Pilot study of a fluidized-pellet-bed technique for simultaneous solid/liquid separation and sludge thickening in a sewage treatment plant

X.C. Wang*, P.K. Jin*, H.L. Yuan*, E.R. Wang and N. Tambo*****

* School of Environmental and Municipal Engineering, Xi'an University of Architecture and Technology, No 13 Yanta Road, Xi'an 710055, China
(E-mail: *xcwang@chinawestwater.net*; *pkjin@chinawestwater.net*; *hlyuan@chinawestwater.net*)

** Beishiqiao Wastewater Purification Center, No 368 Kunming Road, Xi'an 710003, China
(E-mail: *xabsqwtc@public.xa.sn.cn*)

*** The University of the Air, 2-11, Wakaba, Mihama-Ku, Chiba 264-8586, Japan
(E-mail: *tambo@u-air.ac.jp*)

Abstract A fluidized-pellet-bed separator with movable sludge hoppers was applied in pilot scale for the separation and thickening of activated sludge mixture liquid. Under the condition of suspension SS around 4,000 mg/L, polymer (CJX103, cationic, MW 5×10^6) dose at a dry solid ratio of 0.003 and upward flow rate at 5.4 m/hr, the fluidized pellet bed performed solid/liquid separation and sludge thickening well. The SS concentration of the treated water was about 5 mg/L on average and the moisture content of the sludge after screening for 5 min was less than 94%, which is much lower than that after conventional settling and thickening and easy to be finally disposed. At a higher upward flow rate of 7.2 m/hr, similar results could also be obtained but higher polymer dose (solid ratio of 0.004) was required. The morphological characteristics and density–size relationship of the granular particles formed in the fluidized pellet bed were also investigated by image analysis and settling velocity measurement of individual particles. The two-dimensional fractal dimension was evaluated to be 1.6–1.8, showing a good quasi-spherical morphology of the granular particles with their density much higher than the conventional flocs. The results of the pilot study indicate a possible way to innovate the conventional secondary settling and gravitational thickening processes for solid/liquid separation and sludge handling, especially for small scale wastewater treatment plants to reach the goal of space saving and higher treatment efficiency.
Keywords Activated sludge; fluidized pellet bed; organic polymer; solid/liquid separation; thickening

Introduction

Fluidized pellet bed is a newly developed technique for high rate solid/liquid separation in water and wastewater treatment. It has been successfully applied in treating high turbidity water (Tambo *et al*., 1987; Tambo and Matsui, 1989; Tambo and Wang, 1993a), highly colored and turbid water (Tambo and Wang, 1993b), pre-treatment stage of an aerobic biological filter for sewage treatment (Suzuki *et al*., 1993) and chemical coagulation in a combined aerobic-anaerobic sewage treatment system (Shimizu *et al*., 1993). In all these applications, the fluidized pellet bed performs well in improving the morphology, settling and dewatering property of the flocs, and also assists effective SS, BOD and phosphorus removal as utilized for sewage treatment.

The characteristic feature of the fluidized pellet bed operation is to generate aggregates that are of extremely high density. The pellets generated usually have an effective density (buoyant density) one order or more higher than that of the ordinary flocs formed by the conventional coagulation/flocculation operation (Tambo *et al*., 1994). Optimal dosage of metal salts and organic polymer, and moderate agitation in the fluidized bed are the two pre-requisites to achieve particle pelletization. It has been theoretically and experimentally revealed that pellets can be generated by two pathways: *one-by-one attachment* of primary

Water Science and Technology **Vol 49 No 10 pp 81–88** © IWA Publishing 2004

particles onto the surface of a grown particle in a regular manner which brings about the formation of nearly spherical particles with almost identical density independent of particle size; and *mechanical syneresis or restructuring* of previously formed random flocs to drive out the interstitial water and therefore to increase the density of the finally pelletized particles (Tambo and Wang, 1993c). Because of their spherical appearance and relatively high mechanical strength, the pellets can resist high shearing or even pressing forces and sludge thickening and/or dewatering becomes easier. It is desirable that the fluidized pellet bed operation can be combined with a simple mechanical way to achieve solid/liquid separation and sludge thickening or dewatering at the same time, so that sludge handling, which often needs a train of several processes and takes long period of time and vast space, can be simply carried out.

Under the above considerations, the authors worked out a fluidized pellet bed separator equipped with screening sludge hoppers and utilized it in a sewage treatment plant at pilot scale for the treatment of activated sludge mixture liquid to achieve simultaneous solid/liquid separation and sludge thickening. Investigations were conducted on the performance of the pilot system, as well as the characteristics of the particles generated.

Materials and methods

Activated sludge mixture liquid

The pilot study was conducted at Beishiqiao Wastewater Purification Center, Xi'an, China, where domestic wastewater is received from an urban area and sewage treatment is carried out by oxidation ditch (OD) process. After biological decomposition in the OD, the activated sludge mixture liquid flows to the secondary sedimentation tank for solid/liquid separation. The separated sludge, usually with a moisture content of 99.6–99.8%, is led to a sludge thickening tank. The thickened sludge with a moisture content of 94–96% is finally dewatered by a belt filter. Before feeding to the belt filter, organic polymer is utilized for sludge conditioning at a dose of 0.003–0.004 as dry solid ratio. In the pilot study, the activated sludge mixture liquid was collected from the outlet of the OD. The total suspended solids (SS) ranged from 3,000 to 4,500 mg/L.

Fluidized pellet bed separator

Figure 1 is a sketch of the fluidized pellet bed separator equipped with screening sludge hoppers. In the figure, ***A*** is the fluidized pelleting zone with inlet at the bottom and equipped with agitation paddles driven by a motor through a vertical shaft; ***B*** are side windows where pellet particles overflow to the thickening chambers; ***C*** are screening sludge hoppers mounted in the thickening chambers. The hoppers can be lifted by trolleys (not shown in the figure) to a height above water surface to let water flow through the screens on the wall and bottom of the hoppers so that only the thickened sludge remains in the hopper; ***D*** is a circular weir to collect the effluent. The maximum capacity of the device is 2 m^3/hr (as mixture liquid).

Experimental method

The mixture liquid was led to a receiving tank of the pilot plant. It was then pumped to the bottom entrance of the fluidized pellet bed. On the suction pipe of the feeding pump a chemical dosing nozzle was attached and metal salt coagulant could be dosed through the nozzle so that the pump could function as a rapid mixer. At the bottom entrance of the fluidized bed organic polymer (CJX103, cationic, MW 5×10^6) was dosed to the mixture liquid. Sufficient mixing was provided through the jet flow at the bottom entrance. In this study, metal salt coagulant was not applied because the zeta potential of the microflocs in the mixture liquid was measured as about –15 mV which is within the range of a metastable

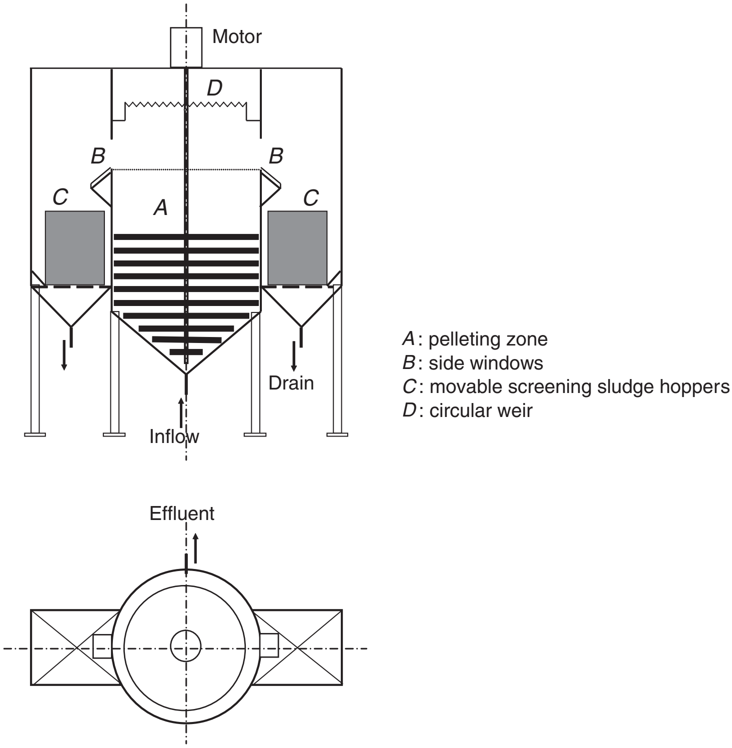


Figure 1 Fluidized pellet bed separator equipped with screening sludge hoppers

state suitable for pelleting operation (Tambo and Wang, 1993a) and charge neutralization by metal salt coagulant was no longer necessary.

In the initial stage of operation, it took about 4–5 hours for the microflocs to aggregate and become compact and granular gradually under mechanical and hydraulic agitation in the ***A*** zone. Finally a stable fluidized pellet bed formed and the grown granular particles became mother particles on to which the incoming microflocs attached to bring about particle growth. An overgrown particle would be broken under shear force and the breakages became mother particles again. As the fluidized pellet bed reached a steady state, there existed a relationship of dynamic equilibrium among several parameters such as particle size distribution, volumetric concentration etc. in the upward water flow. Therefore, there was a constant flux of granular particles over the top of the fluidized bed to the thickening chambers with a quantity equivalent to that of the solid particles in the inflow from the bottom. Solid/liquid separation was thus fulfilled by gravity due to the high settling velocity of the grown granular particles. Treated effluent flowed out through the circular weir on the top.

Because of their good sphericity, high density and relatively strong resistance to shearing force, the granular particles entering the screening sludge hopper could almost keep their spherical shape and the void space in between the particles could provide pathways for interstitial water to flow out. As the screening sludge hoppers were lifted out of the water surface, the interstitial water flowed out easily by gravity and thickened sludge remained in the hoppers. In this study, the screening sludge hoppers were lifted once per hour and then let water flow out of the screen for 5 minutes before sludge samples were collected for moisture content measurement.

The standard operation condition was set as: upflow rate (empty bed velocity) 5.4 m/hr, organic polymer dose 0.003 (as dry solid ratio), total hydraulic retention time 20 min. The influence of higher upflow rate (7.2 m/hr) and/or higher organic polymer dose (0.004) on the treatment result was also investigated.

Image analysis and particle density measurement

Under a given operation condition, particles overflowing to the screening sludge hoppers were collected with a shallow container and photos were taken using a digital camera connected to a personal computer (PC) for particle size measurement. The density of a single particle was calculated from its measured size and free settling velocity.

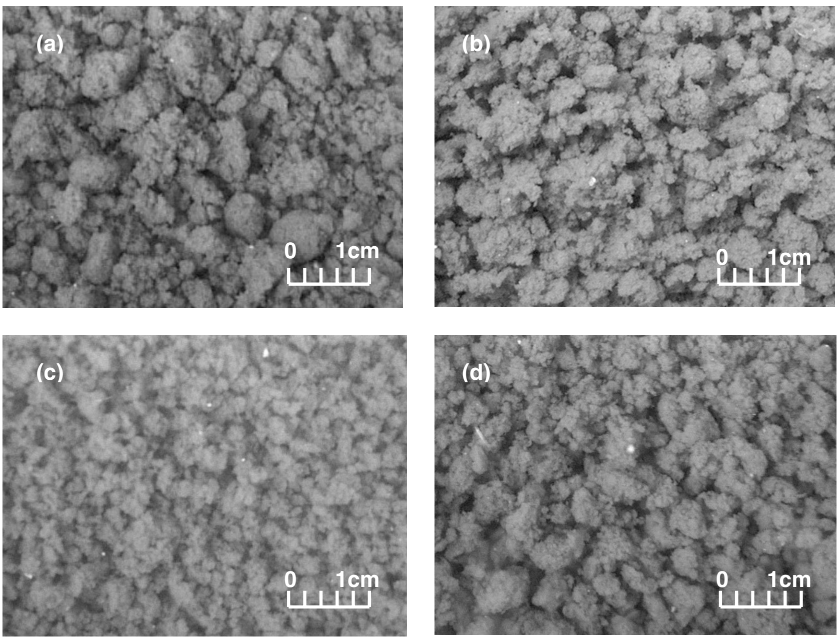
The morphological property of the particles can be characterized by their fractal dimension obtained by image analysis using a computer program. Firstly the projected area of each particle was measured, and then the diameter of the equal-circle-area was calculated. The maximum length of each particle appearing on the photo was also measured. According to the theory of fractal geometry (Chakraborti *et al.*, 2000), there exists a relation between the projected area A and the maximum length L as $A = \alpha L^{Df}$ where α is a proportional coefficient and Df is the two-dimensional fractal dimension (Df = 2 for non-fractal objects). By plotting A against L on a logarithmic paper, Df was thus evaluated from the slope of the linear relationship.

Results and discussion

Pelletization of particles

Figure 2 shows the appearance of the particles formed at different upflow rates and polymer doses. Samples were collected from the top of the screening sludge hopper.

As is shown in this figure, under the standard conditions (Run a), particles flowing into the sludge hopper were almost spherical with sizes mostly ranging from 1 mm to 6 mm. As polymer dose increased to 0.004 (upflow rate unchanged, Run b), the particle size tended to be more identical with no noticeable change in their sphericity. As the upflow rate



(a) upflow rate 5.4 m/hr, polymer dose 0.003; (b) upflow rate 5.4 m/hr, polymer dose 0.004;
(c) upflow rate 7.2 m/hr, polymer dose 0.003; (d) upflow rate 7.2 m/hr, polymer dose 0.004.

Figure 2 Photos of granular particles overflowing to the sludge hopper increased to 7.2 m/hr (polymer dose unchanged, Run c), particle size became smaller (mostly ranging from 1 mm to 3 mm), and as the upflow rate increased to 7.2 m/hr and polymer dose increased to 0.004 (Run d), particle size as well as sphericity tended to be about the same as those under the standard conditions.

Size–density relationship

The size–density relationship of particles formed under different operation conditions is shown in Figure 3 which is a logarithmic plot of particle diameter d against the effective density (buoyant density) ρ_e. There seems to be not much difference in the density of particles of similar size formed under different conditions (Runs a, b, c, d). However, there is apparently a tendency of decreasing in ρ_e while d increases, i.e. the relationship revealed by the floc density function $\rho_e = ad^{-k}$, where a and k are coefficients (Tambo and Watanabe, 1979). For comparison, the typical $\rho_e - d$ relationship for the conventional clay–aluminium flocs (line 1) and that for conventional organic flocs (line 2) were also shown in Figure 3. Apparently, the density of the particles formed by fluidized pellet bed operation is much higher than that of the conventional organic flocs and also higher than that of the conventional clay flocs of the same size range.

Morphological characteristics

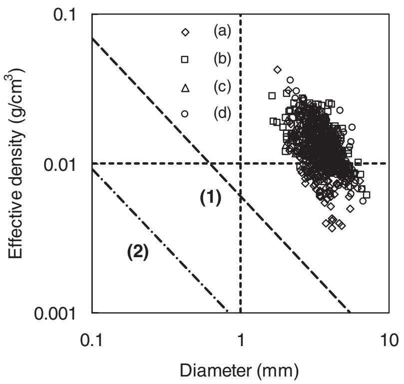
Figure 4 shows the relation of projected area A of the particles with their maximum length L on logarithmic coordinates under standard operation conditions (Run a). There exists a good relationship of $A = \alpha L^{Df,}$ and the two-dimensional fractal dimension Df is derived as 1.7421. Under other operation conditions (Runs b, c, d), Df is derived as 1.8519, 1.5658 and 1.7460 respectively. Those values are higher than the fractal dimension for conventional flocs (usually $Df < 1.5$) and indicate the morphological advantages of particles formed by fluidized pellet bed operation over conventional flocs.

Moisture contents

Table 1 shows the measured moisture contents of the sludge after screening for 5 min. The values are lower than the moisture content of the sludge after conventional thickening operation (94–96% in Beishiqiao Wastewater Purification Center). Higher dose of organic polymer such as 0.004 brings about lower moisture content of the sludge.

Effluent quality

Table 2 shows the effluent quality after solid/liquid separation by the fluidized pellet bed. These are the effluent SS concentrations when the fluidized pellet bed has reached a steady



(1) conventional clay–aluminium flocs; (2) conventional organic flocs.

Figure 3 Size–density relationship of granular particles

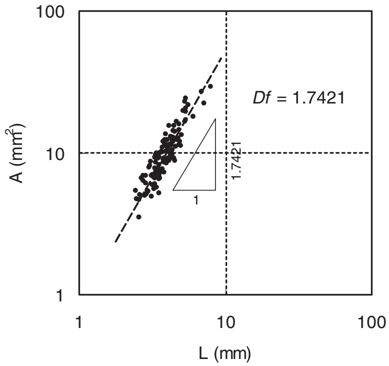


Figure 4 Relationship between the projected area *A* and maximum length *L*

Table 1 Moisture contents of the sludge obtained after 5 min screening

Run	Upflow rate (m/hr)	Polymer dose (kg/t as dry solids)	Moisture content (%)	
			Range	Average
a	5.4	0.003	94.91–92.57	94.00
b	5.4	0.004	94.48–91.80	93.54
c	7.2	0.003	94.67–93.69	94.36
d	7.2	0.004	93.54–92.40	92.99

condition (usually 4–5 hours after the start). Under the standard conditions (Run a), the average effluent SS was as low as 5.5 mg/L. An increase in polymer dose (Run b) brought about a little improvement in effluent SS (average 5.16 mg/L). However, as the upflow rate increased from 5.4 m/hr to 7.2 m/hr with no increase of polymer dose (Run c), it became difficult to maintain a low effluent SS. As polymer dose increased to 0.004 (Run d), the average effluent SS turned to be about 5 mg/L again.

Prospective of fluidized pellet bed in the renovation of conventional solid/liquid separation and sludge thickening processes

In the above mentioned operation, the fluidized pellet bed unit plays the function of two conventional processes – secondary sedimentation tank for solid/liquid separation and thickener for a reduction of the moisture content of the separated sludge. The result is much better than the conventional operation in view of the treated water quality and moisture content of the sludge. The total hydraulic retention time is only 20 min.

The main reason for the high treatment efficiency is the generation of pellet-like or granular particles which are of high density and large size, and therefore great settling velocity. Under the upward water flow, a steady fluidized bed is formed and solid/liquid separation is fulfilled within the fluidized bed while water flows through the high concentration granular particle layer. On the other hand, with spherical shape, the interstitial water between the granular particles can easily flow out. To utilize this property, a movable screen hopper is utilized in this pilot study to fulfill sludge thickening by just lifting the screening sludge

Table 2 Effluent SS by fluidized pellet bed operation

Run	Mixture liquid SS (mg/L)		Effluent SS (mg/L)		Time to reach the steady condition (hr)
	Range	Average	Range	Average	
a	2,800–3,900	3,260	3.77–7.43	5.50	4–5
b	2,800–4,500	3,580	3.27–6.84	5.16	4–5
c	3,600–4,500	4,010	13.7–15.7	14.3	5–6
d	3,500–4,400	3,820	3.77–6.73	5.11	4–5

hoppers out of the water. This is a process of "self thickening". The moisture content of the sludge so thickened is low enough to be sent to a press filter or other unit for final dewatering. The results indicate a possible way to innovate the conventional secondary settling and gravitational thickening processes for solid/liquid separation and sludge handling, especially for small-scale wastewater treatment plants to reach the goal of space saving and higher treatment efficiency.

Conclusion

A fluidized pellet bed separator with movable screening sludge hoppers was applied to sewage treatment for simultaneous solid/liquid separation and sludge thickening. From the pilot study results, the following conclusions can be drawn.

1. Under the condition of suspension SS around 4,000 mg/L, polymer dose at a dry solid ratio of 0.003 and upward flow velocity at 5.4 m/hr, the fluidized pellet bed performed solid/liquid separation and sludge thickening well. The SS concentration of the separated liquid was about 5 mg/L on average and the moisture content of the sludge after 5 min screening was less than 94%, which is much lower than that after conventional settling and thickening and easy to be finally disposed of. At higher upward flow velocity of 7.2 m/hr, similar results could also be obtained but higher polymer dose (solid ratio of 0.004) was required.
2. The particles formed by fluidized pellet operation are granular in appearance. The two dimensional fractal dimension of the particles ranges between 1.6–1.8, showing a good quasi-spherical morphology. The effective density of the granular particles is much higher than that of the conventional flocs.
3. With the good results of solid/liquid separation and sludge thickening achieved within a total hydraulic retention time of 20 min, application of the fluidized pellet bed technique can bring about an innovation of the conventional secondary settling and gravitational thickening processes to reach the goal of space saving and high treatment efficiency.

Acknowledgement

The current study is supported by the National Natural Science Foundation of China (NSFC Project No. 50138020).

References

Chakraborti, R.K., Atkinson, J.F. and Benschoten, J.E.V. (2000). Characterization of alum floc by image analysis. *Environ. Sci. Technol.*, **34**(18), 3969–3976.

Suzuki, T., Tambo, N. and Ozawa, G. (1993). A new sewage treatment system with fluidized pellet bed separator. *Wat. Sci. Tech.*, **27**(11), 185–192.

Shimizu, T., Tambo, N., Kudo, K., Hamaguchi, R. and Nakabayashi, A. (1993). A sewage treatment system composed of fluidized pellet bed separator, aerobic reactor and anaerobic digestion. *Water and Wastewater*, **35**(5), 23–30.

Tambo, N. and Watanabe, Y. (1979). Physical aspect of flocculation process I: The floc density function and aluminum floc. *Wat. Res.*, **13**(5), 409–419.

Tambo, N. and Matsui, Y. (1989). Performance of fluidized pellet bed separator for high-concentration suspension removal. *J. Water SRT-Aqua*, **38**(1), 16–22.

Tambo, N. and Wang, X.C. (1993a). Control of coagulation condition for treatment of high-turbidity water by fluidized pellet bed separation. *J. Water SRT-Aqua*, **42**(4), 212–222.

Tambo, N. and Wang, X.C. (1993b). Application of fluidized pellet bed technique in the treatment of highly colored and turbid water. *J. Water SRT-Aqua*, **42**(5), 301–309.

Tambo, N. and Wang, X.C. (1993c). The mechanism of pellet flocculation in a fluidized-bed operation. *J. Water SRT-Aqua*, **42**(2), 67–76.

Tambo, N., Yu, P.C. and Wang, X.C. (1987). Pellet coagulation treatment of high turbidity water. *China Water & Wastewater*, **3**(4), 4–8.

Tambo, N., Wang, X.C. and Ozawa, G. (1994). Fluidized-pellet-bed operation: a new technique for high-rate solid/liquid separation of high-concentration suspensions. *Proceedings of ICEWW'94*, Beijing, China, 1, 268–277.