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FLUIDIZATION AND SEDIMENTATION OF CARRIER MATERIAL IN A PILOT-SCALE AIRLIFT INTERNAL-LOOP REACTOR

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ABSTRACT

Balsalt (ρ=2760 kg.m^{-3}, d= 0.245 mm) was used as the solid carrier in a pilot-scale airlift internal-loop reactor for wastewater treatment (AILRW), which was filled with tap water in this study, to investigate the regimes of fluidization and sedimentation. Solid sediment was observed even when the liquid velocity in the riser was much higher than the terminal settling velocity of the particles. Circulation cannot be maintained if the superficial liquid velocity in the downcomer u_d is below a definite value (blocking velocity u_b). In a dimensionless model, u_b is related to the bulk volume of carrier solids added (V_t), the available space at the bottom (V_a) and the gap size at the bottom (a_0) according to

$$u_b^2/(a_0.g) = 0.04(V_t/V_a) - 0.036 .$$

KEYWORDS

Airlift-loop reactor, fluidization, sedimentation, blocking, carrier material, solid mass distribution

INTRODUCTION

An airlift-loop reactor has an efficient performance which is attributed to the high concentration of biomass immobilized on solid carrier materials. The carrier material has a great influence on the biofilm growth, the oxygen transfer and the hydrodynamical characteristics of the fluid in the reactor. Various types of solids with various sizes have been used as the carrier material in the three-phase fluidized bed reactors. For instance, Fan *et al.*(1987) used spherical activated carbon particles with an average diameter of 307 and 714 μm, respectively, for phenol degradation by immobilized cells. Verlaan *et al.*(1987) used a solid phase consisting of calcium alginate or polystyrene spheres with a particle density of 1050 kg.m^{-3} and diameter of 2.35 - 2.7 mm in an external-loop airlift reactor. Nikolov *et al.*(1987) used polyethylene granules with diameter 2 - 3 mm and polystyrene spheres with diameter 0.8 - 1 mm and density 330 kg.m^{-3}.

A pilot-scale airlift internal-loop reactor for wastewater treatment (AILRW) was set up in the Lab of Sanitary Eng. at Delft Univ. of Tech.

Three kinds of particles were tested in AILRW by Qian and Nieuwstad (1989) for treatment of the municipal wastewater. The experiments indicated that sand grains with a density of 2600 $kg.m^{-3}$ and diameter 0.5 - 0.8 mm or 0.25 - 0.5 mm were not suitable as a carrier material. However, basalt with density of 2760 $kg.m^{-3}$ and a diameter of 0.2 - 0.3 mm showed to be a good quality carrier.

The concentration of solid material has great effects on the wastewater treatment process as well. As the gas supplement was restricted at a low level to minimize the energy consumption, the solid concentration was also at a low level in this study. The experimental volumetric fraction of the solid mass in circulation was less than 4%, while loadings of 10% to 40% and 40% were described in Fan(1987) and Verlaan's(1987) papers respectively.

APPARATUS, MATERIALS AND METHODS

The tested AILRW with a total volume of 186 litres is schematically shown in Figure 1. The details of the reactor, the adjustment of the connecting gap sizes at the bottom and the installation of the measuring equipment have been described elsewhere (Cai and Nieuwstad. in press). The gas sparger is located in the riser but not at the base, which is based on the consideration to simplify the design and improve the liquid flow patten (Chisti 1989, Qian and Nieuwstad 1989, Cai and Nieuwstad in press).

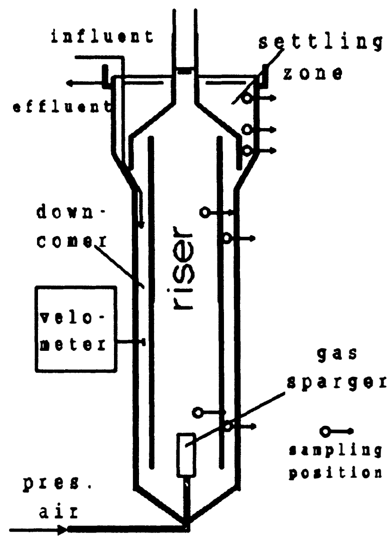

Figure 1 The airlift internal-loop reactor for wastewater treatment.

Basalt with a density ρ=2760 $kg.m^{-3}$ and an average diameter d_p=0.245 mm was used as the carrier material in AILRW filled with tap water. The total load of solid mass W_t in the experiments was equal to 5, 8, 10, 15, 20, 25 kg respectively. In each assigned load of solids, the connecting gap size at the bottom was varied from 25 mm to 90 mm. The gas supplement started from 2500 l/h and decreased step by step until the circulation couldn't be maintained anymore. Meanwhile the liquid velocity in the downcomer was measured. In addition, samples at several points of the reactor were collected for estimating of the solid fraction.

RESULTS AND DISCUSSION

Blocking Phenomenon in an AILRW

The liquid flow and the solid sedimentation at the bottom of the reactor are shown in Figure 2. Three main eddy areas marked as A,B and C

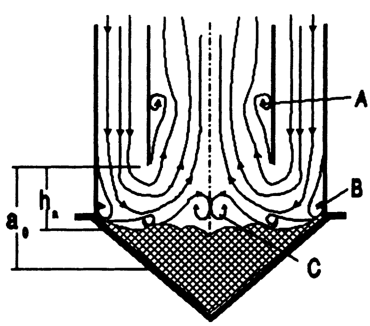

Figure 2 Sedimentation at the bottom of the rector.

in Figure 2 were observed. The solid particles entering the eddies are easy to sedimentate. Most of the particles in eddy A would return to the circulation, while some of the particles in eddy B and eddy C settled to the base of the reactor. Therefore, even when the liquid velocity in the riser is higher than the terminal settling velocity of the particles, there will exist some solid sediment on the base. On the other hand, eddy B and eddy C roll up some solid sediment and return it into the circulation zone. The actual gap size h_a through which the liquid flows changes with the amount of solids sedimentated at the base of the reactor. In a steady state, the sedimentation would be equal to the entrainment. When the gap size a_0 is small and the solids loading W_t is high, the gap might be blocked by the settled carrier material, if the gas supplement is not strong enough to maintain a circulation. At this moment, the riser is like a bubble column and the downcomer is a dead zone.

Blocking Velocity and Fluidization Condition

To maintain a steady-state operation at a fluidized bed reactor, the superficial velocity of the fluid is limited between the terminal settling velocity u_t and the minimum fluidizing velocity u_{mf} of the particles. The ratio u_t/u_{mf} is usually between 9:1 for Re_t>1000 and 90:1 for Re_t<0.4 (Kunii 1969, where Re_t is Reynolds number of the particle with terminal velocity). However, conditions governing the steady-state operation of an AILRW are quite different. By gradually decreasing the gas superficial velocity, the liquid superficial velocity in the downcomer u_d will also decrease until a critical value u_b, the blocking velocity, is reached. Below u_b, the circulation cannot be maintained in the steady-state anymore, since the sedimentation is higher than the entrainment of the particles. Thus $u_d>u_b$ is defined as the fluidization condition of the AILRW.

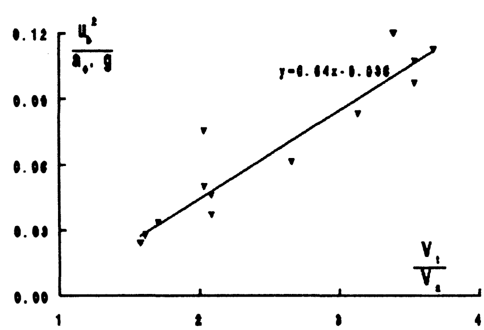

Figure 3 A dimensionless model of the blocking velocity.

The blocking velocity is a function of the available space volume under the inner column V_a, the bulk volume of the total solids (just settled but not be compressed) V_t, the gap size a_0, the sedimentation characteristics and the drag force for the particles. For the assigned carrier material, the dimensionless group $u_b^2/(a_0.g)$ (where g is the gravitational acceleration) was plotted as a function of the ratio of V_t/V_a, as shown in Figure 3. The experimental data regressed to the line of

$$\frac{u_b^2}{a_0 \cdot g} = 0.04\left(\frac{V_t}{V_a}\right) - 0.036$$

with a standard error of 0.009 and 0.94 being the square root of coefficient of fitting determination.

Distribution of Carrier Material

According to the conservation of mass, if no carrier material is washed out with the effluent, the total mass of solids in the reactor, W_t is constant. Three fractions contribute to the total weight:

$$W_t = W_c + W_0 + W_s$$

where W_c is the solid mass in the circulation zone, W_0 is the solid mass in the settling zone at the top, W_s is the solid sediment at the bottom. In Figure 4, the distribution of W_t over the three fractions is presented for two different gap sizes. When the fluid velocity in the downcomer is lower than the blocking velocity u_b, the circulation stops very quickly and all solids settle to the base of the reactor. That is $W_s=W_t$. When the liquid velocity is higher than the blocking velocity, the fluid carrying solid material can maintain a steady-state circulation. In this situation, increasing the liquid velocity only slightly enhances the value of W_c. However, a change of the gap size at the bottom would have a great effect on the distribution of the solid mass. The dotted line in Figure 4 indicates that W_s increases when the gap size a_0 increases from 50 mm to 65 mm, while the blocking velocity decreases from u_{b1} to u_{b2}.

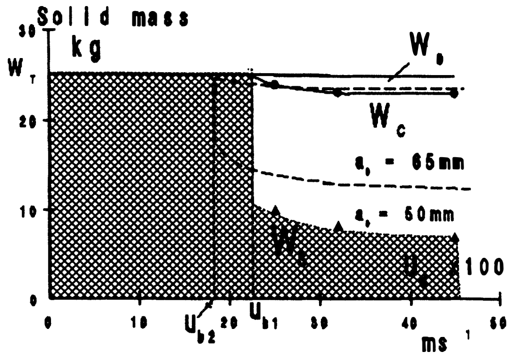

Figure 4 Distribution of the solid mass.

CONCLUSION

In the AILRW, solid sediment is observed at the bottom of the reactor even when the liquid velocity in the riser is much higher than the terminal velocity of the carrier. The blocking phenomenon is one of the most important characteristics of an AILWR. The solid mass would be accumulated at the bottom, block the passage and stop the circulation, if $u_d<u_b$. The dimensionless model for u_b related to the bulk volume of loading V_t and the gap size at the bottom a_0 is $u_b^2/(a_0.g) = 0.04\ (V_t/V_a) - 0.036$. The total loading mass W_t consists of three parts, W_c, W_0 and W_s. In the steady state, increasing the liquid velocity only slightly enhances the value of W_c, while the gap size at the bottom has a great effect on the distribution.

REFERENCES

Cai,J. and Nieuwstad, Th. J.(in press). Hydrodynamic modelling and blank running of a pilot-scale internal loop airlift reactor for wastewater treatment. Environ Tech.

Chisti,M.Y. (1989). Airlift Bioreactor, Elsevier Science Publishers Ltd, London pp133-135.

Fan,L.S., Koichi Fujie, Long, R. and Tang, W.T.(1987). Characteristics of draft tube gas-liquid-solid fluidized-bed bioreactor with immobilized living cells for phenol degradation. Biotechnology and bioengineering 30, 498-504.

Kunii, D. and Levenspiel,O. (1969). Fluidization engineering John Wiley & sons Inc. New York pp72-77.

Nikolov, L. and Karamanev, D.(1987). Experimental study of the inverse fluidized bed biofilm reactor. Canadian J. Chem. Eng., 65, 214-217.

Qian, Y. and Nieuwstad, Th. J.(1989). Treatment of municipal wastewater in a pilot-scale airlift-loop reactor. ISSN-0169-6246 TU Delft,The Netherlands.

Verlaan,P. and Tramper,J.(1987). Hydrodynamics, axial dispersion and gas-liquid oxygen transfer in an airlift-loop bioreactor with three-phase flow Proc. Int.Conf. on Bioreactors and Biotransformations, Auchterarder, U.K.Elsevier Science Publishers B.V. Amsterdam 9-12.