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Suspension concentration profiles during rapid gravity filter backwashing

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Abstract

Rapid gravity, granular media filters are widely used in the water and wastewater treatment industries. Regular backwashing to clean the filters is a vital part of their efficient operation. Experimental data on the development of suspension concentration profiles through laboratory scale filter beds during the backwash process were obtained. Previous attempts to obtain and record backwash profiles of this type have been unsuccessful due to the limited range of existing turbidimeters. The results have been used to validate a new model developed by the authors. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Gravity filtration; Backwashing; Suspension concentration measurement; Deposit removal; Fluidisation

1. Introduction

The backwash process is a vital stage in the efficient operation of rapid gravity filters. The backwash operation typically consists of a reverse flow of water to flush out clogging deposits. The backwash can be accompanied by some form of auxiliary cleaning method such as air scour or surface water jets. The main backwash regimes currently in use are:

1. Water only at a rate sufficient to fluidise the bed;
2. Air scour followed by water only;
3. Simultaneous air and water.

Present practice is to backwash filters on a time in service basis. Additionally headloss across the bed is normally monitored and a high level can initiate the backwash ahead of the time cycle.

Backwash parameters such as the duration and water velocity are normally fixed for a given system regardless of any changes to the influent quality. This can in some cases lead to under washing or over washing of the filter. The former condition can lead to reduced filtration run times and other operational problems, see for example Cleasby et al. [1]. The latter condition is an inefficient use of the final product, i.e. treated water and represents a reduction in terms of the process efficiency and economics.

The filtration and backwash processes in the operational cycle of a rapid gravity filter are inextricably linked. Ineffective backwashing will affect the subsequent filtration cycle. Similarly, changes in the filtration conditions such as an increase in influent concentration can lessen the effectiveness of a fixed backwash regime.

Numerous filtration models have been developed to describe the deposition process and headloss build-up for rapid gravity filters, see for example [2–6]. In contrast few models have been developed to describe the backwash process, particularly in terms of the volume of clogging deposit to be removed from the bed and the time this takes for a given backwash regime. Two attempts at modelling the backwash process along these lines are Bhargava and Ojha (1989) and Huang and Basagoiti [7]. Neither of these models however have the facility to link both the filtration and backwash processes such that each acts as a feedback mechanism for the other.

As far as the authors are aware, no model exists which describes the combined filtration and backwash cycle such that each process is dependent on the other. Some workers ([8]) have touched on this area, particularly when describing the initial degradation of effluent quality whilst bringing a filter back on line following a backwash, commonly known as the ripening period.

This paper describes experimental work undertaken as part of a larger project attempting to model the backwash process in terms of the volume of clogging deposit to be removed and the time required to remove it. The model described previously [9], determines the concentration of the backwash suspension at any depth within the bed throughout the duration of the backwash period. It relies on a suitable filtration model in order to establish the initial conditions in the bed prior to the start of the backwash.

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2. Objectives

The main objectives of the experimental work are:

- to investigate the development of suspension concentration profiles at different depths within the filter bed using different backwash regimes using a simple concentration meter; and
- compare experimental suspension concentration profiles with those generated from the backwash model for a fluidising water wash only.

The content of the paper will be limited to describing the experimental set-up and methods and to also examine some of the results obtained for a fluidising water wash.

A comparison between experimental results and those produced by the model will be presented at a later date.

2.1. Experimental set-up

Experimental arrangement is shown in Fig. 1. The arrangement consists of four identical filter columns. Each column has an internal diameter of 100 mm and consists of two tubular sections. The bottom section forms the underdrain which connects to the top section via a proprietary dome-type filter nozzle. The nozzle design is suitable for simultaneous air and water flow as well as water only. Each filter column has brass pressure and sample ports at heights of 145, 245, 345 and 750 mm measured from the bottom of the filter bed. The pressure ports are connected to a manometer board along with a pressure port connected into the under drain section to allow headloss measurements to be made across sections of the bed.

Leighton Buzzard sand with a supplier specified size range from 0.5 to 1.0 mm and measure density of 2625 kg m^{-3} was used in each of the filter columns. In order to minimise any effects from media size distribution the sand used in each filter column was sieved between two British Standard sieve sizes, 850 and 710 μm (18/22). The uncompacted bed height was 550 mm.

The sample ports extend 45 mm into the filter column and are capped with 80-mesh copper screen. Flow cells are connected to the sample ports in order to measure the concentration of the backwash suspension during the backwash operation.

The flow cell consists of a 20-mm diameter sample jar held within a PVC case. Inlet and outlet pipes allow the sample to flow from the sample port through the cell and to drain. A high power gallium aluminium arsenide (GaAlAs) infrared emitting diode and two light-to-voltage sensors are arranged within the cell to measure forward light attenuation and 90° light scatter. Signals from the light-to-voltage sensors are input to computer via a 16-channel, 12-bit, high speed analogue to digital converter. A software program

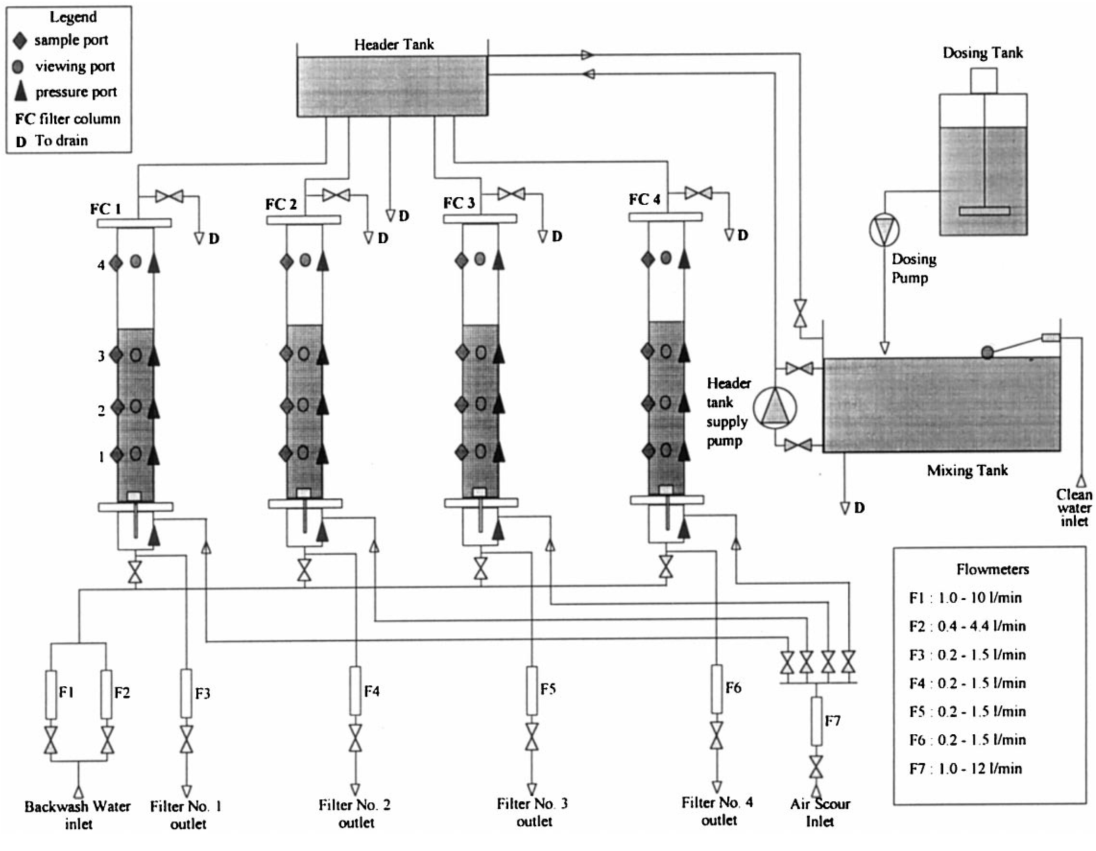

Fig. 1. Experimental set-up.

calculates the ratio of 90 light scatter to light attenuation which are then used within an equation used to model the concentration of a kaolin clay suspended in tap water. The equations used to model the kaolin clay suspension were obtained from a calibration procedure.

Previous attempts to obtain and record backwash profiles of this type have been unsuccessful due to the limited range of existing turbidimeters.

3. Experimental methods

All four columns were run in parallel during the filtration period each receiving the same influent concentration. The clogging suspension used was kaolin clay suspended in London tap water. At the end of a filtration run each of the filter columns were backwashed sequentially using the same backwash regime. During each backwash the flow cell was connected to a different sample port. Using this method typical suspension concentration profiles at various depths within the bed were obtained.

Three kaolin influent concentrations of 200, 350 and 500 mg l^{-1} were used along with filtration periods of 2, 4 and 6 h. Backwash velocities were selected to give a good range of bed expansions up to a maximum of 40% (maximum practical expansion for bed depth and column height). Four backwash velocities were used 5.5, 7.4, 10.6 and 16.8 mm s^{-1}.

4. Results

A typical example representative of the concentration profiles obtained are shown in Figs. 2–5. These are the concentration profiles obtained using the four water only backwash velocities mentioned above with a 6-h filtration period and influent concentration of 200 mg l^{-1}.

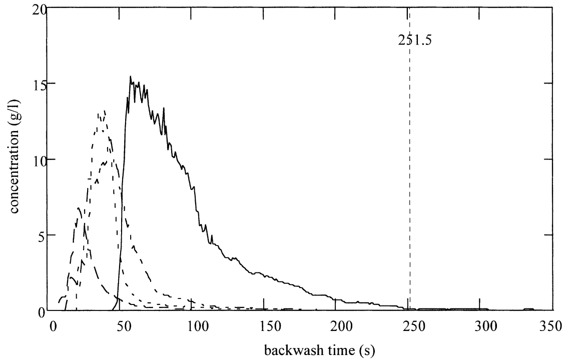

Fig. 3. Backwash concentration profiles. Backwash water velocity 7.4 mm s^{-1}.

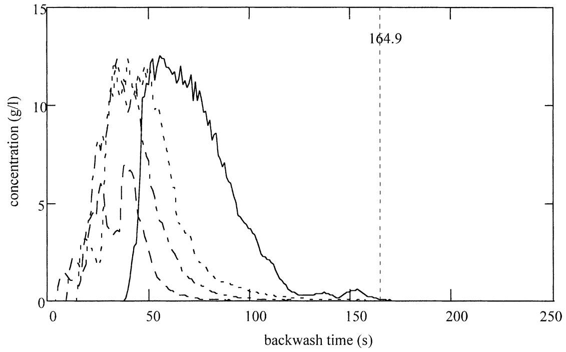

Fig. 4. Backwash concentration profiles. Backwash water velocity 10.6 mm s^{-1}.

The four backwash concentration profiles shown in each of the figures are obtained from sample port No. 1 (dashed curve), sample port No. 2 (dash dot curve), sample port No. 3 (dotted curve) and sample port No. 4 (solid curve). For all bed expansions sample port No. 4 was above the bed whereas all of the other ports were within the bed.

Also shown on each of the graphs is a backwash time marker. This shows the time at which the backwash water concentration emerging from the bed reaches a value of 99.5% of the peak value attained during the backwash. This value was useful as a crude quantitative measure of the backwash duration for different backwash velocities.

All four concentration curves have been placed on a common backwash time basis using the theoretical hydra-

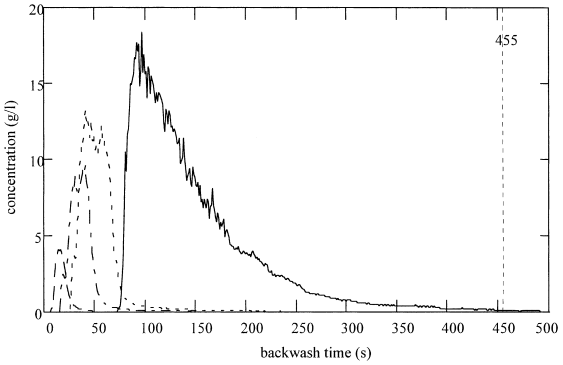

Fig. 2. Backwash concentration profiles. Backwash water velocity 5.5 mm s^{-1}.

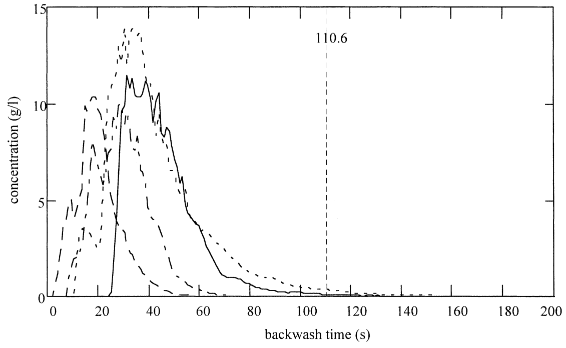

Fig. 5. Backwash concentration profiles. Backwash water velocity 16.8 mm s^{-1}.

ulic retention time function, $\theta(z)$, given as

$$\theta(z) = \frac{L - z}{U/\varepsilon} \tag{1}$$

where L is the expanded bed height; U, the superficial backwash velocity; ε, the expanded bed porosity; and z, the depth within the expanded bed.

5. Discussion

Concentration profiles obtained above the bed have different characteristics to those obtained from within the bed as would be expected given the difference in hydraulic conditions. These profiles have also undergone dilution caused by the volume of influent remaining above the filter bed prior to backwashing.

In general the shape of the concentration profiles are heavily dependent on the hydraulic conditions set up within the bed and the degree of mixing that takes place between adjacent layers. In most cases the profiles can be described as having an initial sharp rise followed by an exponential decay. Mixing can be characterised by the dual peaks present in most of the profiles obtained from within the bed and is most evident in the higher velocity backwashes, see Figs. 4 and 5.

It appears to be caused by uneven bed expansion causing top layers of the bed, with greater clogging deposits, to collapse into lower layers. A number of factors may effect the flow patterns set up in the bed, hence the degree of mixing, such as irregularities in the filter nozzle; uneven flow distribution through the gravel support layers; size distribution and sphericity of the filter media.

Mixing can be observed particularly during the initial stages of the backwash during the period when the bed undergoes expansion, this stage has previously been termed the transient phase by Hall and Fitzpatrick [9]. The degree of mixing may also be dependent on the method of applying the backwash water. In the experiments described here the backwash water was applied manually by first opening an isolating valve and then opening a control valve to achieve the require superficial water velocity. An improvement to the experimental procedures would perhaps be to automate this process through a computer in order to produce repeatable starts and to further investigate the effect of start-up on the degree of mixing during the transient stage.

The mixing phenomenon observed during these experiments may result as a consequence of the filter column construction and scale. However, it is not unreasonable to assume that uneven flow distribution does occur in full-scale industrial filters. It may also be a contributory factor to the initial degradation of effluent during the filter ripening period.

Although the optical method used to measure the concentration profiles are similar to that used by conventional turbidity meters, the high power gallium arsenide infrared emitter and sensitive light-to-voltage sensors allowed concentrations or equivalent turbidities levels to be measured which would normally be beyond the normal working range of most laboratory turbidity meters. The two flow cells used throughout the experimental work were calibrated from clean tap water up to a concentration of 100 g l^{-1} kaolin clay suspension.

The measurements taken with this arrangement are subject to errors caused by changes in the nature and size of kaolin particles or aggregates in the measurement field. Coagulation and flocculation were not carried out during the filtration period to minimise these errors, however, it has been observed that a small degree of flocculation does occur naturally when kaolin clay is added to London tap water. It has also been shown by Gregory and Nelson [10] that the number and size of particles in the measurement light beam cause random fluctuations in the amount light transmitted which may also contribute to errors using this type of measuring technique.

6. Conclusions

1. Backwash suspension concentration profiles have been measured at different depths within the filter bed and emerging from the bed for a fluidising water backwash for four backwash water velocities to give different bed expansions up to a maximum of 40%.
2. The shape of the concentration profiles broadly follow those predicted by the model [9]. The model does not, however, predict the mixing phenomenon as characterised by the dual peaks shown on the measured concentration profiles.

The degree of mixing may be dependent on the magnitude of the backwash water velocity and on the method by which it is applied. The initial degradation in effluent quality experienced during filter ripening period may be linked to the amount of mixing that has occurred during the transient (i.e. bed expanding) stage of the backwash process.

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