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Turbidity removal by the up-flow pelletisation process for low turbidity water

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ABSTRACT: A fluidised-bed pellet reactor was successfully used to remove turbidity from synthetic high-turbidity (2000 NTU) raw water, as is done in China. In this study, an up-flow pelletisation process, after a certain start-up process, removed the turbidity present in the synthetic low-turbidity (50 NTU) feed water. The process consisted of a rapid-mixing unit and an agitated fluidised-bed pelletiser with an overflow effluent weir. Poly aluminium chloride and anionic polymer were used as the coagulant and coagulant aid, respectively. The pellets thus formed were very stable and were of a very high density. A high up-flow velocity of 30–40 cm/min. (18–24 m/h) in the reactor resulted in a shorter retention time of only 4–5 min in the pelletiser, while still producing a very clear effluent of better than 3 NTU quality. This retention period is much less than the 2–3 h retention time normally employed in conventional sedimentation tanks, and can therefore drastically reduce the construction cost.

INTRODUCTION

Historically, the agglomeration technique has been known for at least 50 years. The pelletisation process is considered as one of the agglomeration techniques, however, the definition and the mechanism of the pelletisation process have not been conclusive [1–4].

Yusa & Gaudin [4] presented the formation of pellet-like flocs of kaolinite by polymer chains from an aqueous suspension. On the basis of their experiment, a pelletising machine consisting of a horizontally mounted drum was constructed. With the partially hydrolysed polyacrylamide added to a kaolinite suspension, the rotating drum could produce the pellet-like flocs that could be readily wet-screened. Wet pelletising engineering offered a basis for a new scientific approach to solid–liquid separation [3]. Compact flocs were produced by a third coagulation, referred to as pellet flocculation, as distinguished from normal coagulation and flocculation. In this process, the polymer was used as the inter-particle bridging agent. Voluminous flocs formed by flocculation would roll over or collide against a wall and the water was exuded from flocs by external forces which were distributed unevenly on surface of the flocs. The results were pellet flocs and separated water.

The concept was applied to water treatment by Tambo & Matsui [1]. The pelletizer, or separator as it was called by them, was tested for its separation of high turbidity suspensions, ranging from hundreds to thousands of mg/L of suspended solids concentration, at a very high up-flow rate of 30 cm/min, equivalent to only a 5-min retention time.

The process has also been used in a sludge-pelletising thickener [5]. With certain inorganic coagulants (to neutralize the surface charge of sludge particles) and amphoteric polymers (as a sludge conditioner), the device could produce strong pellets of 8–20 mm diameter with only a 10–20 min retention time.

OBJECTIVE

Turbidity in natural surface waters for most regions is not as high as those tested by Tambo & Matsui [1]. For example, the turbidity in the Chao Phraya River, which is the main water source for the Bangkok Metropolitan area, has been reported to be in the region of 20–200 NTU. This low turbidity water is not thought to be treatable by pelletisation or fluidised-bed systems. It is however, the objective of this study to do just that, i.e. to develop a novel technique, as well as to explore the possibility and efficiency of this process in treating the low 50 NTU turbidity water.

MATERIALS AND METHODS

Figure 1 illustrates the experimental apparatus used in this study. It consists mainly of a constant header tank, a rapid-mix plastic unit of 5.4 cm inner diameter and 30.2 cm height, and a fluidised-bed pelletisation reactor of 5.4 cm inner diameter and 2.67 m height. Synthetic water of 50 NTU was prepared by mixing 5000 mg/L kaolin with tap water in a 700×1500 mm^2 tray, and after 24 h of free settling, the supernatant was taken at a depth of 72 mm from the water surface, and diluted with tap water. From Stoke's law, this water should mostly contain colloids of 1 μm diameter. The total hardness, alkalinity and TDS were about 50–80, 70–100 mg/L as $CaCO_3$ and 60–200 mg/L, respectively. Since pellet formation is less likely for low turbidity water, the system investigated in this

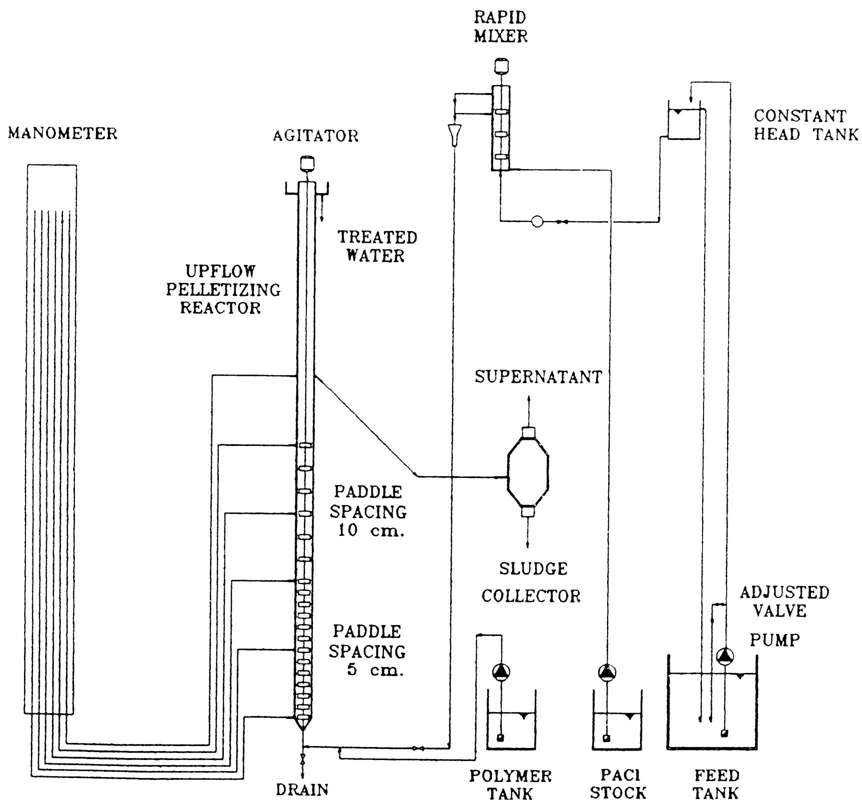

Fig. 1 Diagram of the up-flow pelletisation process setup.

Table 1 Scope of this study

Independent variables	
Raw water	Synthetic with kaolinite and tap water, 50 NTU, pH = 7–7.5
Coagulant	PACl, at 1, 2, 3 and 4 mg/L
Flocculant	anionic polymer, at 0.1, 0.2 and 0.3 mg/L
Up-flow feed velocity	30 and 40 cm/min (or 18 or 24 m/h)
Paddle speed	5, 10 and 15 r.p.m.
pH adjustment	none
Dependent variables	
Detention time in rapid-mix unit	41 and 45 s
Detention time in pelletiser reactor	5 and 3.8 min

Table 2 Properties of PACl used in this study

Manufacturer	Takei Chemical
Code	PAC-250 AD
Appearance	Hygroscopic powder
Al_2O_3 (%)	Min. 30
Fe (%)	Max. 0.03
Basicity (%)	50 ± 5

Table 3 Properties of the anionic polymer

Manufacturer	SNF
Code	Floerger An 910 PWG
Type	Anionic polyacrylamide powder
Stability (days)	5

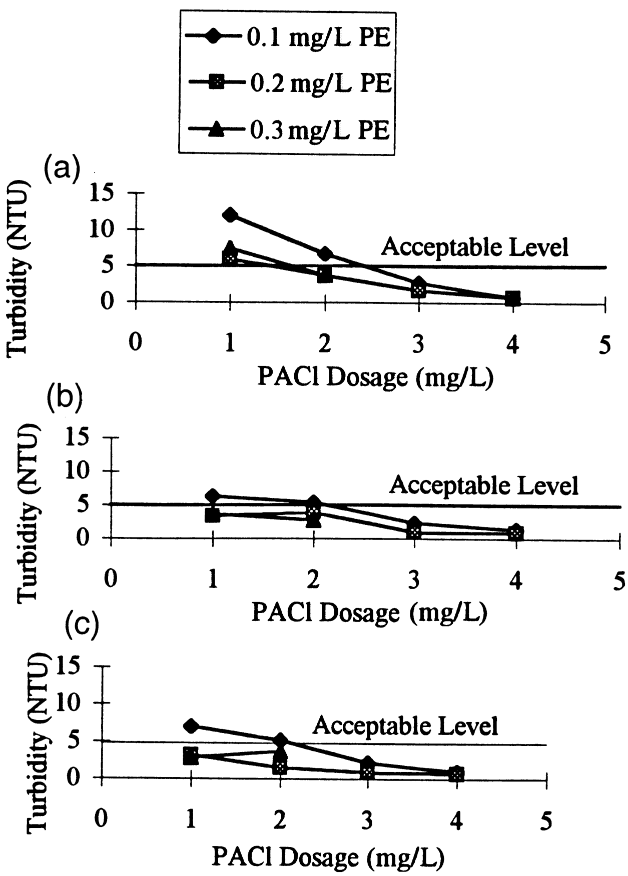

Fig. 2 Effluent turbidity for the 30 cm/min up-flow velocity condition. Paddle speed: (a) 5 r.p.m., (b) 10 r.p.m., (c) 15 r.p.m.

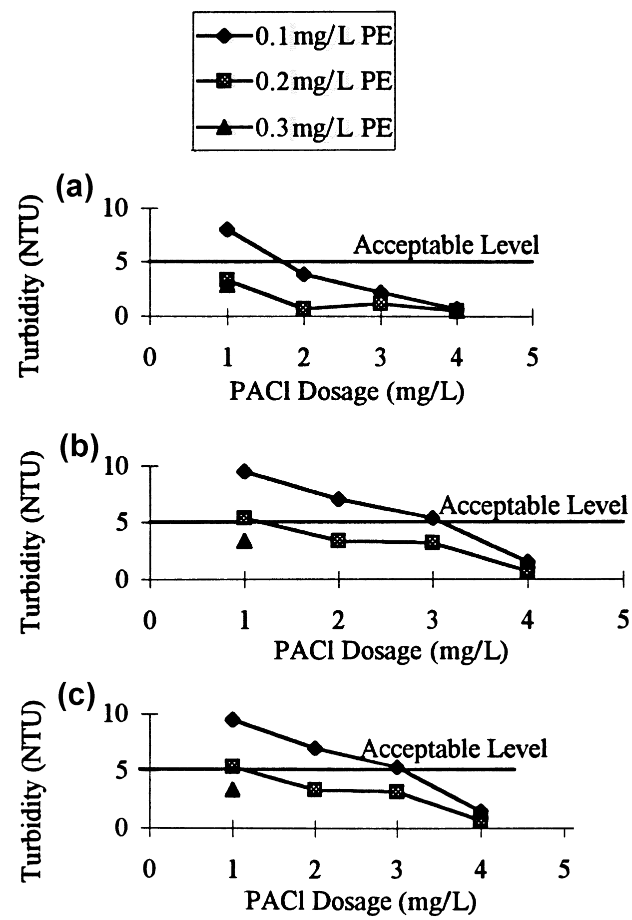

Fig. 3 Effluent turbidity for the 40 cm/min up-flow velocity condition.

study was therefore initiated by introducing feed water of 3000 mg/L kaolin to the reactor. Approximately 1 h was required before pellets were formed, after which the process was fed with the 50 NTU synthetic water. This synthetic water was then pumped to the constant header tank prior to being discharged to the 100 r.p.m. rapid-mix unit where the poly aluminium chloride solution (at a concentration of 1–4 mg PACl/L) was introduced, and where the destabilisation process took place. The destabilised water was then mixed with dosage of an anionic polymer (0.1–0.3 mg/L) before entering the bottom part and flowing upward through the length of the fluidised bed reactor, in which an agitator provided a different but sufficient degree of mixing for a better pelletisation process. The treated water then overflowed the outlet trough into a collecting basin for the subsequent hourly sampling and analysis. The turbidity was determined by use of a HACH 2100 A turbidimeter. The induced sludge or excess pellet floc was continuously removed from the reactor at 15% of the inflow from the sludge withdrawal port, 150 cm from the reactor bottom. Table 1 shows the scope of the study, and Tables 2 and 3 tabulate the properties of the PACl coagulant and the anionic polymer used in this research.

RESULTS AND DISCUSSION

After the special start-up process with 3000 mg/L kaolin feed water and subsequent 6 h of continuous running, the operation of the test unit appeared to reach a steady state. Figures 2 and 3 show the results of the experiments in these conditions, with different dosages of PACl and polymers, as well as at various paddle speeds for the 30 and 40 cm/min up-flow velocity cases, respectively.

For the first case, it is evident from Fig. 2 that a higher PACl dose gave a better result and that at least 2 mg/L PACl was required to achieve treated water at the 5 NTU level which is accepted by the Bangkok Metro Waterworks Authority (MWA) prior to filtration. Higher polymer doses also produced a better quality water; however the effect was not as pronounced with the higher doses or with 0.2–0.3 mg/L of the anionic polymer. The lower agitation level at a 5 r.p.m. paddle speed apparently did not work as efficiently as the higher level of 10 and 15 r.p.m. speed. The effect of paddle speed is however, not very pronounced. In short, if one wishes to produce treated water of a quality of at most 5 NTU turbidity,

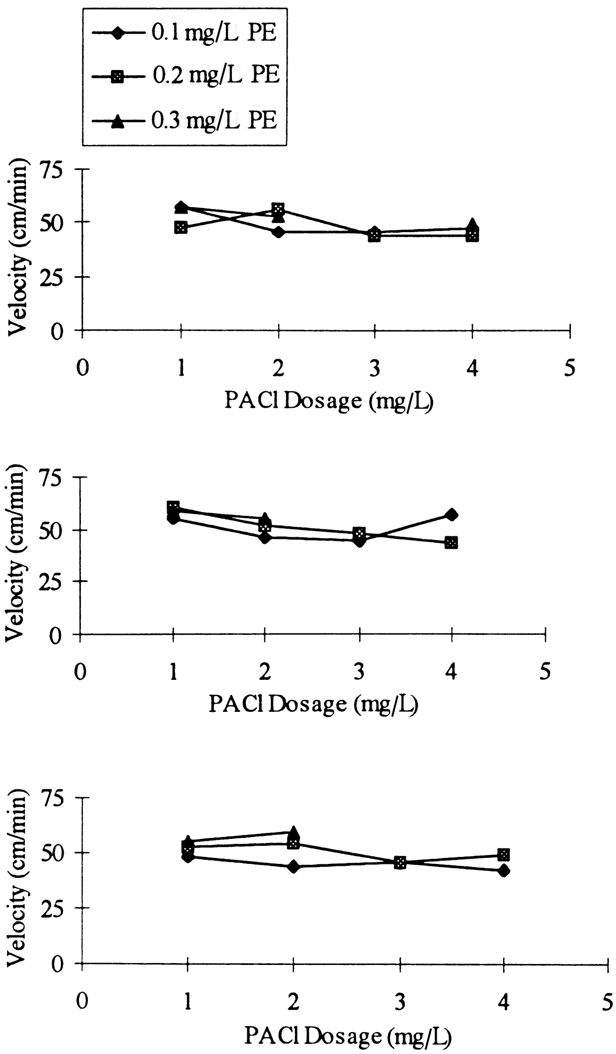

Fig. 4 Pellet-floc settling velocity for 30 cm/min up-flow velocity condition. Paddle speed: (a) 5 r.p.m., (b) 10 r.p.m., (c) 15 r.p.m.

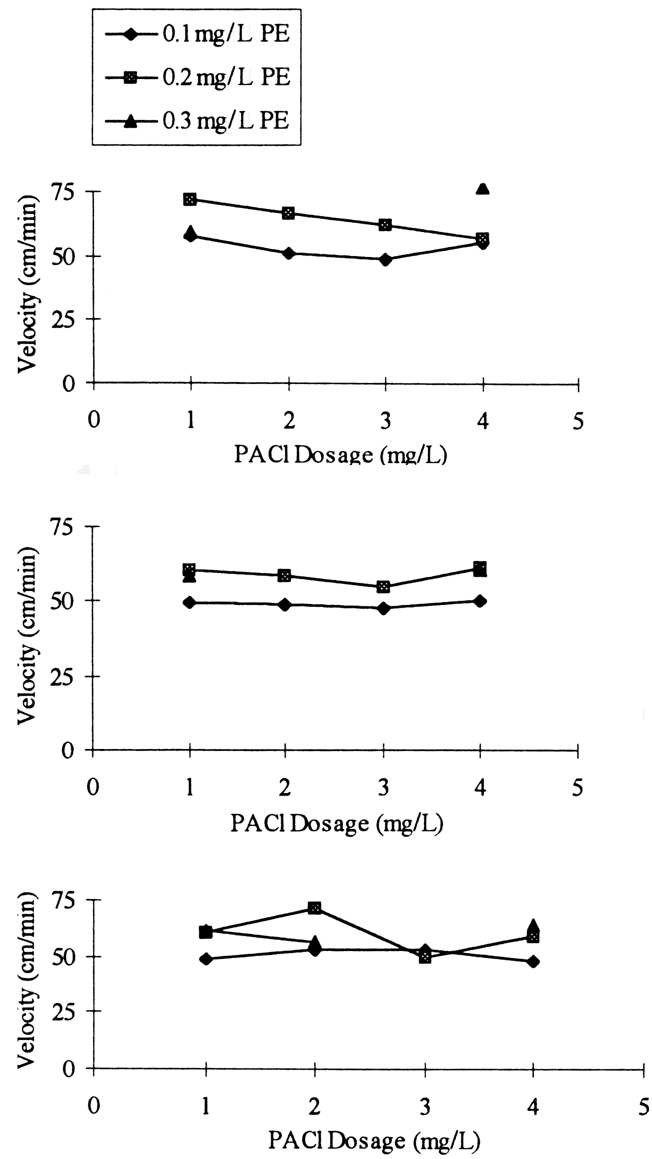

Fig. 5 Pellet-floc settling velocity for the 40 cm/min up-flow velocity condition. Paddle speed: (a) 5 r.p.m., (b) 10 r.p.m., (c) 15 r.p.m.

one may select 2 mg/L of PACl in addition to 0.2 mg/L of the polymer, or 2.5 mg/L of PACl with 0.1 mg/L polyelectrolyte, at any paddle speed of between 5 and 15 r.p.m.

For the second case, or the 40 cm/min up-flow velocity condition, similar conclusions as for the 30 cm/min situation could be drawn (see Fig. 3). On the other hand, probably due to the greater degree of uplift of turbid particles by the higher up-flow velocity, the lower agitation level evidently worked better at turbidity removal. In other words, the 5 r.p.m. paddle speed seems to be a better choice than does 10 or 15 r.p.m. This resulted in another advantage, based on its lower energy requirement. With the 5 r.p.m. mixing, the 2 mg/L PACl plus 0.1 mg/L polymer combination or 1 mg/L PACl with 0.2 mg/L polymer approach was required for water of 5 NTU.

During these experiments, samples were taken of the solids drawn from the excess sludge port for a settling velocity analysis (see Figs 4 and 5 for the test results of the 30 and 40 cm/min conditions, respectively). The settling velocity of the pellet flocs, although it was irregular, was shown to be very high—in the range of 40–60 cm/min and 45–70 cm/min for both conditions, respectively. This very high pellet settling velocity enabled the pelletizer to function at a very high feeding rate, resulting in a very short retention time of only 3.8–5 min in the reactor.

This retention period is very much shorter than that of a conventional clarifier which needs a capacity of 2.5–4 h. This finding, together with the absence of a flocculation unit in the process, makes it even more attractive than the regular sedimentation tanks which are universally employed. It is noteworthy that the results shown here were drawn from laboratory scale experiment with synthetic water. More research work is needed before its application can become reality.

CONCLUSION

The pelletizer was shown to be applicable for low turbidity synthetic water of 50 NTU. An up-flow feed velocity of up to 40 cm/min (24 m/ h) was shown to be effective in the process, resulting in a very low detention time of as little as 3.8 min. Together with the 'non-requirement' of a slow-mixing unit, the lower dosages of coagulant and polymer in the system make the process very attractive, both technologically and economically. To obtain 5 NTU treated water, as little as 2 mg/L of PACl with 0.1 mg/L of the polymer were required at a paddle speed of 5 r.p.m.

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