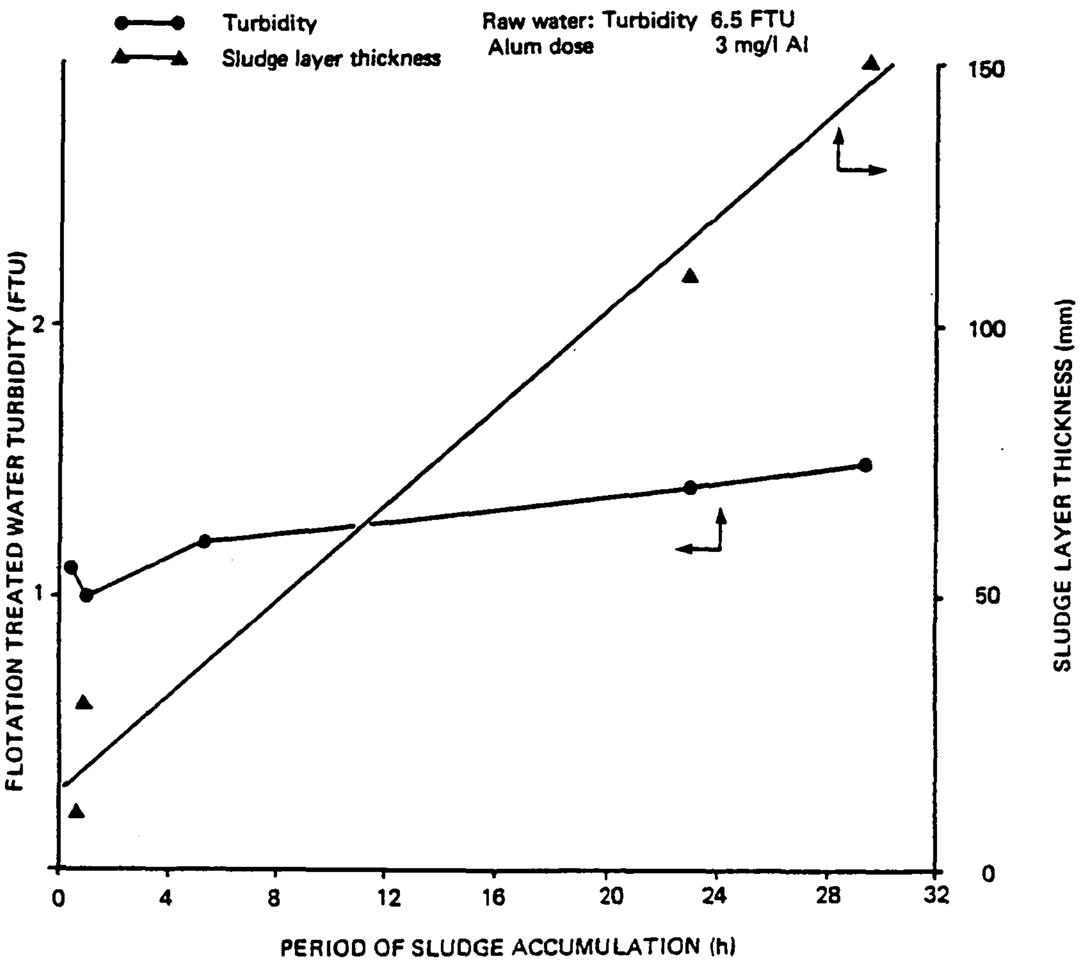


Fig. 23. Effect of sludge accumulation on flotation treated water quality - Strensham

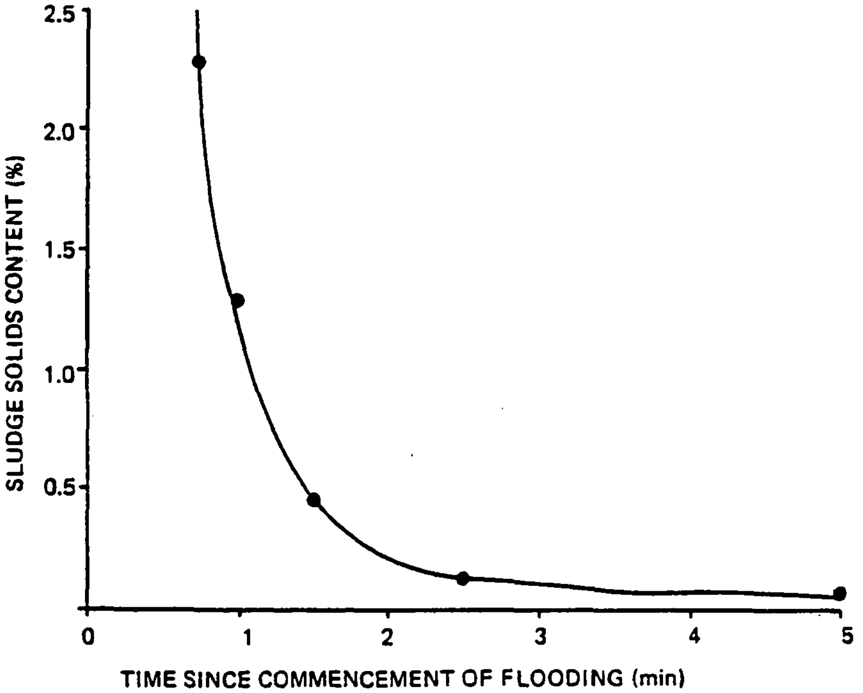


Fig. 24. Reduction of sludge solids content with time since commencement of flooding - Strensham

At a later stage of the investigation a sludge beach scraper (sludge roll) was installed on the plant. The eight rubber blades of the scraper rotated over the sludge take-off weir and pushed the sludge up the beach into the sludge trough. Tests showed that best results could be achieved by operating the scraper continuously and maintaining a thin layer of sludge 10 to 20 mm thick on the surface by adjusting the water level in the flotation tank. Intermittent removal resulted in sludge break-up and a deterioration in treated water quality. Operating the sludge roll continuously during treatment of low turbidity raw water (< 10 FTU), sludge solids concentrations of 3 to 4% were consistently produced. No tests were carried out during high raw water turbidity conditions which would probably have yielded higher sludge solids concentrations.

6.1.2. Filter pressing of the sludge

Sludge samples collected from the flotation plant tended to separate upon standing into two layers: a floated and a settled layer. Before filter pressing, the sludge was de-aerated by stirring and gently agitated at intervals to provide uniform feed to the press.

Two sludges produced by continuous trickling were investigated: an 8% solids concentration alum sludge and an 11% PAC sludge. The filter pressing was carried out at a pressure of 800 kPa (115 psi) in a 229 mm (9 in) laboratory unit. The results are shown in Table 15.

Table 15. Results of sludge filter pressing trials: filter pressure 800 kPa (115 psi); cake thickness 22 mm (7/8 in) - Strensham

Type of sludge	Sludge solids concentration	Press time	Cake solids concentration
	%	h	%
Alum	8.1	4.75	52
PAC	11.6	4.50	40

These filter press results were achieved without the addition of polyelectrolytes. Capillary Suction Time (CST) determinations carried out on the PAC sludge according to the Stevenage procedure(7) indicated that even better sludge pressing results could be achieved by the addition of 0.1% Magnafloc LT27 (anionic polyacrylamide) based on the weight of dry solids in the sludge.

6.2. SLUDGE PRODUCED FROM THE TREATMENT OF STORED, LOW-TURBIDITY, HIGHLY-COLOURED WATER - ARNFIELD

6.2.1. Sludge removal and its effect on treated water quality

The sludge produced from the treatment of low turbidity, highly coloured water behaved very differently from the sludges produced from the treatment of the other raw waters. On the Arnfield pilot plant, if the sludge was allowed to accumulate on the surface of the flotation tank, break-up of the sludge occurred after only

30 minutes of accumulation, resulting in sludge particles in the flotation treated water. Although the deterioration of turbidity and residual coagulant levels was relatively small (Fig. 25), a significantly greater rate of headloss development was observed (Fig. 26). There was, however, no effect on the filtered water quality (Fig. 27). Attempts to remove the sludge by mechanical scraping after several hours' accumulation led to a severe deterioration in treated water quality with residual coagulant levels reaching 30 mg/l Fe. After prolonged periods of sludge accumulation a considerable depth of sludge (250 mm) built up at the bottom of the flotation tank.

Dosing starch-based polyelectrolytes on the Main Works sedimentation plant improved the floc blanket stability (polyacrylamides were not successful in pilot plant trials). Experiments were therefore carried out dosing the non-ionic starch-based polyelectrolyte 'Fostarch SP' on the flotation plant to try to improve the stability of the floated sludge during sludge accumulation. However, no improvement in the sludge stability was obtained. The effect of using aluminium sulphate instead of ferric sulphate as the primary coagulant was also investigated. This did not improve the stability of the sludge produced either.

To avoid the problem of sludge break-up, the sludge had to be removed continuously. A full-length mechanical scraper was installed on the flotation tank and two methods of sludge removal were investigated: continuous scraping and continuous flooding. For continuous scraping it was found that the best results in terms of flotation treated water quality and sludge solids concentration were achieved at a scraper speed of about 0.5 m/min (Fig. 28). At slower scraper speeds the sludge remained sufficiently long on the surface for sludge break-up to occur. At higher speeds both the sludge solids concentration and the treated water quality deteriorated.

Table 16 gives a comparison of the treated water quality and sludge solids concentration obtained by continuous scraping and continuous flooding. The data show that a slightly better treated water quality but a substantially lower solids concentration resulted from continuous flooding. The solids concentration obtained by continuous scraping was about 1% which was similar to that produced in the concentrators of the sedimentation tanks of the Main Works.

Table 16. Comparison of sludge removal by continuous flooding and continuous scraping - Arnfield

Sludge removal method	Flotation treated water quality		Water loss	Sludge solids concentration
	Turbidity FTU	Residual coagulant mg/l Fe	%	%
Continuous flooding	0.69	0.64	1.6	0.11
Continuous scraping	0.77	0.73	0.2	1.0

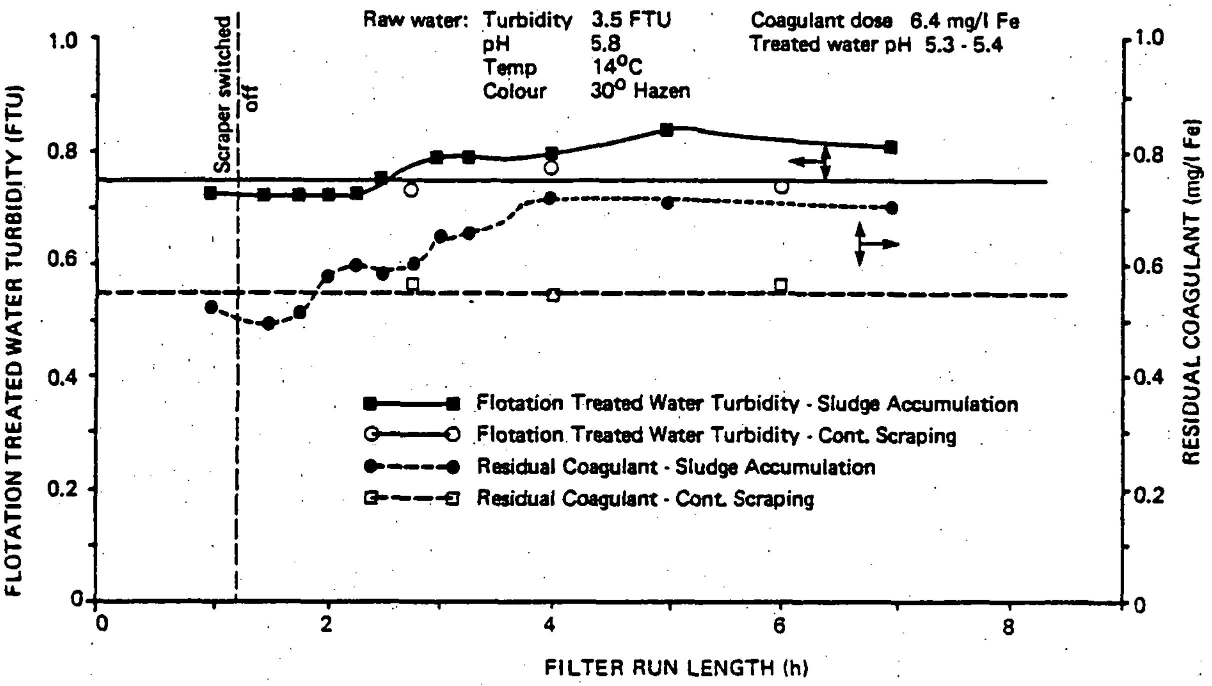


Fig. 25. Effect of sludge accumulation on flotation treated water quality - Arnfield

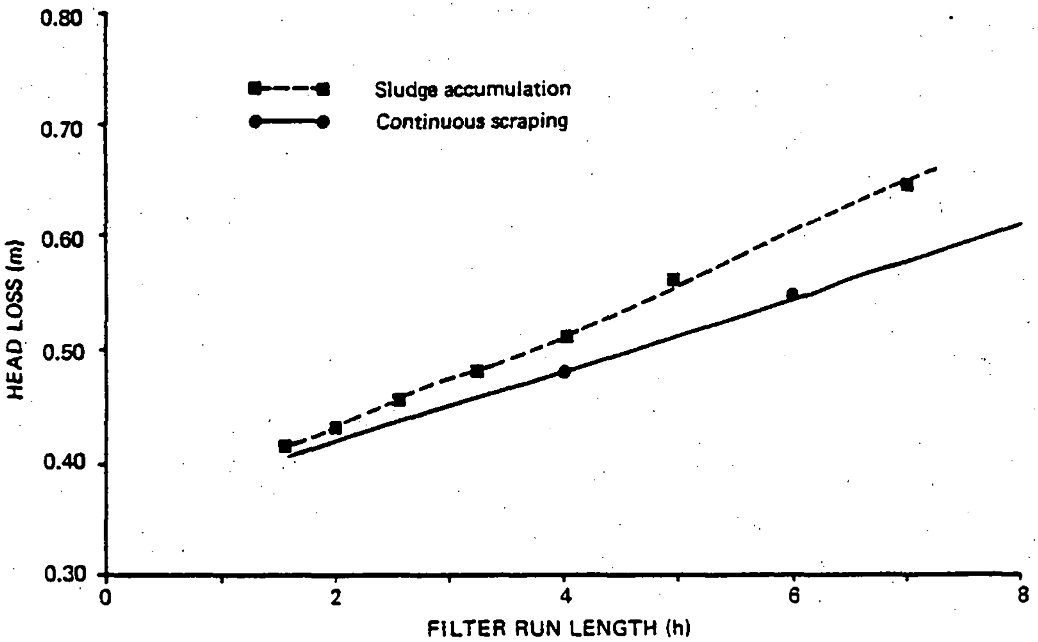


Fig. 26. Effect of sludge accumulation on filter headloss development - Arnfield

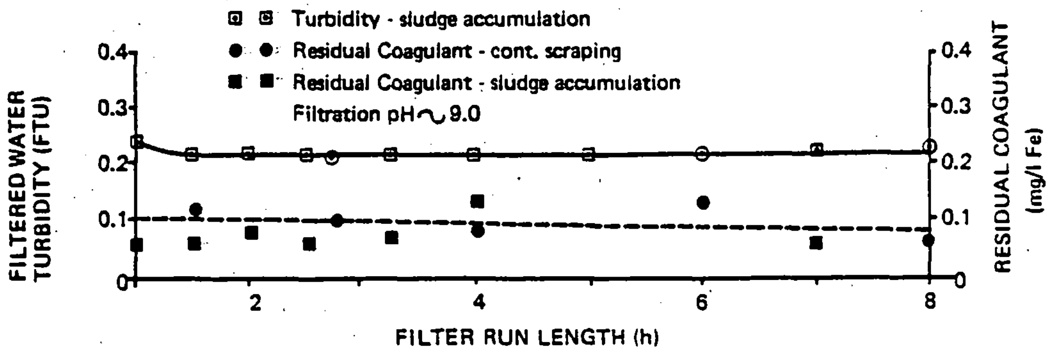


Fig. 27. Effect of sludge accumulation on the filtration of flotation treated water - Arnfield

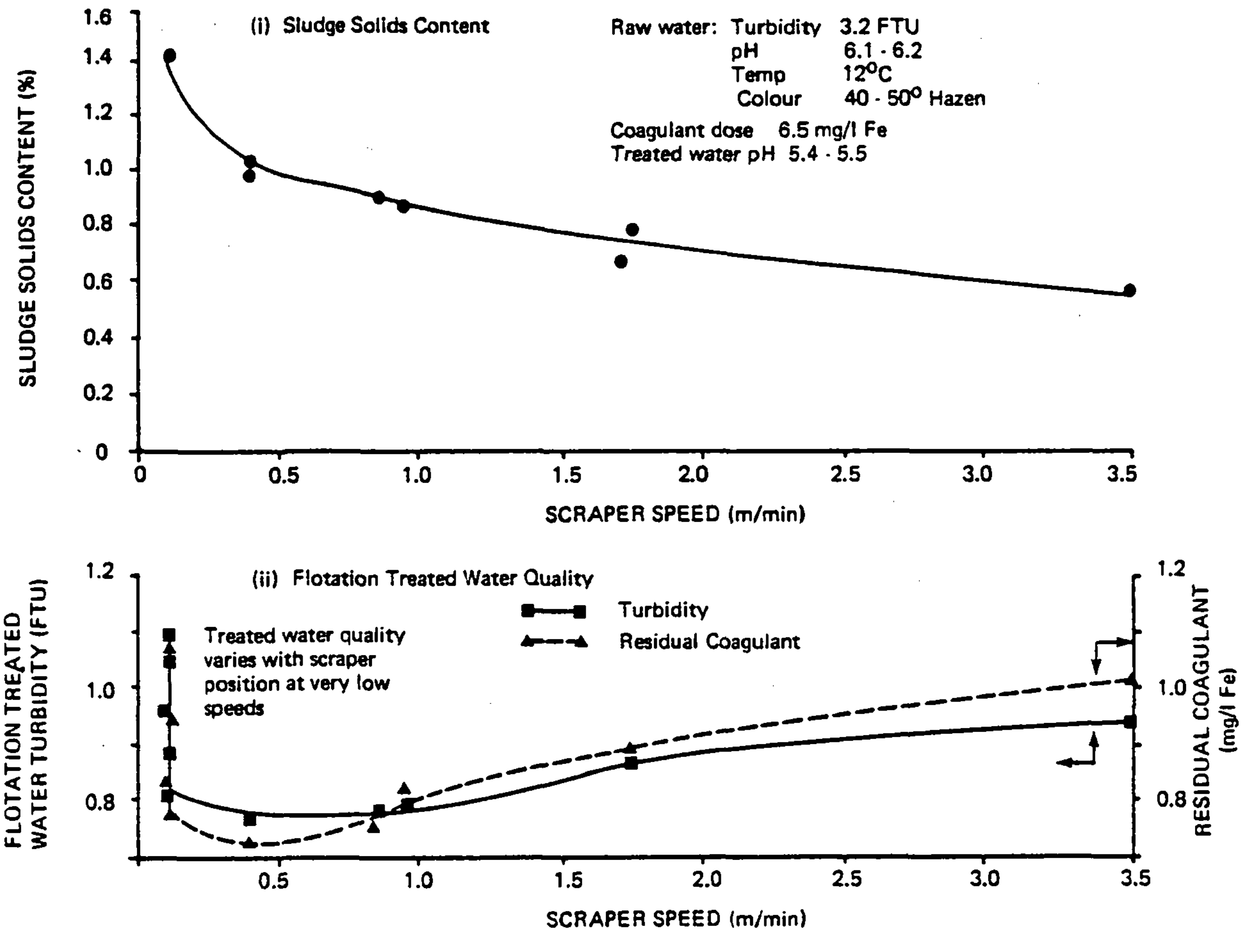


Fig. 28. Effects of scraper speed - Arnfield

6.2.2. Filter pressing of the sludge

Filter pressing trials on the flotation sludge at Arnfield produced a 16 mm (⅝ in) thick cake of 15 to 20% dried solids concentration in 5½ hours' pressing time without the addition of polyelectrolyte or lime. Sludge samples taken from the outlet of the sludge collection chamber contained very little entrained air.

6.3. SLUDGE PRODUCED FROM THE TREATMENT OF NUTRIENT-RICH, LONG-TERM STORED WATER WITH ALGAL PROBLEMS - ARDLEIGH

6.3.1. Sludge removal and its effect on treated water quality

Tests were carried out on the effect of sludge accumulation on the flotation treated water quality when using aluminium sulphate and chlorinated ferrous sulphate as coagulants. Sludge accumulation of up to 16 hours did not result in any deterioration in treated water quality. The sludge appeared quite frothy especially during periods of high algal counts in the raw water, and the thickness of the sludge layer after 16 hours' accumulation sometimes exceeded 200 mm. The accumulated sludge could be removed within approximately 10 minutes by flooding.

Again, because of the relatively large quantity of water required to remove the sludge (1% of plant flowrate when desludging every 16 hours), the solids concentration of the sludge produced by flooding was low (< 0.1%).

To improve the solids concentration of the sludge taken off the flotation tank, a sludge beach scraper similar to that described in Section 6.1.1 was installed. Initially the scraper was fitted with eight blades to ensure that one of the blades was always in contact with the sludge take-off beach. Figure 29 shows the effect of the rotational speed of the scraper on the treated water quality after sludge accumulation for 2 hours. The results show that only a small deterioration in treated water quality occurred during the initial scraping period. At the slow rotational speed (0.9 rev/min) 30 minutes were required to remove all the sludge from the surface of the flotation tank; whereas at the higher speed (3.75 rev/min) it took only 5 minutes. The sludge solids concentration at the lower speed was greater (1.5%) than at the higher speed (1.0%) because at the higher speed more water was drawn over the beach with the sludge.

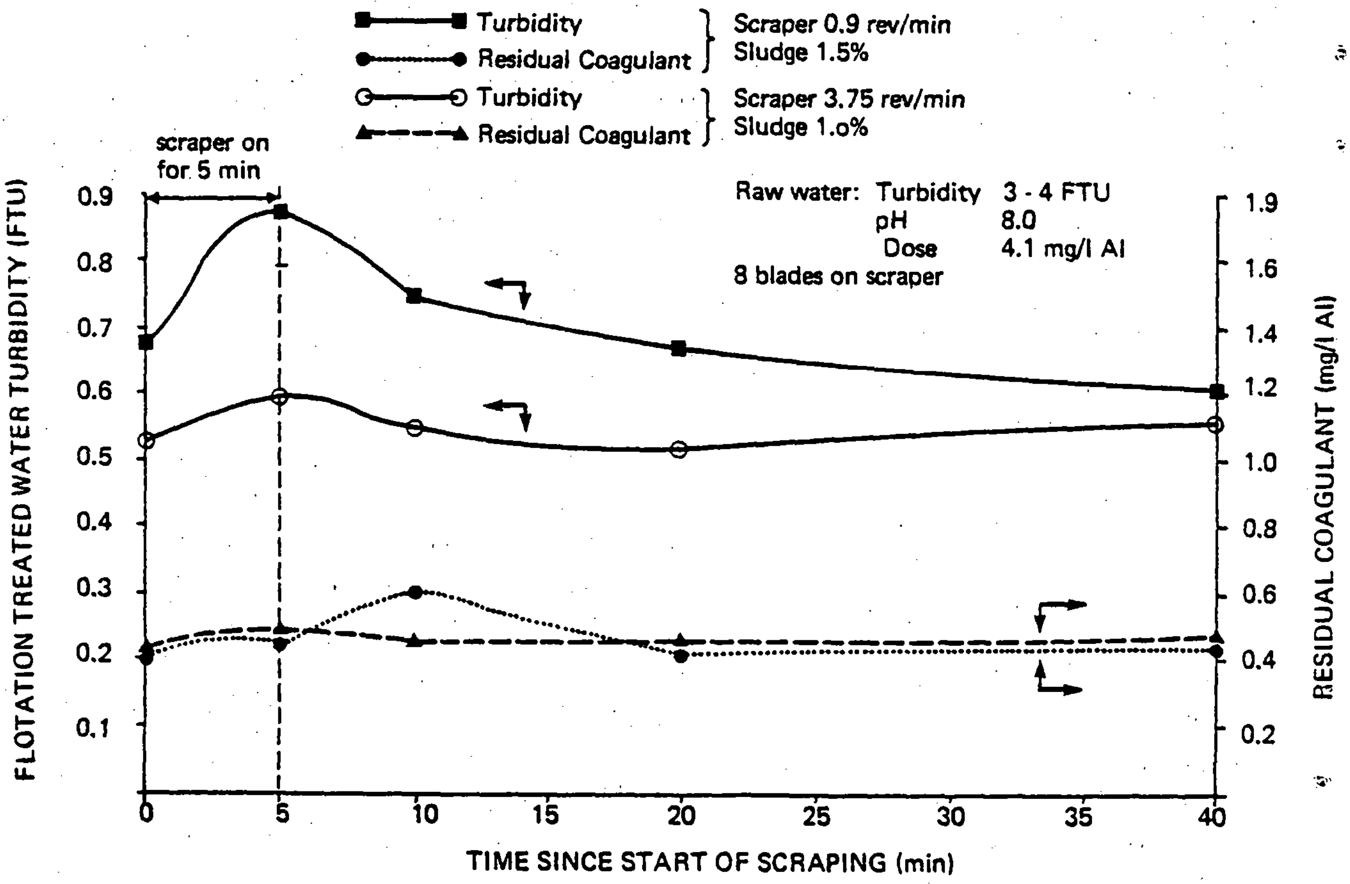


Fig. 29. Effect of intermittent scraping on flotation treated water quality - Ardleigh

A comparison of operating the sludge scraper with four and eight blades at 0.9 rev/min (the minimum rotational speed) showed that a thicker sludge could be produced by adjusting the water level in the flotation tank to the bottom of the beach and by reducing the number of blades to four (Table 17).

Table 17. Comparison of operating the sludge beach scraper with four and eight blades - Ardleigh

Number of scraper blades	Water level in the flotation tank	Sludge solids concentration %	Treated water quality Turbidity FTU	Residual coagulant mg/l Al
8	Bottom of beach	1.4	0.61	0.49
	Top of beach	0.6	0.61	0.48
4	Bottom of beach	3.0	0.72	0.62
	Top of beach	0.6	0.68	0.54

By adjusting the water level to the bottom of the beach, the blades moving over the beach came only in contact with the sludge and not the underlying water. Therefore, less water was drawn over the beach by the blades.

The best operation of the scraper in terms of flotation treated water quality and sludge solids concentration was achieved by operating the scraper continuously at the slowest speed and adjusting the water level in the flotation tank to the bottom of the sludge take-off beach.

6.3.2. Filter pressing of the sludge

Gentle stirring of the sludge collected from the flotation pilot plant was required to de-aerate it and prevent it separating into two layers. Table 18 shows the results from the filter press trials on sludges produced from the coagulation of the raw water with aluminium sulphate and chlorinated ferrous sulphate.

Table 18. Results of sludge filter pressing trials: applied pressure 800 kPa (115 psi); cake thickness 22 mm (7/8 in) - Ardleigh

Raw water Turbidity FTU	Algal count cells/ml	Coagulant used	Sludge solids concentration %	Press time h	Cake solids concentration %
4.9	51.4	Alum	1.0	4.1	15.9
4.8	79.7	Alum	6.4	2.7	17.0
5.2	136.1	Chlorinated ferrous sulphate	2.2	2.4	22.8

The cake solids concentration produced was relatively low (16 to 23%) compared with the cake solids concentration of 50% obtained from the filter pressing of sludge produced from the treatment of turbid river water at Strensham. The Ardleigh results were also obtained without the addition of any polyelectrolyte.

7. FILTRATION OF FLOTATION-TREATED WATER

Previous work with River Thames water(4) had shown that the filtrability of flotation and sedimentation treated waters was similar provided the waters going onto the filters had similar turbidities and residual coagulant concentrations. To confirm this for the different raw water types being studied, provision was made at all the pilot plant sites to compare the filtering characteristics of the flotation treated water with the treated water from the Main Works primary process. The results obtained from the different plants will be discussed separately.

7.1. FILTRATION OF WATER PRODUCED FROM THE PRIMARY TREATMENT OF THREE-DAY STORED RIVER WATER - LANGHAM

The Main Works treatment at Langham comprised horizontal sedimentation and coarse rapid gravity filtration followed by slow sand filtration. Details of the rapid gravity filter media are given in Table 19.

During periods of high algal counts in the raw water (mainly diatoms), coagulant had to be used on the Main Works and the loading of the works rapid gravity filters had to be reduced to as low as 0.9 mm/s (66.0 gal/h ft^2). Filter run lengths of only 6 to 8 hours were achieved and appreciable numbers of algae (up to 5000 cells/ml) passed to the slow sand filters, which in turn required more frequent cleaning.

Table 19. Details of rapid gravity filter media - Langham

Works filters	Pilot filters
0.46 m of 0.8 - 1.8 mm sand	0.61 m of 0.4 - 0.8 mm sand
	0.10 m 1.2 - 2.4 mm sand
0.30 m of gravel	0.10 m 2.4 - 4.8 mm gravel
	0.15 m 4.8 - 9.5 mm gravel

Provided the correct coagulant dose and pH were used in the flotation pilot plant, the filtered water quality produced from the pilot rapid gravity filter fed with flotation treated water was comparable to the slow sand filtered water quality during periods of high algal blooms, and a filtration rate of 2.0 mm/s (150 gal/h ft^2) was maintained. Details of the pilot filter media are also given in Table 19. Filter runs of 24 hours were usually possible, although these were reduced to 12 hours during periods of extreme algal loads. Table 20 shows typical water qualities produced by the Main Works treatment and by the filtration of flotation treated water.

Table 20. Comparison of raw water, primary filtrate, flotation treated water, slow sand filtrate, and flotation filtrate quality - Langham

	Dose mg/l Fe	pH	Turbidity FTU	Residual coagulant mg/l Fe	Algae cells/ml	Filter loading mm/sec	Filter run length h
Raw water	-	8.26	4.0	-	42 000	-	-
Main plant primary filtrate	5.6	7.76	1.2	0.28	2 600	0.9	8 hour wash cycle
Flotation treated water	4.0	7.9	1.5	1.1	2 800	-	-
Slow sand filtrate	-	7.5	0.14	N.D.	1 000	-	-
Flotation filtrate	-	7.9	0.22	0.04	1 400	2.0	12 hours to 2 m headloss

During winter conditions when few algae were present in the raw water, it was possible to operate the pilot filter fed by flotation treated water at rates up to 2.6 mm/s (195 gal/h ft^2) without significantly affecting the filtered water quality, though the run time was reduced by half compared with operating at a rate of 1.5 mm/s (110 gal/h ft^2).

7.2. FILTRATION OF WATER PRODUCED FROM THE PRIMARY TREATMENT OF TURBID RIVER WATER - STRENSHAM

Two pilot rapid gravity filters were available at Strensham to compare the filtration of flotation and sedimentation treated water. The filter media in the two filters were identical and the same as those of the Main Works rapid gravity filters, Table 21.

Table 21. Details of rapid gravity filter media - Strensham

0.31 m of 1.25 to 2.5 mm anthracite (NCB No. 2)
0.38 m of 0.5 to 1.0 mm sand

Although the upflow sedimentation treated water usually had a lower turbidity and residual coagulant concentration than the flotation treated water, there was no difference in filtered water quality. However, longer filter runs were achieved when filtering the sedimentation treated water. Long filter runs were common for both the filtration of sedimentation and flotation treated water, and in the summer, runs of up to 96 hours were achieved when filtering flotation treated water. Table 22 shows the performance of the filters fed with sedimentation and flotation treated water.

Table 22. Comparison of raw, flotation treated, sedimentation treated, and filtered water quality - Strensham

Water	Dose	pH	Turbidity FTU	Residual coagulant mg/l Al	Rate of headloss development h
Raw	-	8.20	7.0	-	-
Flotation treated	2.0	7.35	1.4	0.5	-
Sedimentation treated	1.8	7.45	1.0	0.2	-
Flotation filtered	-	7.5	0.15	0.04	45.5
Sedimentation filtered	-	7.5	0.15	0.04	19.6

7.3. FILTRATION OF WATER PRODUCED FROM THE PRIMARY TREATMENT OF STORED HIGHLY - COLOURED, LOW-TURBIDITY WATER - ARNFIELD

At Arnfield only one pilot filter was available. The description of the filter media is given in Table 23.

Table 23. Details of rapid gravity filter media - Arnfield

0.61 m of 0.4 to 1.0 mm sand
0.15 m of 1.0 to 2.0 mm sand

To make a comparison between the filtration of sedimentation and flotation treated waters successive filter runs had to be carried out.

To facilitate manganese removal, the pH of the water fed to the filters was increased from about 5 to about 9. The results in Table 24 indicate that similar filtered water quality was produced by the filtration of flotation and sedimentation treated water, but that a reduced run length was obtained for the filter fed with flotation treated water.

Tests carried out on the flotation plant during a period of low raw water temperatures (2 to 3 °C) showed that the flotation treated water quality could be improved by reducing the flow rate through the flotation plant. Figure 30 (i, ii and iii) illustrates the effect of the improved flotation treated water quality on filtration. Operating the flotation plant at half the design flow rate (46 m^3/h) resulted in a longer run and improved filtered water quality. In both filter runs the filter loading was 1.6 mm/s (120 gal/h ft^2). Usually the Main Works filters operated at 1.35 mm/s (100 gal/h ft^2). It is likely that the difference in filtered water quality caused by a poorer flotation treated water quality would be negligible at the lower filter rate used in the Main Works filters. During the same period of cold raw water temperatures, the Main Works filters operated at a rate of 1.40 mm/s (103 gal/h ft^2) and produced a water with a turbidity of 0.36 FTU and a residual coagulant of about 0.06 mg/l Fe on a 48-hour wash cycle.

Table 24. Comparison of raw, flotation treated, sedimentation treated, and filtered water quality - Arnfield

Sample	Dose mg/l Fe	pH	Turbidity FTU	Colour °Hazen	Iron mg/l Fe	Manganese mg/l Mn	Filter run length to 1.35 m head-loss h
Raw	-	6.2	3.2	45	0.70	0.11	-
Flotation treated	8.5	4.8	0.72	2	0.58	0.16	-
Sedimentation treated	6.0+ 0.8 polyelectrolyte	5.05	0.50	0	0.36	0.14	-
Flotation filtered*	-	9.0	0.19	0	<0.05	<0.02	25
Sedimentation filtered*	-	10.5	0.29	0	<0.05	<0.02	30

* Filtration rate 1.6 mm/s (120 gal/h ft^2)

7.4. FILTRATION OF WATER PRODUCED FROM THE PRIMARY TREATMENT OF NUTRIENT-RICH, LONG-TERM STORED WATER - ARDLEIGH

Two pilot filters were installed at Ardleigh to compare the filtrability of flotation and upflow sedimentation treated water. The filter media in the pilot filters were identical to the media in the Main Works rapid gravity filters (Table 25).

Table 25. Details of rapid gravity filter media - Ardleigh

0.22 m of 1.25 - 2.5 mm anthracite (NCB No. 2)
0.55 m of 0.50 - 1.0 mm sand

The two upflow sedimentation tanks (Precipitators) of the Main Works generally produced poorer water quality in terms of turbidity, residual coagulant levels and algae counts than that obtained from the flotation plant. The better performance of flotation was reflected in better filtered water quality and longer filter runs. During heavy algal blooms in the reservoir the algal counts in the flotation treated water were usually lower than those obtained after filtration of the upflow sedimentation treated water and filtration of the flotation treated water reduced the algal counts to very low levels (Table 26).

Table 26. Comparison of raw, flotation treated, sedimentation treated, and filtered water quality - Ardleigh

	Dose mg/l Al	pH	Turbidity FTU	Residual coagulant mg/l Al	Algae (*Microcystis*) cells/ml	Rate of headloss development mm/h
Raw water	-	8.3	5.8	-	98 000	-
Sedimentation treated	3.50	7.25	2.2	1.04	18 000	-
Flotation treated	3.10	7.15	0.8	0.56	3 100	-
Sedimentation filtered	-	7.5	0.63	-	4 600	48
Flotation filtered	-	7.6	0.3	-	58	42

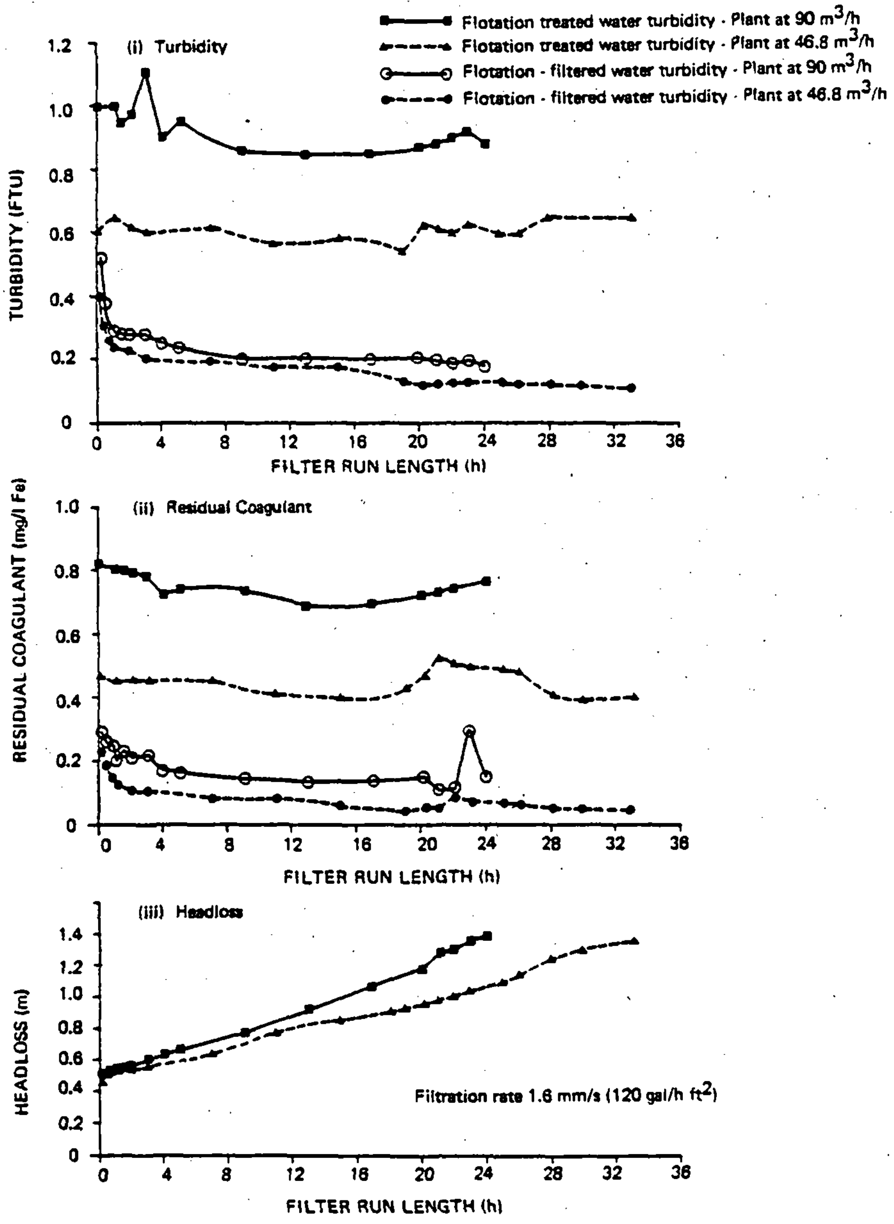


Fig. 30. Effect of the flotation treated water quality on the filtration - Arnfield

8. DISCUSSION

The work carried out on the different 95 m^3/h pilot plants has clearly demonstrated the considerable promise of flotation as a rapid water clarification process for a range of waters. The trials have verified the results previously obtained from the 8.2 m^3/h pilot plant operating at Medmenham on River Thames water. The decision to carry out large-scale pilot plant trials on different raw waters before recommending full-scale plants has been fully justified by the results obtained. Valuable information has been gained on the scale-up, operation and sludge removal of the plants.

Efficient mixing of the coagulant and pH adjustment chemicals was beneficial. When in-line dosing was employed, there was no need for a flash mixer. However, it was important that the first chemical was thoroughly mixed with the raw water before the addition of the second chemical as otherwise a deterioration in treated water quality could occur.

The coagulant dose and optimum pH requirements for flotation were similar to those for sedimentation for algal-laden waters. For high turbidity river water, and for low turbidity, highly coloured water, an improvement in performance resulted from a slightly higher dose (e.g. an extra 2 mg/l Fe or 1 mg/l Al). However, there was no benefit in dosing polyelectrolytes when flotation was used.

Adequate flocculation was found to be essential for efficient flotation. In general three-stage flocculation with a flocculation time of 12 minutes was sufficient to produce acceptable water quality. However, the results obtained on the soft, highly coloured water, and turbid river water have indicated that increasing the flocculation time produced an improvement in flotation treated water quality. An economic optimisation can therefore be made in terms of flocculation time and filter run length as a longer flocculation time results in better treated water quality which requires less frequent back washing of the filters.

In sedimentation plants the maximum upflow rate, which can be as low as 1 m/h, is limited by the settling velocity of the flocs. Exceeding the maximum upflow rate results in a rapid deterioration in treated water quality. The results show that increasing the load on the flotation tank at constant flocculation times up to 12 m/h upflow rate did not result in a deterioration in treated water quality. This was independent of the type of raw water being treated.

Flotation, therefore, has considerable advantages over upflow sedimentation for the treatment of waters containing light flocs. In addition, polyelectrolytes which are used in sedimentation plants to increase the settling velocity in order to produce more economical upflow rates are not beneficial for flotation.

The high rate of the process requires relatively small, shallow plants (1.2 to 1.6 m deep) which are easy to house and are especially advantageous at sites where excavation is difficult.

Protection of the flotation tank from wind and rain was essential if break-up of the floated layer was to be avoided.

Pressures of between 350 and 420 kPa and a recycle of between 7 and 8% were found to be adequate for optimum performance during normal operating conditions. These requirements were similar to those for the 8.2 m^3/h pilot plant treating River Thames water. Only when treating high turbidity river water was an improvement in treated water quality observed when the pressure and the recycle were increased (520 kPa and about 10% recycle). The total air requirement for flotation was between approximately 7 and 10 g of air/m^3 of treated water (5.4 - 7.7 l air/m^3 at NTP).

Several different sludge removal methods have been investigated. To preserve the advantage of producing a high solids content sludge the installation of a mechanical sludge removal device is recommended. The best design of the equipment depends on the type of raw water to be treated. During sludge removal a deterioration in treated water quality can occur which can be minimised by continuous or frequent removal of the sludge and correct adjustment and design of the sludge removal system.

Treating directly abstracted river water with rapidly changing raw water quality showed that close control of the coagulant dose and coagulation pH was critical for satisfactory operation, especially during periods of high turbidity. Generally the sedimentation plant produced better treated water quality; however, indications are that increasing the flocculation time would improve the flotation treated water quality. Although flotation produced inferior treated water quality during periods of high turbidity, the filtered water quality was the same as that produced by filtering sedimentation treated water, but the run length of the filter operating on flotation treated water was reduced. However, a higher solids sludge was produced by flotation (about 3%) which could be easily dewatered further by filter pressing.

The most promising application for flotation is the treatment of stored waters with algal problems. Much improved treated water quality was produced by flotation at an upflow rate of 12 m/h compared with 1.5 m/h for sedimentation; this was also reflected in longer filter runs and superior filtered water quality from the filter operating on flotation treated water. In addition, the sludge removed from the flotation plant had a solids concentration of about 3% which made it suitable for further dewatering in a filter press without an intermediate thickening stage.

A further promising application of flotation is the treatment of stored, low turbidity, highly coloured water. The flocs produced when treating this type of water are light and sedimentation plants can only be operated at low upflow rates (approximately 1 m/h). Flotation could be operated at rates of up to 12 m/h producing an acceptable water quality for further treatment by filtration. An improvement in flotation treated water quality was obtained by increasing the flocculation time. However, one advantage of flotation, the production of a high solids content sludge, was not achieved in this application. In this case the sludge had to be removed continuously from the flotation tank producing a sludge of about 1% solids concentration which was similar to the sludge produced in the sludge concentrators of the sedimentation tanks.

Another advantage of flotation was found to be the short start-up time required. Treating low turbidity, highly coloured water, the flotation treated water reached steady quality within 45 minutes of start-up, whereas it could take up to 21 days before consistent treated water quality was produced by the upflow sedimentation plant.

9. CONCLUSIONS

9.1. APPLICATION OF FLOTATION

9.1.1. The pilot trials have demonstrated the considerable potential of flotation for the clarification of different raw waters.

9.1.2. The capital cost of flotation is less than for floc blanket sedimentation but its operating cost is higher. The overall cost is very similar to that of sedimentation.

9.1.3. The process is particularly effective for the treatment of stored water containing heavy algal loads, and for stored, low turbidity, highly coloured water.

9.1.4. Treating algal-laden waters, flotation produced water of better quality than sedimentation, particularly with respect to algal removal. This resulted in better, more consistent filtered water quality and longer filter runs.

9.1.5. Clarifying stored, highly coloured, low turbidity water, flotation produced good quality treated water at much greater loadings (12 m/h) than sedimentation (1 m/h).

9.1.6. Treating turbid river water by sedimentation produced generally better water quality than flotation. However, the final water quality after filtration was the same. During periods of rapidly changing raw water quality close control of the chemical dosing for the flotation plant was essential. This is difficult to achieve with existing technology and therefore if flotation is used for this application raw water storage should be provided.

9.1.7. Treating the water abstracted from the hard flashy stream at Bucklesham, flocculation proved to be difficult. Satisfactory flotation treated water quality could only be produced when polyaluminium chloride was used as the coagulant.

9.2. SCALE-UP AND OPERATING EXPERIENCE OF FLOTATION

9.2.1. Coagulant dose and pH requirements for flotation were generally similar to sedimentation, but when clarifying high turbidity river water or low turbidity, highly coloured water, the treated water quality could be improved using a slightly larger dose (e.g. 1 to 2 mg/l Fe extra). However, polyelectrolyte addition was not beneficial.

9.2.2. Good mixing of the chemicals with the raw water was required, with adequate separation of the dosing points for the coagulant and the pH adjustment chemical. In-line mixing gave better results than dosing into a flash mixer.

9.2.3. For optimum performance of the flotation plants, efficient flocculation was essential. Three flocculation stages were sufficient and, generally, tapering of paddle speeds was not necessary. The optimum power requirement for flotation expressed as average velocity gradient was about 75/s.

9.2.4. A flocculation time of 12 minutes was sufficient for algal-laden waters. Improvements in the treatment of turbid river and highly coloured waters were possible with longer flocculation periods.

9.2.5. Usually, sufficient air for flotation was supplied by a recycle of about 7% and a pressure of 420 kPa. However, when treating river water with very high solids loadings, it was beneficial to increase the recycle up to 11%.

9.2.6. Adequate mixing of the released air with the flocculated water was achieved with an injection nozzle spacing of 300 mm.

9.2.7. Flotation treated water had similar filtration characteristics to sedimentation treated water provided that the turbidity and residual coagulant levels of the water going onto the filter were similar.

9.2.8. Rapid start-up was possible, with treated water of steady quality being achieved after 45 minutes.

9.3. SLUDGE REMOVAL

9.3.1. The sludges produced by the treatment of algal-laden waters and turbid river waters could be successfully removed by beach scrapers resulting in final sludge concentrations of approximately 3%.

9.3.2. Treating highly coloured, low turbidity waters, sludge accumulation was not possible and continuous removal by a full length scraper was necessary, giving solids concentrations of about 1%.

9.3.3. The sludges produced by flotation could be further dewatered by filter pressing provided the excess air was removed by gentle agitation prior to the pressing.

APPENDIX A – COST OF DISSOLVED-AIR FLOTATION

The cost of dissolved air flotation is compared with the cost of floc blanket sedimentation as this is at present the most widely used primary treatment process for the production of potable water in the United Kingdom. Data published by the WRC(8) have indicated that the cost of the primary treatment stage, such as floc blanket sedimentation, is only about 15 to 20% of the total cost of water treatment in United Kingdom practice. Any cost comparison therefore has to be viewed in relation to the relatively small percentage of the total treatment cost.

Only limited data on the cost of flotation are available because only a few contracts for this process have been awarded so far, most of which were for relatively small plants. Based on the relatively limited amount of data available, an attempt has been made(9) using discounted cash flow analysis to compare the total costs - construction and operating costs - for floc blanket sedimentation and for flotation. The cost comparison showed that the capital cost of flotation is less than for floc blanket sedimentation but that its operating cost is greater. As a result, for normal water treatment conditions in the United Kingdom, the overall cost of flotation is very similar to the cost of floc blanket sedimentation. The indications are that flotation is likely to be the cheaper process where floc blanket sedimentation can only be operated at upflow rates of less than about 2 m/h.

However, any additional process advantages, such as better treated water quality, greater flexibility of the plant, shorter start-up time and no need for polyelectrolyte addition or easier sludge treatment, can have a substantial influence on the final selection of the process. It is therefore important to try to include in such a cost analysis factors which add support to the selection of a particular process.

It has also been shown(9) that low utilisation will favour flotation because of its relatively higher saving in operating cost (Table 27).

Table 27. Example of the effect of utilisation in the cost of sedimentation and flotation*(9)

Utilisation %	100	80	50
Sedimentation, pence/m^3	0.151	0.189	0.302
Flotation, pence/m^3	0.153	0.179	0.264

* Chemical costs are not included.

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