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AFFORDABLE WATER SUPPLY AND SANITATION

Design aspects of hydraulic flocculators

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SINCE 1992 the Civil Engineering Departments of the Universities of Edinburgh and Malawi have been collaborating on investigations of hydraulic flocculation in the treatment of turbid surface waters.

Laboratory studies have been carried out at Edinburgh with field studies based at Thyolo water treatment works in Malawi. The system layouts for the two sites are shown in Fig.1. Aluminium sulphate (alum) coagulant and the natural coagulant *Moringa oleifera* **Lam.** (M.oleifera) have been used following earlier evaluations (McConnachie, 1993, Sutherland et al, 1993 & 1993)

Test procedure at Edinburgh

Synthetic river water was formed from tap water with added kaolin (200 mg/l for "low" turbidity and 666 mg/l for "high" turbidity) + 200 mg/l Na_2HCO_3 (for 2 meq/l alkalinity to promote aluminium hydroxide floc) + 0.0334 ml conc acetic acid per 1000 l of water (for pH of 7±0.2). Flow to the flocculator was 30 or 40 l/min at temperatures of 15, 20, or 28°C for 4 flocculator bed slopes (1 in 40, 48, 60, and 120) and various arrangements of the baffle types shown in Fig.2 as listed in Table 1.

Alum coagulant was used for 70 test runs, at 85 mg/l for high kaolin concs. and 50 mg/l for low concs. M.oleifera was used for 12 tests, all for high kaolin, at dosages established from jar tests. Coagulant was added by drip feed at the flow inlet. In addition, where noted in Fig.4 as "stirrer", a turbine-bladed stirrer agitated the mixture at the inlet, or, alternatively, where noted as "injection", the coagulant was added to the raw water inlet pipe 300mm before its end with wire mesh inserted into the pipe over this length to increase agitation.

After steady-state conditions were reached the flow was stopped within the flocculator and the floc allowed to settle, with samples being taken after 10 and 30 minutes settling from 20mm below the surface at positions equivalent to flow retention times of 10, 15, 20, 25 and 30 minutes. The turbidity of the samples was measured directly in normalised turbidity units (NTU).

It should be noted that residual turbidity values have been used for assessing the efficiency of flocculation which give comparative rather than absolute results as the nature of the floc in size and strength, which will affect its removal in subsequent stages such as passing through a settling tank or sand filters, was not evaluated.

Figure 1. General layout of flocculators at Edinburgh and Thyolo.
a) Sectional elevation b) Plan

Figure 2. Baffle types.

To assess the relative turbulence created by the baffles laser-Doppler anemometry (LDA) was used to measure horizontal and vertical flow velocities and corresponding velocity fluctuations at 10mm steps downstream from each of the three baffle types at five depths and at six points across the width of a 75mm wide channel for a flow rate of 100 l/min. At each location the average of over 80000 readings taken over 1 minute has been recorded and for each level the average values across the width are shown in Fig.5 along with values for no baffle in place.

Test results at Edinburgh

Fig.3 shows mean values from pairs of tests with alum as coagulant under different baffling arrangements as detailed in Table 1. Error bounds are typically ±0.2%. The higher initial kaolin in the raw water produces relatively better results in terms of percentage residual turbidity as shown by the broken lines. The Fig. shows that for any test the retention time in the flocculator should be between 20 and 25 minutes.

The poorest results for both high and low initial turbidity come from no baffles and arrangement 5 with no baffles in the first 30 channels. (For the flow of 30 l/min channel 30 is reached after approximately 12 minutes). There appears to be no advantage in having strong baffling (type 4) beyond the 12 min retention zone although some baffling (type 2) improves the high turbidity results.

Fig.4 shows the results using M.oleifera as coagulant. Moringa floc tends to be less dense than that from alum giving lower settling efficiency and residual values of the order of two times the alum values. Error bounds are ±0.4%. Best results came from the use of increased agitation at the coagulant mixing zone with the injection method appearing to be an improvement over mechanical fast stirring. Retention time between 20 and 25 minutes would appear to be adequate with the overall residual turbidity reducing by only 0.4% or so for an extra 5 minutes. The effect of baffles is not clear cut and further testing is necessary.

The LDA results shown in Fig.5 are for the horizontal velocity fluctuations only. The strongest surging comes from the baffle with 40% of its area blanked off (type 4). The mesh baffle (type 3) gives relatively uniform values over the depth for the distances shown as might be expected. Direct relationship to flocculation efficiency awaits completion of LDA measurements.

Pilot plant tests at Thyolo

A range of standard water quality parameters has been examined during the pilot scale studies. Here, however, treatment efficiency has been recorded solely in terms of reduction in turbidity. Raw water turbidities ranged from 130 NTU to 1060 NTU with the majority of runs being carried out at an initial turbidity of approximately 200 NTU. Coagulant dosage was in the range 50 - 150 mg/l as found from jar tests on the raw water.

The mixing tank is 880mm long, 250mm wide and 400mm deep, with a V-notch weir for flow rate measurement. Coagulant was added into the nappe of the dis-

Table 1. Details of baffle arrangements for the Edinburgh flocculator.

Baffle arrangement no.	Type of baffle (see Fig. 2) - symmetrically spaced along channels
1	Channels 2 to 30: 2 no. type 1 + chs. 31-60: 3 no. type 2
2	Chs. 2 to 30: 2 no. type 1 + chs. 31-45: 1 no. type 3 + chs. 46-60: 1 no. type 2
3	Chs. 2 to 30: 2 no. type 1
4	Chs. 2 to 30: 2 no. type 1 + chs. 31-45: 3 no. type 3
5	Chs. 31-45: 3 no. type 3
6	Chs. 1 to 5: 4 no. type 1

Figure 3. Edinburgh test results - alum coagulant.

Figure 4. Edinburgh test results - Moringa coagulant.

Figure 5. Laser-Doppler anemometry measurements.

Figure 6. Thyolo test results.

charge from the V-notch weir to promote rapid mixing in the turbulence of the reversing flow.

Flow from the mixing tank dropped directly into the flocculator channel through a 230mm by 60mm rectangular slot. The mixing tank was fed through a flexible pipe allowing it to be positioned at any point along the flocculator channels for the required flocculator retention time.

An alternative mixing procedure by-passed the mixing tank, by dosing coagulant directly into the raw water pipe 250mm from its outlet end. A plastic mesh inserted into the pipe over this end section effected the mixing.

Each of the three hydraulic flocculators is 5200mm long, 1200mm wide and 250mm deep with an average slope of 3.5% to the horizontal, containing 120 channels of 40mm width. The flocculators are linked in series and connected to the sedimentation tank by an 80mm wide channel. Runs have been carried out using from 60 channels to 360 channels, giving retention times in the flocculators at the applied flow rate of 30±2 l/min of between 20 and 120 minutes. When using any portion of the flocculators the upstream sections were blocked off. For 5 of the tests 3mm square plastic mesh was inserted across the first 15 channels to increase turbulence and accentuate tapered flocculation.

The sedimentation tank is a rectangular horizontal flow tank of effective capacity 4.2 m^3, giving a nominal retention time of 2h 20min. Tube settlers fill the tank and are of 50mm o.d. PVC and 1.15 m in length, inclined at an angle of 60° to the horizontal and arranged in an array of 25 over the tank width and 50 over the length. The clarified water decants into a series of 10mm diameter openings along the length of 4 outlet tubes placed longitudinally at the top of the tank. For some tests the tank outflow was passed downwards through a sand filter bed with nominal retention time of around 15min.

Test results at Thyolo

Fig.6 shows results from six typical test runs. During most runs removal efficiencies were less than 90% for the first two to three hours. It was concluded that this period was required for the sedimentation tank to come to thermal equilibrium, as, although shaded, the steel walled tank was subject to warming on standing. This effect was more pronounced for the less dense Moringa flocs than for alum.

Comparing tests 1 and 2, an extended retention time of 120 minutes brings no benefits in unbaffled flocculators. From tests 2 and 3, increasing the turbulence early in the flow improves turbidity reduction, and with mesh in the inflow pipe similar results are obtained to test 3 with a retention time of 40 minutes (test 4) and also 20 minutes (test 6).

Alum (test 5) gives better results than Moringa (test 4) at the settling tank outlet, probably due to denser floc, but after the sand filtration stage (tests 4, 5 and 6) the final effluent quality for either coagulant is consistently close to, or below, 1 NTU and is thus substantially below the WHO guideline for drinking water of <5 NTU.

Additional trials will be carried out in Malawi during the next rainy season (from December 1994). Work will be concentrated on the lower range of retention times in the flocculators and on optimisation of the tube settler unit.

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