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Optimisation of the operating parameters in an experimental DAF process for wastewater treatment

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INTRODUCTION

Many water and effluent treatment processes involve the separation of solids from a liquid phase, whether the solids are present naturally or result from the treatment process itself. Dissolved Air Flotation, DAF, is a particularly effective means of attaining solid/liquid separation,and its field of application is extensive. In a DAF process, air and water are mixed together at a high pressure, causing the air to dissolve in the water. The resultant dispersion water, ideally bubble-free, is released into a flotation vessel, where it mixes with the wastewater to be treated. The sudden reduction of pressure effected by the release device, generates a mass of minute air bubbles as the air comes out of solution. Attachment of the bubbles to the solid material present in the wastewater accomplishes its removal by lifting it to the surface, from where it may then be removed.

DAF has been employed outside of the water treatment field since the early 1900's, principally for mineral processing and mining. The general variety of dispersed materials which have been separated by flotation in industrial and wastewater treatment, imply DAF to be a nonselective method.To satisfy the future legislation requirements concerning wastewater treatment and disposal, current practices need to be investigated for possible improvements. Interest in DAF is consequently being renewed, its advantages over the more orthodox techniques of sedimentation and filtration, being realised. To offer DAF as a possible means of satisfying the demands of the future, necessitates the generation of data pertaining to design details, and their subsequent affect upon post-flotation water quality.

The work reported here was undertaken to determine the effect upon process performance, of the initial depth of wastewater column to be treated. The effect of this parameter on flotation was optimised as a function of effluent suspended solids concentration.

EXPERIMENTAL

Materials

Flotation data are presented for an effluent of poor quality simulated by blending anaerobic digested sludge with tapwater. A bulk sample of secondary wastewater sludge was collected from a North West Water Treatment Works, Liverpool, to minimise variations in contaminant concentrations of the wastewater mixture, on a daily basis.

In full scale DAF plants the gas source is dissolved under pressure into a recycle flow of treated effluent. Although most gases are suitable for flotation, in practice air is used almost exclusively, being readily available and inexpensive. For the bench scale experiments performed, imposed equipment limitations did not favour a continuous flow situation, resulting in a series of batch tests. The air was dissolved in tapwater, before release into the flotation column.

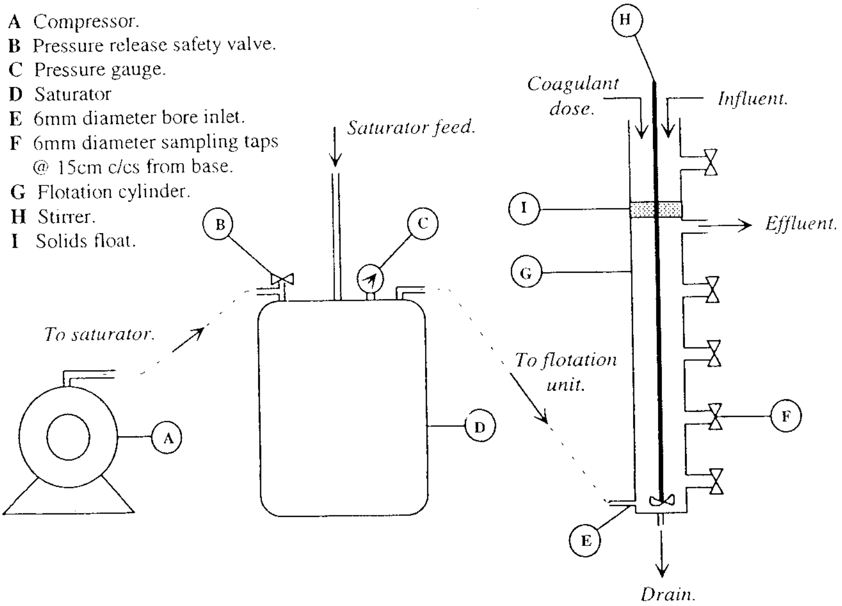

Figure 1. - Schematic diagram of bench-scale DAF apparatus.

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Methods

A schematic diagram of the apparatus used is shown in Figure 1. The saturator was filled with a volume of recycle liquid (tapwater), at least one litre more than required for a particular run. This avoided a sudden discharge of compressed air to the flotation cylinder towards the completion of blending. The wastewater to be treated was placed in the flotation cylinder, constructed from plexiglass cylindrical tubing with a depth of 95cm and an effective volume of 6.5 litres. A key feature of the cylinder was the inclusion of six sampling points at depths of 15cm centre to centre. This enabled samples of treated effluent to be obtained throughout the height of the column.

The coagulant, ferric chloride, was added to the sample directly and mixed thoroughly in the column by a stirrer. A rapid mixing speed of 400 rpm. was maintained for two minutes, followed by a flocculation period of five minutes, during which stirring at 20 rpm was practised. The stirrer was removed with care to avoid floc damage.The air saturated feed was discharged via a length of tubing from the saturator and was introduced to the wastewater through a 6mm opening at the base of the flotation vessel. Timing of flotation commenced immediately after valve closure, when the liquid in the flotation column was constant. Duplicate samples of 50ml of post flotation effluent were taken from the desired depth and analysed for solids concentration. Temperature and pH readings were recorded at the time of sampling.

Operating conditions

Overall DAF performance depends largely upon favourable interaction between the equipment and the process variables. Preliminary investigations were carried out to determine an optimum range of operating conditions for the given apparatus and materials to be used. Numerous researchers[1-4] have reported optimum recycle flow rates and system operating pressures. For the particular apparatus herein, a saturator pressure of 7 bar, combined with a recycle flow of 20% of the wastewater to be treated, was found to be the most beneficial to performance. The higher pressure was found to overcome the restrictive nature of the air release device whilst simultaneously producing smaller bubble diameters advantageous to flotation efficiency.

Comparable concentrations of wastewater samples were achieved for the individual batch tests by blending 25ml of concentrated sludge with 975ml of tapwater alternately, producing a simulated effluent with a solids concentration of 2580mg/l. Continual mixing was maintained throughout the blending process, which was conducted within the flotation vessel itself to avoid deposition of solids in a separate mixing vessel. This approach had the further advantage of reducing solids settlement prior to flocculation, enabling a more uniform distribution of solids throughout the wastewater column to be achieved.

Laboratory coagulation tests were performed in accordance with the recommendations of the Water Research Centre. It was envisaged that different rates of coagulant dissolution may have been instrumental in improving both solid preparation and separation. To eradicate such a nonuniformity from the results, liquid coagulant feed was used. An optimum dosage of 44mg/l was added to the wastewater for the flotation experiments performed.

A DAF test was monitored over a 30 minute period for each sampling depth. As anticipated the efficiency of the process increased with time, provided the sludge float was well formed. During the flotation period, continuing flocculation prevailed. Substantial increases in floc size were observed but following a period of about 15 min. no measurable additional suspended solid reductions were realised in the flotation column. A flotation time of 15 minutes was taken to be required to achieve optimum performance. This value was in agreement with results detailed by *Morse, J.J.*[5], who indicated periods of detention within the vessel need only be in the region of 15 - 30 minutes.

RESULTS AND COMMENT

The study into the effect of initial wastewater column depth upon flotation performance was conducted in two directions. The first was to investigate the efficiency of solids removal throughout the profile of each sample. The second was to relate the efficiency of suspended solids removal to the initial depth of wastewater to be treated. The data sets were taken over the same period of time and with the same frequency of sampling, providing a usefulness between test comparisons. A series of nine experimental runs was required to examine the effect of depth.

Figure 2 shows the efficiency of DAF throughout the height of the flotation column for the respective initial depths of water indicated. For initial depths of wastewater upto 55cm, particularly high levels, ranging from 60-80%, of suspended solids removal were obtained. As the sampling depth increased, a general trend of decreasing removal efficiency occurred reaching a minimum value, beyond which efficiency once again appeared to improve. This inversely proportional relationship postulated between the efficiency and sampling depth was found to be most evident within a range of initial depths of column from 45-60 cm. For initial heights of column greater than this decreasing efficiency was observed as the height of sample increased. It is possible that the higher performance rates at the greater sampling heights, for the range of initial columns 45-60cm are a consequence of settling prior to flocculation, or settlement of the flocculated particles, too dense to float. Lack of experimental evidence prevents any definite reason being given.

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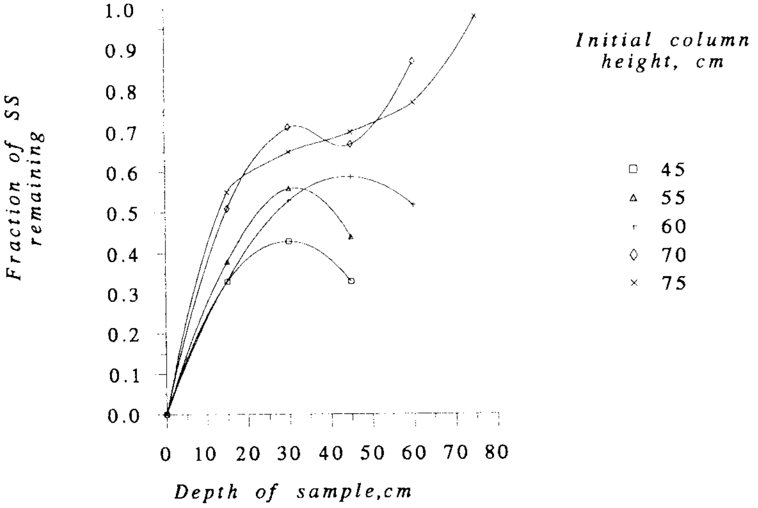

Figure 2. - DAF efficiency versus sampling depth over an initial column height range of 45-75cm.

While *Dick, R.I and Ewing, B.B.*[6] , showed that the initial depth of sludge in laboratory columns has a substantial effect on the initial gravity subsidence rate of activated sludge, the influence of initial depth on performance in flotation tests has not been reported. The data from the tests showing the effect of initial depth upon flotation performance are plotted in Figure 3.

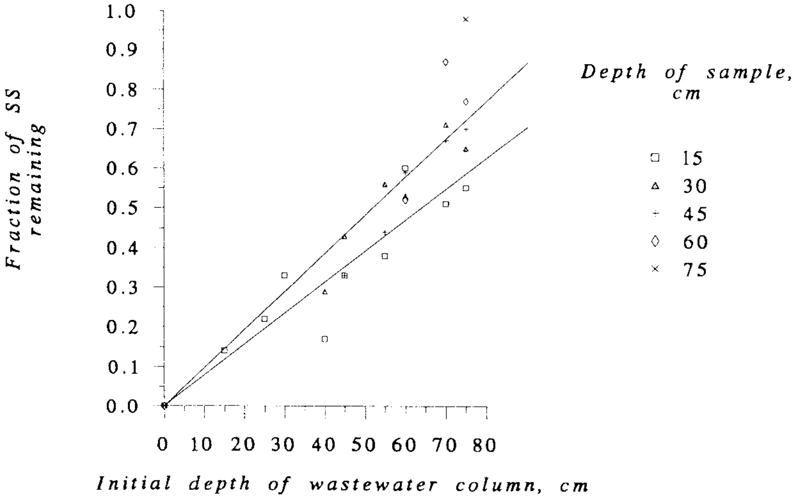

Figure 3. - Effect of initial column height on DAF performance.

For depths of sample taken at 15cm and 30cm, the data plotted as straight lines. Beyond this height limited values were available and to force a distribution to conform to these points may have perpetuated an error. It was observed that efficiency decreased with increasing initial column height. Furthermore, the results indicate that for a given initial depth of influent, at higher sampling points the performance is reduced to a more noticeable extent than for sampling depths below it. This observation is in keeping with results reported by *Dick, R.I. and Ewing, B.B.*[6] who illustrated, from gravity sedimentation data, that the more solids present, the less efficient the performance. Additionally, variations in operational conditions will influence DAF performance to differing extents, and must therefore be acknowledged as possible causes of discrepencies. A comprehensive monitoring system of the role of such operating parameters as pH and temperature was considered to be beyond the scope of this study.

It became apparent during the experimental runs, that at a higher value of initial column depth, the amount of recycle flow required was quite significant in volume. During its addition into the cylinder unusual flow conditions were observed. The air bubbles and floc were found to rise to approximately half of the depth of the column of water, causing floc at this depth to then circulate downwards in the flotation vessel along the face opposite to the inlet. This phenomena was thought to contribute to the decreasing efficiencies at higher depths, and is attributed to the constraints of the dimensions of the flotation cylinder and the vessel being slightly inclined.

In introducing the larger amounts of recycle flow, the opening and closing of the valve enhanced bubble-bubble agglomeration within the feed line. The larger bubbles had a tendency to cause turbulence within the vessel, and subsequent reductions in performance to be observed. The only method of avoidance, was to keep the feed line length to the minimum required for connecting the saturator to the flotation cylinder.

Of noticeable importance was the effect of rapid mixing detected at the higher initial column depths. For depths up to and including 55cm, rapid mixing was effective in its application. Beyond this value, vorticity in the mixture was noted, the stirrer no longer functioning effectively throughout the sample. This not only prevented the achievement of a uniformly distributed sample, but was believed to influence the quality of floc in the upper region of the vessel. In addition, the turbulent conditions took time to diminish, effectively reducing the flocculation period and strongly influencing the quality of floc available for flotation.

It was concluded that the greater the initial height of column above the air inlet, the less efficient the process performance was found to be, throughout the complete depth of the sample. This was most significant for initial heights above 55cm, beyond which performance was dramatically reduced. It is possible that a relationship exists between the height of column and the cylinder diameter. No verification of this was practicable from the results obtained.In keeping with current full-scale DAF applications, where the effluent is withdrawn from the base of the tank, the highest quality was consistently at the lower sampling point of 15cm. The superior performance at this lower depth is in keeping with the objectives of the DAF procedure; to raise the solids to the liquid surface.

Wood, R.F. and Dick, R.I. [7] have shown that the rate at which the air would pass upward through the cylinder is affected by the rate at which the recycle flow and sludge are blended. For a greater initial column depth thorough mixing may require a longer period due to the larger volume of fluid present. It is possible that the time allowed for blending should consequently be adjusted in accordance with the volume of recycle flow required, whilst considering this in relation to the detrimental effect of stirring upon bubble-floc agglomerates.

CONCLUSIONS

Theory has yet to be developed to predict the quality of effluent that may be expected from the minimum of experimental work. This bench scale batch flotation investigation has shown the feasibility of treating secondary wastewater effluent by dissolved air flotation, ensuring an acceptable level of suspended solids removal. Chemical reaction, flocculation and flotation operating parameters have been studied. The conclusions drawn from this research are as follows:

- The coagulant dose addition has an important influence on the performance of the system. Tests demonstrated the importance of complete and thorough mixing, and the need for solid/liquid separation processes to be designed to reflect important characteristics of the wastewater, including particle concentration and size distribution.
- A minimum level of flocculation detention time was found to be required. The sensitivity of the overall performance to the floc size was immense. Analysis of floc diameters was not observed, but it was concluded that a shorter flocculation period would have beneficial effects, under the same operating conditions.
- The diameter of batch flotation vessels and the manner in which the blended sludge was placed in the vessel, were found to affect batch flotation results significantly. The literature available does not indicate that these factors have been considered in interpreting the performances of the batch flotation test or in the use of the data obtained from them. A closer study of the appropriate technical equipment is a definite pre-requisite, if batch flotation tests are to be of use in the design of full-scale DAF units.
- The appearance of the floc structure was an indication of the chemical's ability to pretreat the solids. A large floc was not necessarily the best, since agitation caused it to fall apart. A floc that was small and tight, proved to be the most desirable.

- There was a clear indication of a correlation between initial depth of column and efficiency. The arguments for such, in the absence of further findings, are of limited relevance, since the experimental results are system specific. Generally, performance decreased dramatically at a high initial depth. It is suggested that the factors outlined which adversely affected the batch test results, be considered more closely, in order to assist full-scale DAF efficiency. The small amount of data collected lead to a low degree of confidence being associated in predicting full-scale performance from the established bench scale procedure.

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