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WASTEWATER TREATMENT BY ION EXCHANGE

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Abstract—Treatment of secondary sewage effluent by anion exchange has been investigated. A number of strong-base anion exchange resins were employed in laboratory trials to determine their suitability for effluent treatment. In particular, phosphate, nitrate and colour removals were compared. Three resins were selected for more detailed investigation at a sewage treatment works, using a column which was specially designed for this project. The results indicated that substantial improvement in effluent quality could be achieved, notably by reductions in dissolved organic matter, phosphate and nitrate. Interesting data were obtained showing the way in which various contaminants were removed throughout the depth of the resin bed. In spite of the benefits, it was concluded that, for various reasons, application of the process would be limited to a few rather special cases.

INTRODUCTION

CONVENTIONAL sewage treatment processes produce effluents which may still contain appreciable amounts of organic matter (both dissolved and particulate), together with inorganic forms of nitrogen and phosphorus which are potential nutrients for algal growths in the receiving water. The major portion of inorganic phosphorus in biologically treated effluents consists of orthophosphate since considerable hydrolysis of condensed phosphates takes place during biological treatment (MENAR and JENKINS, 1970). Inorganic nitrogen may be mainly present as ammonia or nitrate, depending on the degree of nitrification achieved in the treatment.

Often it would be desirable to reduce the levels of some or all of these contaminants, especially when the effluent enters a standing body of water, such as a lake or reservoir, where eutrophic conditions may develop. Consequently, a number of tertiary or "polishing" processes have been developed. These include microstraining or filtration for the removal of suspended solids, activated carbon or ozone for the removal of soluble organics, lime or alum precipitation of phosphate, biological denitrification and air stripping of ammonia.

Treatment of the effluent by a column of anion exchange resin might be expected to achieve reductions in the levels of nitrate and phosphate by ion exchange, dissolved organics by adsorption and suspended solids by filtration. The pilot scale studies of ELIASSEN *et al.* (1965) and ELIASSEN and BENNETT (1967) gave promising results, using a strong base anion exchanger in the chloride form and effluent from an activated sludge plant which was pre-treated either by flocculation and filtration or by filtration alone. The results showed substantial reductions in nitrate, phosphate and organic matter (COD), that regeneration with brine was reasonably effective and that about 175 bed volumes of effluent could be treated before the phosphate level in the treated water rose to an unacceptable value. A significant finding was that "fouling" of the resin was not a serious problem and could largely be overcome by a periodic cleaning treatment. It was found that sulphate was completely removed from the effluent by ion exchange and that this removal continued for a considerable time after phosphate

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began to break through. Of course, release of chloride from the resin led to a significantly increased level of chloride in the product water.

In the present study, nine commercially available strong base anion exchange resins have been used in preliminary laboratory trials on the treatment of a secondary sewage effluent. Three resins were used in larger scale treatment of the effluent at the sewage treatment works. In this section of the work a specially designed column was employed, which enabled information to be obtained on removal patterns throughout the resin depth.

PRELIMINARY TRIALS

The nine resins used were all those listed by GREGORY and DHOND (1972) except De-Acidite N-IP, which was obtained after the preliminary trials had been completed. 50 ml quantities of the resins were transferred to glass columns, 2·5 cm i.d. and 35 cm long. The resin bed height was about 20 cm. Complete conversion of the resins to the chloride form was ensured by passing 5 per cent NaCl solution. The resins were then thoroughly rinsed with de-ionized water.

Secondary sewage effluent was obtained from the Maple Lodge Works of the West Hertfordshire Main Drainage Authority, and used within 2 or 3 days of collection. 5 l. (100 bed volumes) of the effluent was passed through each of the resins at a rate of 20 ml min^{-1} (25 BV/h^{-1}). The product from each column was collected and analysed for chloride, alkalinity, phosphate, nitrate, colour and total organic carbon. Chloride was determined by the Mohr titration, alkalinity by titration with standard acid phosphate by the molybdate-stannous chloride method (*Standard Methods*, 1965), nitrate by a nitrate-sensitive electrode (Orion Research Inc.), colour by absorbance at 400 nm on a Unicam spectrophotometer and total organic carbon on a Beckman Carbonaceous Analyser (at the Water Pollution Research Laboratory, Stevenage). It has since been discovered that the nitrate electrode responds slightly to bicarbonate ion and for this reason the results will usually be slightly too high. This probably accounts for the fact that nitrate values determined by the electrode were never below about 2 mg l^{-1} (as N).

TABLE 1. COMPOSITION OF EFFLUENT BEFORE AND AFTER ION EXCHANGE TREATMENT

	Chloride (mg l^{-1})	Alkalinity (mg l^{-1} $CaCO_3$)	Phosphate (mg l^{-1} PO_4)	Nitrate (mg l^{-1} N)	Colour (absorbance × 100)	Organic carbon (mg l^{-1})
Before treatment:	125	188	15	16	10.3	14.2
After treatment by:						
FF-IP	320	94	0·06	2·3	0·9	8·0
K-MP	275	148	1·4	2·5	0·7	4·3
MP 500	300	116	0·11	2·5	0·8	5·3
MP 600	290	124	0·06	2·5	1·0	6·5
M 600	305	100	0·15	2·3	3·8	10·8
IRA 900	300	115	0·08	2·5	1·2	6·3
IRA 904	260	160	8·9	2·5	1·3	6·0
IRA 910	300	122	0·05	2·5	1·4	6·5
XE 258	330	73	0·05	2·5	1·6	9·5

After treating 5 l. of effluent, each resin was regenerated with 5% NaCl, rinsed and then used to treat a further 5 l. of effluent. The product was again collected and analysed. Results from the two runs were averaged and are presented in TABLE 1.

It is evident that most of the resins reduce the phosphate level to very low values, the exceptions being K-MP and, especially, IRA 904. This is just what would be expected from the equilibrium data of GREGORY and DHOND (1972), although the lower total capacity of these two resins may also influence the result.

The alkalinity of the effluent is mainly due to HCO_3^- and HPO_4^{2-}. Since alkalinity is not much reduced, it is clear that the bicarbonate ion is not taken up by the resins to any significant extent. This is fortunate, considering the high levels of bicarbonate found in many effluents.

Removals of colour are significant, but correspond only approximately with those of organic carbon. The worst resin in this respect is M-600 and it may be significant that this is the only conventional gel-type resin investigated.

As a result of these preliminary trials, the resins FF-IP and IRA 910 were chosen for more detailed investigation. A third resin, N-IP, was also included since, from equilibrium data, there was good reason to believe that phosphate removal would be better than with FF-IP.

LARGE COLUMN EXPERIMENTS

Ion exchange column

This consisted of a perspex tube, 1 m long and 5 cm i.d., fitted with conical end pieces to allow uniform flow distribution. The bottom cone was fitted with a stainless steel mesh, of approximately 200 μm aperture, which acted as a support for the ion exchange resins. Sampling and pressure tappings were provided at 2 cm vertical intervals over the lower 50 cm of the column. These tappings were staggered around the circumference of the column to minimize the possibility of channeling. Attached to the sampling points were lengths of 3 mm rubber tubing leading to sample bottles. The pressure points were connected to glass manometer tubes 2·5 m high and 4 mm i.d.

Flow of feed water to the column was from a constant head tank and the flow rate through the column was controlled by a device similar to that described by MOHANKA (1969). Provision was made for backwashing the resin after a run. The column and associated equipment are shown in FIG. 1. Complete details have been given by DHOND (1970).

Preparation of resins

All the resins were supplied by the manufacturers in the chloride form. Before use they were washed thoroughly with distilled water and then soaked in 5 per cent sodium chloride solution for 24 h. Exactly 1 l. of each resin was measured out and introduced into the column, giving a bed depth (after compaction) of about 50 cm.

Secondary effluent

The Maple Lodge Works employs a conventional two stage process consisting of primary settling followed by activated sludge treatment. The effluent is of very good quality, BOD and suspended solids being generally both below 10 mg l^{-1}. Effluent was taken from the outlet weir of the final settling basin and fed to the ion exchange unit.

Column operation

Feed water (secondary effluent) was pumped to the constant head tank and then allowed to flow by gravity through the resin bed at the required flow rate. Samples were withdrawn continuously from 13 sampling points at 4 cm intervals. The sampling rate at each point was 1 ml min^{-1} so that the total sample flow was 780 ml h^{-1}. Since flow rates through the column ranged from 25 to 45 l. h^{-1}, the sampling rate was never more than about 3 per cent of the total flow rate. Samples were collected each hour (i.e. 60 ml from each point) and manometer readings were recorded at hourly intervals.

The samples were transported to University College London and analysed for phosphate, nitrate, chloride, alkalinity and colour by the methods described earlier. Total organic carbon analyses were performed on some of the samples by the Water Pollution Research Laboratory. The final product from the column was tested each hour for phosphate at the Maple Lodge Works and a run was usually terminated when the level rose to 1 mg l^{-1} (as PO_4). This was taken as an arbitrary "breakthrough" value.

In some cases the product from a run of 200 BV was composited and subjected to standard wastewater analyses in the Laboratory of the West Hertfordshire Main Drainage Authority.

Regeneration

After breakthrough occurred (1 mg l^{-1} PO_4) the resin was backwashed with product water for 10 min at a bed expansion of 50–70 per cent to release suspended matter trapped by the resin. The resin was then allowed to settle and was regenerated by flowing 4 l. of 20% NaCl solution through the column at about 6 l. h^{-1}. The resin was finally rinsed with about 4 l. of product water.

The volume and strength of the regenerant solutions were chosen to ensure complete conversion of the resins to the chloride form and they represent a large excess over the stoichiometric requirement (about 12-fold). In practice it should be possible to reduce the amount of regenerant considerably.

Conditioning of resins

Before taking any results each resin was "conditioned" by passing about 200 l. of secondary effluent and regenerating as described above. Three such conditioning cycles were carried out for each resin.

Schedule of experiments

There were two periods of operation: October–November 1969 and March–April 1970. During the first of these only one resin was used (De-Acidite FF-IP) at flow rates of 25 and 35 bed volumes (BV) per hour, i.e. 25 and 35 l. h^{-1}.

During the second period three resins were used: De-Acidite FF-IP, De-Acidite N-IP and Amberlite IRA 910. Flow rates were 35 and 45 BV h^{-1}.

RESULTS

Owing to the large amount of data collected, only a selection of the results can be given here. For complete information the reader is referred to DHOND (1970).

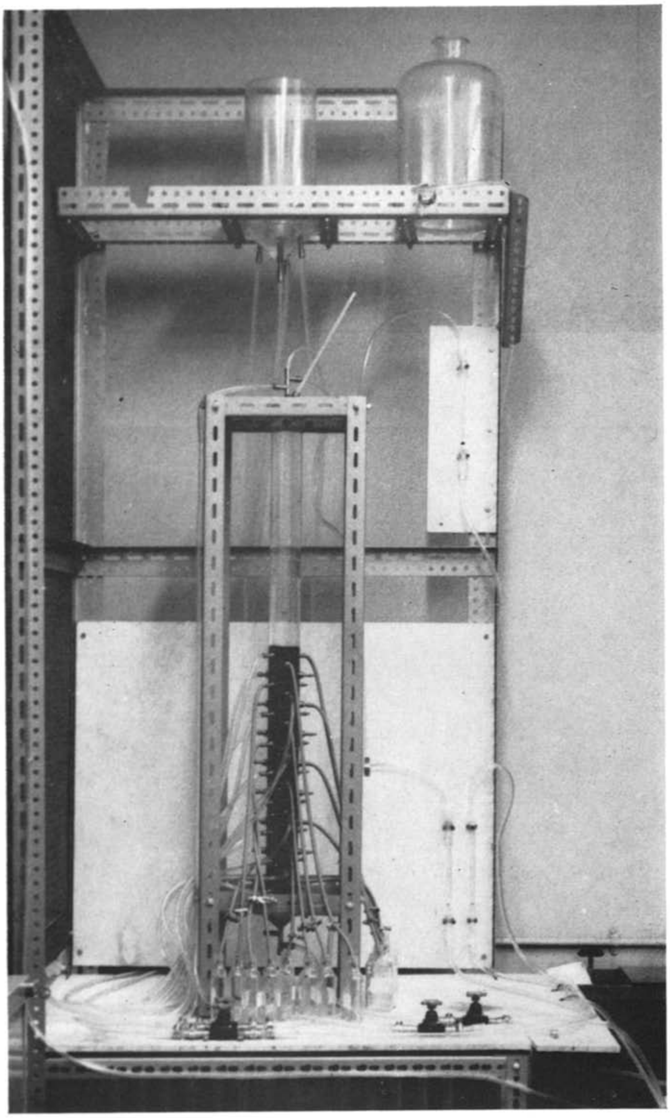

FIG. 1. Ion exchange column.

(*Facing p.* 684)

Period 1: *October–November* 1969

Concentration vs. depth curves. All concentrations are expressed as fractions of the feed concentration C/C_0. FIGURES 2 and 3 show the way in which nitrate concentration and colour vary with depth in the column at different times. The flow rate in these cases was 35 BV h^{-1}; the corresponding curves for 25 BV h^{-1} were of similar form.

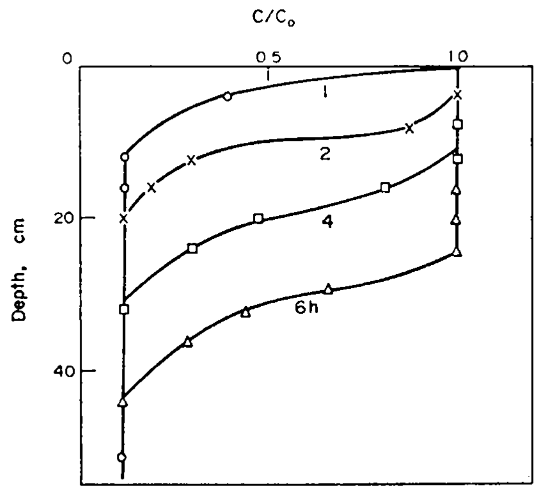

FIG. 2. Nitrate removal vs. depth at various times. Resin: De-Acidite FF-IP. Flow rate: 35 BV h^{-1}. Feed nitrate concentration: 16–18 mg l^{-1} (as N).

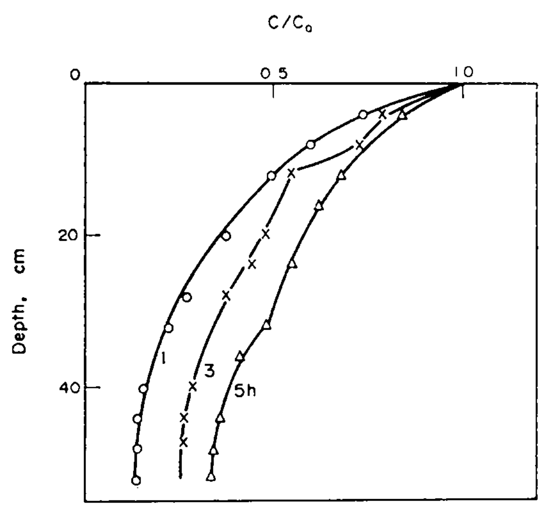

FIG. 3. Colour removal vs. depth at various times. Resin: De-Acidite FF-IP. Flow rate: 35 BV h^{-1}. Feed colour: 0·07–0·075 (Absorbance).

It is clear from FIG. 2 that the nitrate front is quite sharp and descends through the column in a manner which is entirely typical of column behaviour when the ion being removed is favoured by the resin (HELFFERICH, 1962). In contrast, there is no sharp boundary observed for colour removal in FIG. 3, but rather a diffuse exchange zone and early breakthrough. For a single anion this type of behaviour would be expected if equilibrium were only slowly attained, but of course the measured colour in a secondary effluent is due to a large number of constituents, not all of which are in the anionic form. Corresponding curves for total organic carbon removal are of similar form.

In the case of phosphate removal, the behaviour is rather more complex and is illustrated in FIG. 4. After 1 h of operation the concentration-depth curve is of the

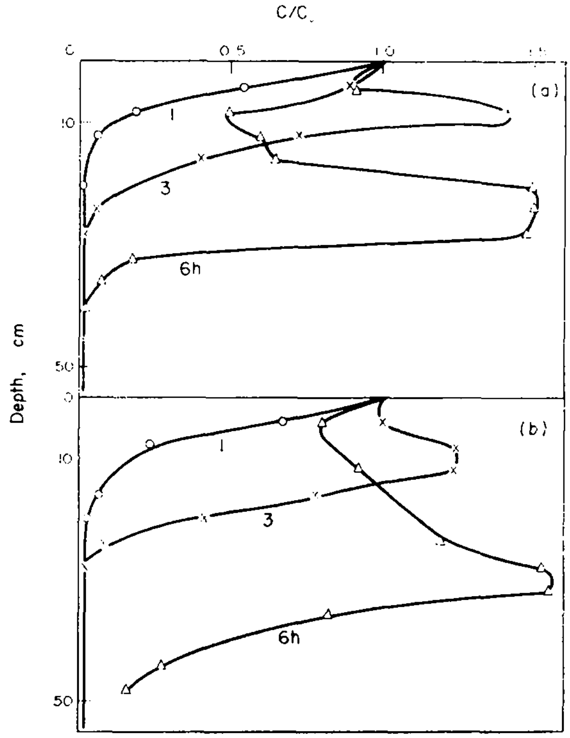

FIG. 4. Phosphate removal vs. depth at various times, and for two flow rates. Resin: De-Acidite FF-IP. Flow rate: (a) 25 BV h^{-1}. (b) 35 BV h^{-1}. Feed phosphate concentration: 15–18 mg l^{-1} (as PO_4).

usual form for a preferred anion, but subsequent curves show a maximum phosphate concentration at some point within the resin. This maximum value can be considerably higher than the phosphate concentration in the feed water. All experiments conducted so far have shown the same type of phosphate behaviour, indicating an uptake and subsequent release of phosphate by the ion exchange resins.

Head loss. Head loss results, derived from the manometer readings, are shown in FIG. 5 for two flow rates. The results for 25 BV h^{-1} indicate a rather sudden clogging of the bed between the fourth and fifth hour of operation. It is clear from the shape of the curves that this clogging is restricted to the top layer of the resin bed. The cause was probably a sudden increase in the level of suspended solids in the feed water, although measurements were not conducted to test this. At 35 BV h^{-1} increase in head loss occurs in a more uniform manner, but it is still apparent that most of the

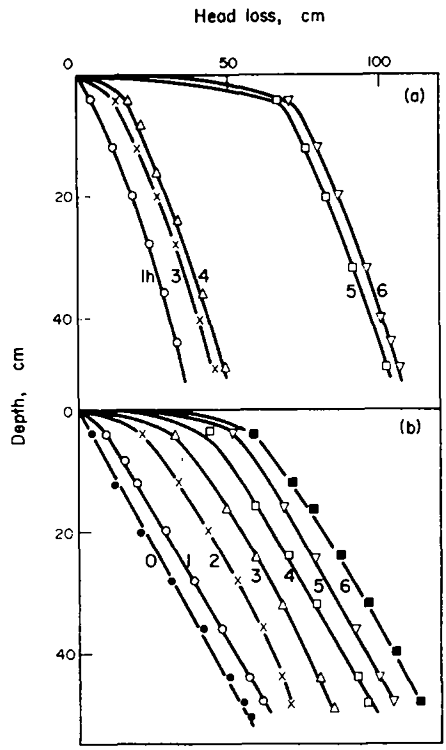

FIG. 5. Head loss vs. depth at various times and for two flow rates. Resin: De-Acidite FF-IP. Flow rate: (a) 25 BV h^{-1}. (b) 35 BV h^{-1}.

TABLE 2. COMPOSITION OF EFFLUENT BEFORE AND AFTER ION EXCHANGE TREATMENT. 200 BV TREATED

[Resin: De-acidite FF-IP; Flow rate: 35 BV h^{-1}; October 1969; Results in mg l^{-1} (except colour and pH)]

	Feed (secondary effluent	Product from column
Suspended solids	9·0	2·0
BOD, 5 days	6·2	2·2
Permanganate value, 4 h	8·0	2·6
Total organic carbon	11·0	5·5
Colour (Hazen units)	75	7
Ammoniacal nitrogen	0·05	0·01
Albuminoid nitrogen	0·58	0·33
Nitrate (as N)	17·4	1
Phosphate (as PO_4)	18·0	0·5
Sulphate	118	0
Alkalinity (as $CaCO_3$)	220	200
Chloride	130	266
Anionic detergents (as Manoxol OT)	0·50	0
pH	7·4	7·4

deposition occurs in the top 4 cm of the bed. Below this level, even after 6 h of operation, the slope of the head loss curve is very similar to that of a clean resin bed. Undoubtedly, smaller particles penetrate further into the resin but their effect on head loss is not noticeable.

In very few cases, the build up of head loss was so great that a run had to be terminated before breakthrough of phosphate occurred. In these cases there seemed to be a greater quantity of suspended solids, especially fairly large flocs, being carried over from the settling basin.

Complete analyses. Extensive analytical results for the composite product of an experiment at 35 BV h^{-1} are presented in TABLE 2, together with the corresponding feed values. Substantial reductions of many significant contaminants can be seen. The chloride increase is accounted for almost exactly by the reduction in nitrate, phosphate and sulphate.

Period 2: March–April 1970

During the second period of operation the quality of the plant effluent was generally even better than previously. Lower levels of suspended solids produced only slight build up of head loss and clogging was not a problem.

Concentration vs. depth curves were obtained for the three resins at a flow rate of 35 BV h^{-1} and are given by DHOND (1970). Since they are of similar form to the curves in FIGS. 2–4 they will not be given here.

Tabulated analytical data for feed and composite product are presented for three resins and two flow rates (35 and 45 BV h^{-1}) in TABLES 3–5. The values in all cases show that the increased flow rate leads to less phosphate removal. Generally the product is of lower quality at the higher flow rate.

TABLE 3. COMPOSITION OF EFFLUENT BEFORE AND AFTER ION EXCHANGE TREATMENT. 200 BV TREATED
[Resin: De-acidite FF-IP; Flow rates: 35 and 45 BV h^{-1}; March 1970]

	35 BV h^{-1}		45 BV h^{-1}	
	Feed	Product	Feed	Product
Suspended solids	4·0	1·6	7·2	2·4
BOD, 5 days	7·5	3·8	11·9	2·0
Permanganate value, 4 h	8·8	3·0	11·2	3·2
Total organic carbon	11·0	6·0	—	—
Colour (Hazen units)	70	8	70	10
Ammoniacal nitrogen	0·16	0·06	0·21	0·13
Albuminoid nitrogen	0·74	0·50	1·17	0·36
Nitrate (as N)	17·6	1	16·4	1·5
Phosphate (as PO_4)	14·0	0·5	13·5	1·5
Sulphate	122	0	118	0
Alkalinity (as $CaCO_3$)	170	150	240	170
Chloride	126	280	120	260
Anionic detergents (as Manoxol OT)	0·5	0	0·46	0
pH	7·4	7·4	7·4	7·4

TABLE 4. COMPOSITION OF EFFLUENT BEFORE AND AFTER ION EXCHANGE TREATMENT. 200 BV TREATED [Resin: De-acidite N-IP; Flow rates: 35 and 45 BV h^{-1}; March 1970]

	35 BV h^{-1}		45 BV h^{-1}	
	Feed	Product	Feed	Product
Suspended solids	5·4	2·4	5·0	1·4
BOD, 5 days	5·9	2·2	5·0	3·4
Permanganate value, 4 h	9·2	3·6	9·2	4·2
Total organic carbon	17·5	9·5	—	—
Colour (Hazen units)	80	8	80	14
Ammoniacal nitrogen	0·16	0·12	0·10	0·07
Albuminoid nitrogen	0·71	0·42	0·65	0·14
Nitrate (as N)	16·5	1	16·5	1·7
Phosphate (as PO_4)	13·0	0·5	13·5	1·4
Sulphate	120	0	120	0
Alkalinity (as $CaCO_3$)	220	210	210	140
Chloride	128	266	124	300
Anionic detergents (as Manoxol OT)	0·41	0	0·51	0
pH	7·4	7·4	7·2	7·2

TABLE 5. COMPOSITION OF EFFLUENT BEFORE AND AFTER ION EXCHANGE TREATMENT. 200 BV TREATED [Resin: Amberlite IRA 910; Flow rates: 35 and 45 BV h^{-1}; March 1970]

	35 BV h^{-1}		45 BV h^{-1}	
	Feed	Product	Feed	Product
Suspended solids	3·8	1·6	4·4	1·6
BOD, 5 days	4·4	2·0	5·8	3·6
Permanganate value, 4 h	8·4	1·0	8·0	2·2
Total organic carbon	10·5	5·5	—	—
Colour (Hazen units)	70	5	70	10
Ammoniacal nitrogen	0·09	0·08	0·14	0·12
Albuminoid nitrogen	0·45	0·21	0·53	0·31
Nitrate (as N)	13·3	1	17·4	1·5
Phosphate (as PO_4)	13·0	0·5	13·5	1·4
Sulphate	115	0	120	0
Alkalinity (as $CaCO_3$)	200	160	170	170
Chloride	112	240	110	240
Anionic detergents (as Manoxol OT)	0·37	0	0·31	0
pH	7·4	7·4	7·2	7·2

The effect of flow rate on phosphate removal is also shown in FIG. 6, where concentration (C/C_0) in the product water is plotted against volume produced. It is clear that breakthrough of phosphate occurs earlier at the higher flow rate, as would be expected from elementary ideas of column operation.

Results in the second period did not indicate any great differences in the behaviour of the three resins, although it does appear that IRA-910 gives consistently better removal of colour and lower permanganate values. Phosphate breakthrough occurs earlier for FF-IP than the other two resins and this observation is consistent with the

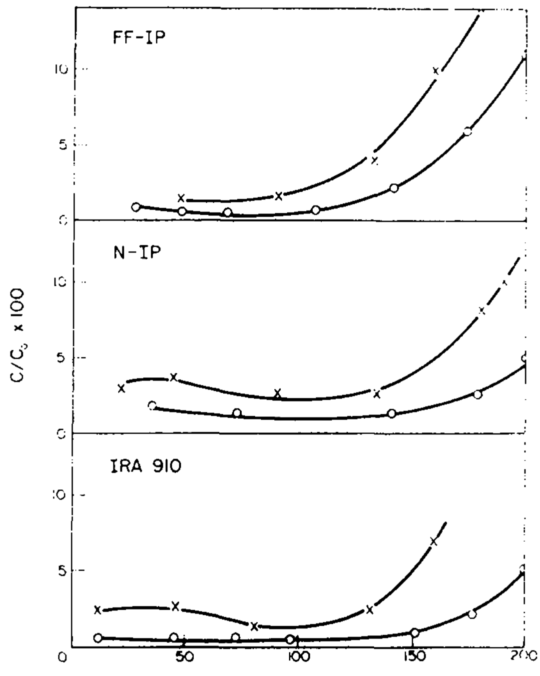

FIG. 6. Phosphate level in product vs. volume produced, for three resins and two flow rates. ○ 35 BV h^{-1}. × 45 BV h^{-1}.

differences in phosphate affinity between the resins which was reported by GREGORY and DHOND (1972).

DISCUSSION

The results obtained in this work demonstrate that a number of significant pollutants can be effectively removed from a secondary effluent by treatment with anion exchange resin, but also serve to underline a number of problems.

Suspended solids

The removal of suspended solids is of value but inevitably leads to, at least, partial clogging of the resin bed and a consequent increase in head loss through the column. Since the secondary effluent used in this work was of exceptionally low suspended solids level, clogging was not a serious problem. In more usual effluents, however, it is likely that clogging of the bed would cause termination of a run before chemical exhaustion of the resin. In such cases removal of only the large suspended particles, e.g. by microstraining might be sufficient pretreatment. Quite high concentrations of smaller particles might be tolerable, since these would penetrate further into the bed and head loss build up would be more gradual, especially at higher flow rates. In that case backwashing of the resin might require larger quantities of water to effectively remove the deposited particles.

If a reduction in suspended solids level were not essential, then it would be worth considering the use of ion exchange resin in the form of a fluidized bed.

Nitrate and phosphate

The reduction in levels of these nutrients would be of benefit in many effluents, but the great preference of the resins for sulphate represents a serious disadvantage. Many effluents contain fairly high levels of sulphate (100–150 mg l^{-1}), all of which would have to be removed in order to effect worthwhile phosphate reduction by conventional ion exchange. This, of course, leads to high levels of chloride in the product water and large regenerant requirements. From the results in TABLE 2 it can be calculated that sulphate accounts for about 65 per cent of the effective exchange capacity of the resin, whereas phosphate represents only about 10 per cent.

The pattern of phosphate removal through the depth of the resin (FIG. 4) suggests that, at the end of a run, most of the phosphate removed would have been displaced to the lower part of the resin bed. It might be possible to make use of this effect in designing a more efficient regeneration system. The reason for the observed phosphate behaviour is not fully clear but might be due to a kinetic effect, phosphate ions entering the resin beads more rapidly than sulphate and "overshooting" the equilibrium resin concentration. Eventually, sulphate equilibrium would be established, causing a displacement of much of the phosphate. This phenomenon is currently being studied in more detail.

Organic matter

The uptake of organic matter by the resins may be regarded as a beneficial side-effect of ion exchange treatment. Removal of organics is not complete, as shown by the significant proportion of BOD, organic carbon etc., remaining in the product. Some of the removal may be accounted for by the reduction in suspended solids, but the results indicate that adsorption and/or ion exchange of dissolved constituents are more significant mechanisms. Colour of the secondary effluent is markedly reduced by ion exchange treatment and anionic detergents are completely removed. Much of the colour removed is subsequently released on regeneration, as evidenced by the intense colour of the spent regenerant, but quantitative data on the recovery of organic mat ter by regeneration were not obtained. Undoubtedly some essentially irreversible uptake of organic matter will occur and a periodic cleaning procedure would be needed (ELIASSEN and BENNETT, 1967).

Over the limited number of cycles employed in this work, uptake of organic matter did not appear to interfere with the ion-exchange behaviour of the resins.

Regeneration

As already mentioned, the choice of 4 BV of 20% NaCl was arbitrary and does not represent the optimum regenerant level. In principle it would be possible to reduce the volume or the strength of the regenerant solution or both. Regeneration with much less than 4 BV of solution would present some practical difficulties, but using more dilute solutions would lead to larger volumes of spent regenerant for disposal (see below). It has been found in some preliminary experiments that concentrations of NaCl less than 10 per cent do not give adequate release of organic matter from the resins.

Disposal of Wastes

Three waste streams are produced in the process: backwash water, rinse water and spent regenerant. The first two present few problems since they could be returned to the inlet of the sewage treatment plant and pass through the purification processes a second time. Even so, it would be best to restrict the volume of these wastes to a reasonably small fraction of the product.

The spent regenerant consists of a strong solution of NaCl together with large amounts of sulphate, nitrate and phosphate. Provided the volume was reasonably small, evaporation in shallow basins might be practical, depending on climatic conditions. Marine disposal is another possibility but would, of course, be highly dependent on the location of the plant. If phosphate could be removed easily from the spent regenerant, e.g. by precipitation with lime, then re-use of the regenerant solution at least once might be possible. Since regenerant disposal may be the most significant problem in the whole process, it is clear that more attention would have to be paid to this aspect in any future work on ion exchange treatment of effluent.

Cost

A provisional cost estimate of ion exchange treatment for secondary effluent has been attempted. The following assumptions were made:

Plant capacity: 190 $m^3 h^{-1}$ (1×10^6 gal day^{-1}).
Unit size: 2·7 m dia. $\times$ 0·8 m bed depth.
Resin: Amberlite IRA 910 at £890 ton^{-1}.
Flow rate: 35 BV h^{-1}.
Product: 200 BV $cycle^{-1}$ 95% P removal.
Regenerant level: 2 per cent of throughput with 10% NaCl. Salt at £8 ton^{-1}.
Resin replacement: 1000 cycles.
Amortization, interest and maintenance: 20% yr^{-1}.

The cost estimate is given below, together with that of ELIASSEN and BENNETT (1967), which was based on somewhat different assumptions, e.g. a flow rate of only 10 BV h^{-1}.

	Present p m^{-3}	Eliassen p m^{-3}
Amortization, interest and maintenance	0·75	1·09
Resin replacement	0·46	0·30
Resin restoration	—	0·18
Salt	1·60	0·40
	2·81	1·97

(Note: 1 p $m^{-3} \equiv$ 4·5 p 1000 Imp. $gal^{-1} \equiv$ 9·5 c 1000 US gal^{-1}.)

The resin replacement costs differ because Eliassen and Bennett assumed a longer resin life (1350 cycles) and this difference is close to the amount they estimated for the cost of resin restoration, which was not considered in the present work. Total cost for resin restoration and replacement would probably not exceed 0·5 p m^{-3}.

The large difference in the salt costs between the two estimates is accounted for by (a) the lower regenerant level assumed by Eliassen (1 per cent of throughput with

10 per cent brine) and (b) much lower salt price in California than in the U.K. (about half).

Neither estimate considers the cost of spent regenerant disposal.

Evidently any improvement in regeneration efficiency, e.g. by re-use of regenerant, would give considerable cost savings, especially since ultimate disposal problems would be lessened.

Cost estimates for alternative methods of nitrogen and phosphorus removal vary widely, but the following may be quoted for comparison purposes (BAYLEY, 1970):

	$p\ m^{-3}$
Precipitation of phosphate with alum	1·0
Precipitation of phosphate with lime	0·5
Air stripping of ammonia	0·5

The estimates for the precipitation processes do not include sludge disposal. Such methods would probably not give the degree of removal of organic matter and colour which is achieved by ion-exchange resins.

Other possible processes for sewage effluent treatment include ion-exchange demineralization, electrodialysis and reverse osmosis. These all achieve a substantial reduction in total dissolved solids and are not strictly comparable with the previous methods.

CONCLUSIONS

Large scale and widespread applications of anion exchange treatment of effluents are unlikely for two major reasons:

(a) For many effluents, nutrient removal would have little or no effect on the receiving water, either where climatic or other conditions did not lead to eutrophication problems or where plentiful alternative sources of nutrients were available.

(b) In those cases where nutrient removal was considered necessary, it would often be sufficient to remove only phosphorus, for which precipitation processes would be considerably cheaper than ion-exchange.

It is possible, however, to envisage cases where local conditions might dictate a very high quality effluent, with minimal quantities of nitrogen and phosphorus. An example would be the effluent discharged to a recreational lake. In such cases, the ion exchange method might be well worth considering, especially if the effluent had fairly low sulphate content.

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