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Yusumi Nagahashi* John R. Grace† Norman Epstein‡
Yutaka Asako** Akira Yokogawa††

*Kochi National College of Technology, Japan, naga@me.kochi-ct.ac.jp
†University of British Columbia, jgrace@chml.ubc.ca
‡University of British Columbia
**Tokyo Metropolitan University, Japan, asako@ecomp.metro-u.ac.jp
††Kochi University of Technology, Japan, yokogawa.akira@kochi-tech.ac.jp

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FLOW CHARACTERISTICS OF FULLY WETTED BINARY SOLID MIXTURES IN GAS FLUIDIZED BEDS WITH INCLINED GAS DISTRIBUTORS

Nagahashi Y. Dept. Mech. Eng., Kochi National Coll. Technol.
200-1, Monobe, Nankoku-shi, Kochi, Japan, 783-8508
T: 81-88-864-5532, F:81-88-864-5521; E: naga@me.kochi-ct.ac.jp
Grace J.R. and N. Epstein, Dept. Chem. & Biological Eng., UBC, Canada
T: 1-604-822-3121, F: 1-604-822-6003; E: jgrace@chml.ubc.ca
Asako Y., Tokyo Metpl.Univ., Japan, E: asako@ecomp.metro-u.ac.jp
Yokogawa A., Kochi Univ. Technol., Japan, yokogawa.akira@kochi-tech.ac.jp

ABSTRACT
A unique system in which gas-fluidization is enhanced by adding a little water has potential for soft abrasive washing of various products. Preliminary experiments were carried out for washing farm products. Gas fluidized beds of binary solids mixtures with inclined gas distributors provide hydrodynamic and mixing data, assisting the design of dry and wet gas-fluidized beds.

INTRODUCTION
When small quantities of water are added to gas-fluidized beds of large non-wettable particles, such as 6-mm polystyrene spheres, the water can cause a dramatic increase in the extent of fluidization. We have previously reported[(1),(2)] the characteristics of this unique fluidized bed. It has advantages for soft-abrasion, due to movement of light rounded particles, and also for reducing water usage for washing, due to the small quantities of water needed. These characteristics are desirable for industrial washing of farm products or fragile industrial devices requiring soft abrasive washing.

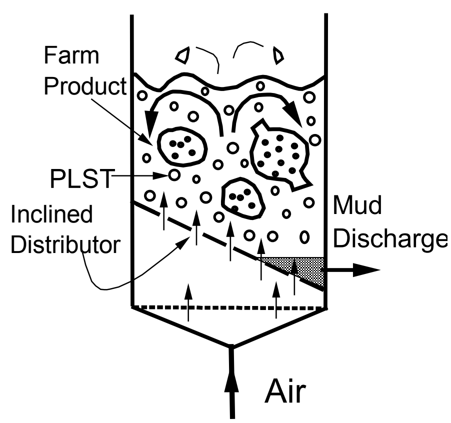


Fig.1 Fluidized bed with inclined gas-distributor

For such applications, inclined gas-distributors, as shown in Figure 1, are effective for separating and removing solid wastes from the bed materials as a mud. This paper reports preliminary experimental results on the washing of agricultural products.

Possible gas-distributors, including inclined distributors, are discussed for dry single-particle fluidized beds to optimize the system for discharge of the washing waste. The flow characteristics of gas-fluidized beds of binary solid mixtures with inclined gas-distributors are discussed for dry and wet fluidized beds. The two species in the binary solids mixture simulate the large washing solids medium and the small particles to be removed as waste solids (mud).

APPARATUS AND METHODS

1) Bed Column and Distributors: The experimental apparatus is shown in Fig. 2. The two columns were transparent half-cylinders of 180 mm inside diameter x 1000 mm height, and 280 mm dia. x 1500 mm tall. The gas distributors were a horizontal plate, inclined flat plates with inclination angles to the horizontal of 10, 20, and 30°, convex and concave plates with 20° angle to the horizontal, and a cone drilled with 2.4 mm dia. holes (overall open area 1.3 %) and covered by a wire mesh #400 cloth plate, as shown in Figure 3. The plenum chamber wall was provided with three pressure taps.

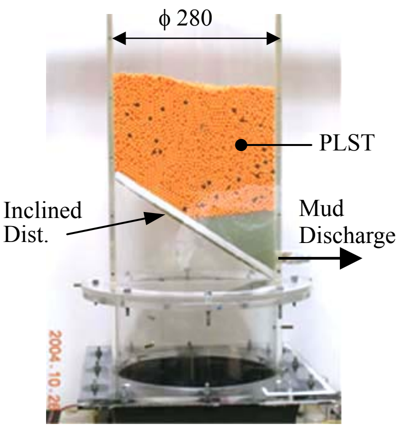


Fig.2 Bed column with inclined distributor.

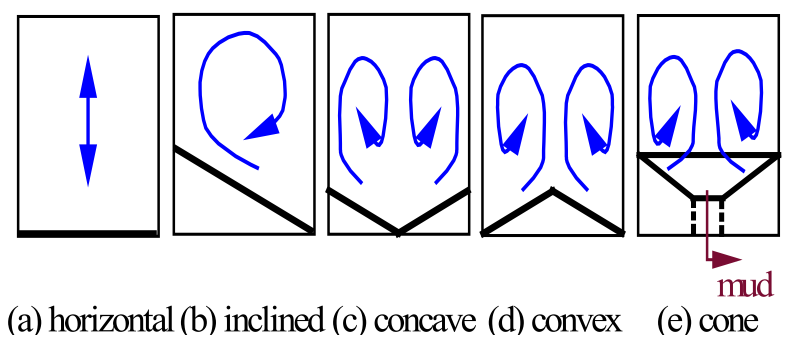


Fig.3 Schematic of distributor configurations and qualitative solids circulation patterns.

2) Particles: We used 2 types of polystyrene particles (6-mm spheres and 3.2-mm rounded cylinders of mean diameter 3.2 and length 3.2 mm) and 2 sizes of spherical glass beads (mean diameters 1.0 and 0.6 mm).

Table 1 Particle Properties

Particles	Polystyrene		Glass Beads	
	6-PLST	3.2-PLST	1-GB	0.6-GB
d_P [mm]	6.0	3.2x3.2	1.0	0.6
U_{mf} [m/s]	1.45	0.70	0.43	0.26
ρ_s [kg/m^3]	1010		2450	
Shape	Sphere	Rounded-edge cylinder	Sphere	

Key properties appear in Table 1.

3) Water Content α and Ratio of Particle mixture β

The water content, α, and ratio of particle mixture β are defined as :

$\alpha = V_{WTR}/V_{TOT}$ ——— (1) , $\beta = V_i/V_{BLK}$ ——— (2)

where V_{WTR} = volume of added water, V_{BLK} = total dry static bulk volume of solids mixture, V_i = static bulk volume of smaller particles, and V_{TOT} = static bulk volume of solids mixture, including added water.

4) Experimental Methods

Most experiments were carried out for L_o/D=static bed height / column diameter =1.0, but values of L_o/D of 0.5 to 2.5 were also used to observe the influence of distributor configuration. The static bed height, L_o, for each distributor is based on the same volume of particles as for a horizontal distributor.

Small particles (either glass beads or polystyrene cylinders), simulating waste mud, were added to the column with 6 mm polystyrene particles. Fluidizing air was then introduced through the distributor. The gas flow rate was raised to ~1.5U_{mf}, then gradually decreased to 0.2 - 0.3 U_{mf}. Data were taken at each downward step in U. Next the gas flow rate was quickly raised to ~3U_{mf}, then slowly reduced to U_{mf} to obtain the rest of the data. The operating conditions for the wet bed were the same as for the dry one. All measurements and observations were carried out after completion of mixing of the two species of solids, and after tap water was added by pouring from the top of the bed. This required at least a minute for each case.

PRE-TEST FOR FARM PRODUCT WASHING

To confirm the ability of this system to wash farm products, a preliminary washing experiment was carried out. A single soiled ginger or potato was suspended in the centre of the bed (Figure 4) in the 180 mm inner diameter half-column with a distributor inclined at 30° to the horizontal. The ginger and potato had densities of 1020 kg/m^3 and 990 kg/m^3, respectively, and typical sizes of ~35 mm (maximum diameter) × 120 mm in length and about 30 mm (maximum thickness) × 60 mm width × 150 mm length, respectively, although the ginger was very irregular.

After 6 minutes of washing at U/U_{mf}=2.0, promising results were obtained. With small quantities of water (20 vol% of bulk bed volume), soft-abrasive washing was achieved.

The surface of the sweet potato was not damaged by the fluidization washing, whereas it was damaged seriously by conventional hand washing with a soft-hemp brush. However, a small amount of mud remained in narrow crevices. Small high-density particles, either mud from the soiled products or newly-added

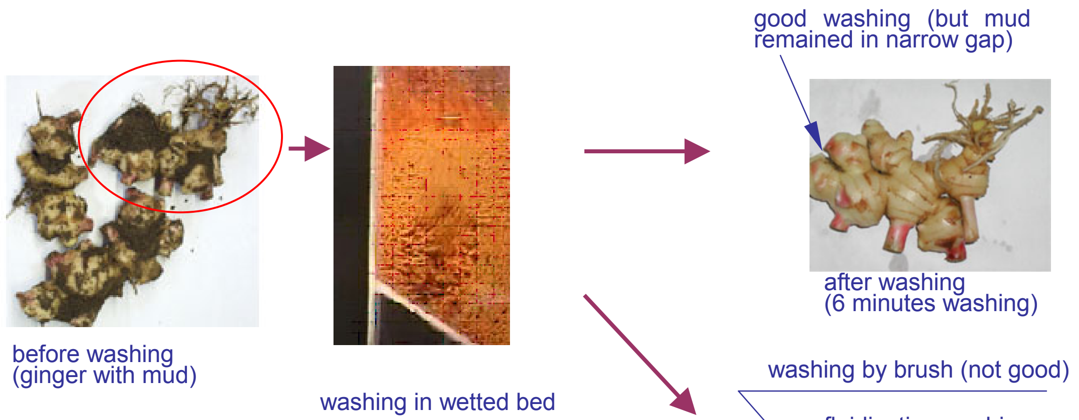
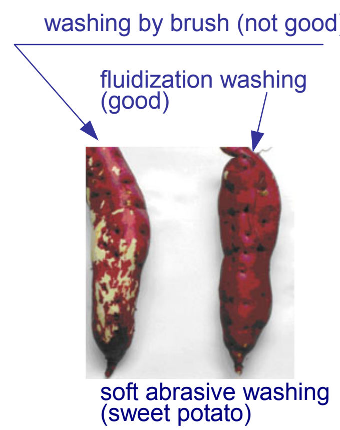


Fig.4 Pre-test for farm products washing



glass beads, might be desirable to remedy this problem and improve the washing performance. The advantage of the fluidization enhancement with added water relies on the bed material being non-wettable and of low density, provided such small particles do not over-crowd the bed.

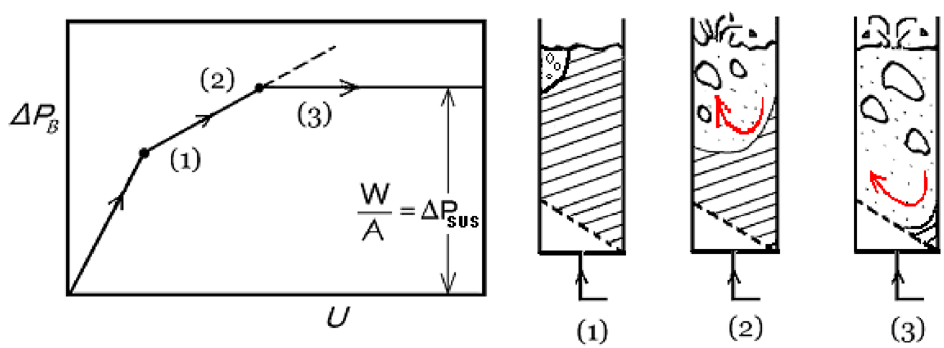
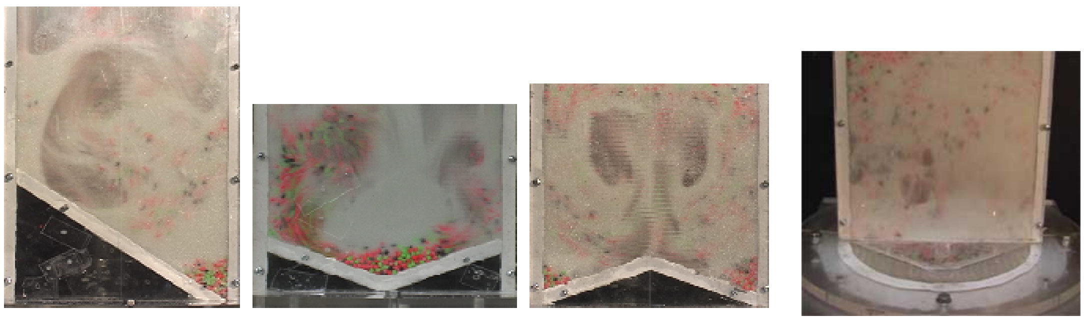


Fig.5 Illustration of bed transition with inclined gas-distributor (dry bed)

INFLUENCE OF DISTRIBUTOR-GEOMETRY ON DRY-BED-FLUIDIZATION

The influence of the distributor geometry was investigated to optimize the discharge of solid wastes in a single-particle-species dry fluidized bed. Little previous work has been reported on inclined gas-distributors, but some information is available from previous work[4]. Unlike conventional fluidization, partial fluidization occurs around the shallowest upper region (left corner in Fig. 2 or 5) due to less resistance. Therefore the ΔP-U line is more inclined than for a fixed bed, as shown in Fig. 5, where (1) denotes the initial fluidization point. Fluidization develops over the whole cross-section at point (2); after point (2) the whole bed reaches the fully fluidized condition with a constant pressure loss at (3), as for conventional fluidized beds. The solid circulation for each distributor configuration was checked via frame-by- frame analysis of video images (Fig. 6), confirming the circulation patterns shown in Fig. 3. For the inclined distributor, solids move upward along the slope of the distributor plate. The solid circulation can be controlled by the distributor geometry.



(inclined) (concave) (convex) (conical)

Fig.6. Typical solid circulation for each distributor configuration from video photos.

In the case of the cone distributor, the circulation was unstable and complex. For every other case, a defluidized zone was observed at the lowest corner or vertex from where washing waste could be successfully removed. Video photography was performed to confirm the solids circulation and the effectiveness of solids waste discharge with coloured polystyrene particles as tracers. Control of solids circulation was critical. The pattern was as shown schematically for solids circulation in Figure 3 for every gas-distributor geometry except the cone-distributor, for which the flow pattern could not be seen clearly.

Figures 7-a, 7-b show the influence of the gas distributor geometry for 0.6 mm glass beads (figure 7-a) and 6 mm PLST (figure 7-b) with L_0/D=1.0. For the glass beads, seven distributor configurations were tested under dry conditions. In every case, minimum

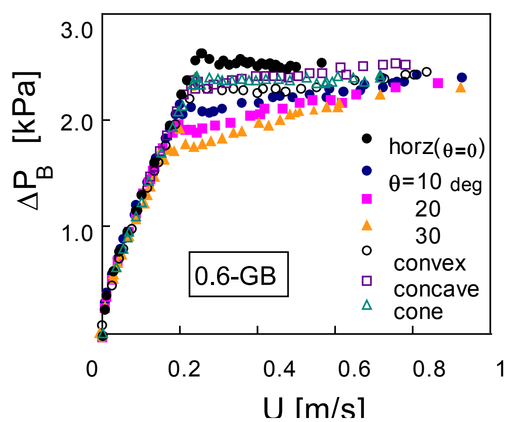


Fig.7-a Influence of distributor inclination angle for 0.6 mm - GB bed

fluidization occurred at a lower gas flow rate than for a horizontal distributor, with $(U_{mf})_{30°} < (U_{mf})_{20°} < (U_{mf})_{10°} < (U_{mf})_{conv}$, $(U_{mf})_{conc}$, $(U_{mf})_{cone} < (U_{mf})_{horizontal}$. A similar trend was obtained or the 6-PLSTbed with inclined gas distributors, although the magnitude of the differences was smaller than for the glass beads.

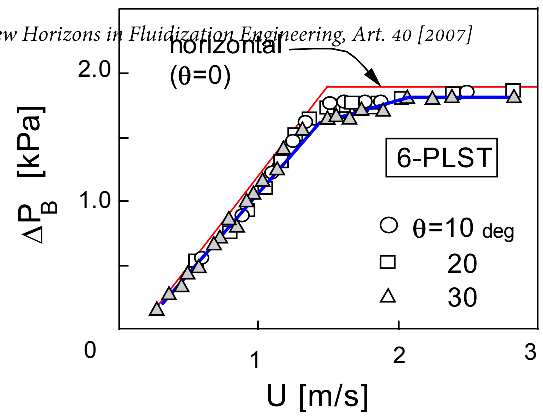


Fig.7-b Influence of distributor inclination angle for 6 mm - PLST bed

DRY/WET BINARY MIXTURE FLUIDIZATION WITH INCLINED DISTRIBUTOR

1) General Characteristics

Figure 8 shows a typical ΔP_B-U diagram for this unique gas-fluidized bed. In general there was hysteresis between the increasing and decreasing gas velocity curves due to the difference from the initial packing of the particles. The velocity-descending line was more reproducible and is thus used here. Straight horizontal lines, indicative of pressure drop = (particle weight, W) / (cross- sectional area, A), imply an ideal suspension; the numbers at the right correspond to those values. The α=0 line is for the corresponding dry bed with U_{mf}=1.45 m/s. U_{mf} decreased with increasing water content, indicating fluidization enhancement.

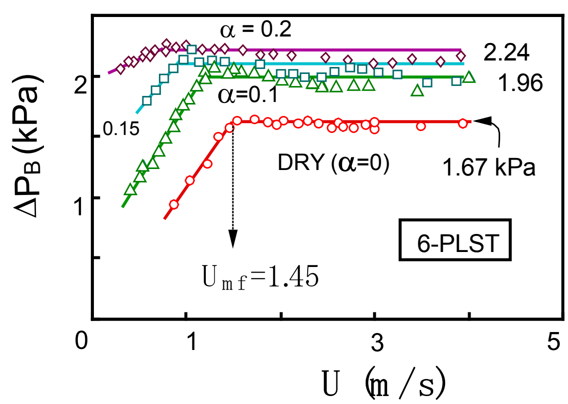


Fig.8 ΔP_B-U diagram (velocity-descending lines) for fully-wetted gas-fluidized bed of 6 mm-PLST particle bed with horizontal distributor

2) Binary-Mixture Fluidization with Horizontal Distributor

When particles of lower U_{mf} are added to particles of higher U_{mf}, the resulting U_{mf} gradually approaches that for the smaller U_{mf}- particles(3), i.e. U_{mf} decreases. This trend is shown in Figure 9, both for dry and wetted beds. In this case, small PLST was added to large PLST. Water addition enhanced fluidization (i.e. U_{mf} decreased). On the other hand, for large-PLST and small glass beads, water addition contributed negatively to mobilization (U_{mf} increased; Fig 10).

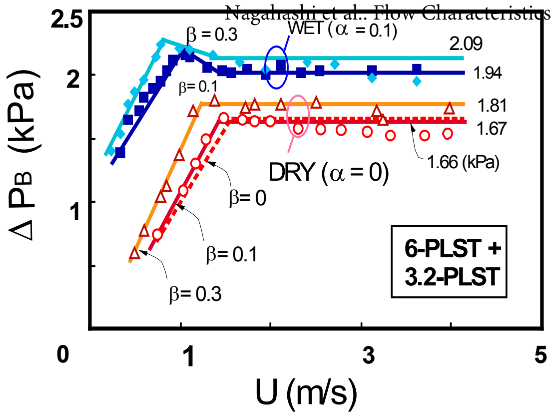


Fig.9 ΔP_B-U diagram ((velocity-descending lines) for binary solids dry and wet fluidized beds, (horizontal-distributor/6-PLST+3.2-PLST)

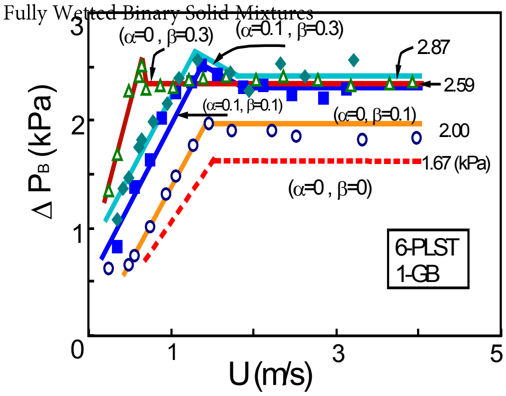


Fig.10 ΔP_B-U diagram (velocity-descending lines) for binary solids dry and wet fluidized beds, (horizontal-distributor/ 6-PLST+1-GB).

3) Binary Mixtures with Inclined Distributor

Figure 11 shows the influence of water addition for a single-species system (6-PLST). In this case (single-species, inclined distributor), water addition did not cause an appreciable change in U_{mf}, but the pressure drop lines differ for dry and wet beds. For a dry bed, the pressure drop line was similar to that in Figure 5; the line finally reached the ideal suspension value (W/A) and remained constant at high flow rates. However, for wet beds, the line increased linearly with U beyond U_{mf}, possibly due to friction resistance of aggregates held together on the column wall by water. The vigorous motion of aggregates can be seen in Figure 12. They were more apparent in the binary solids bed.

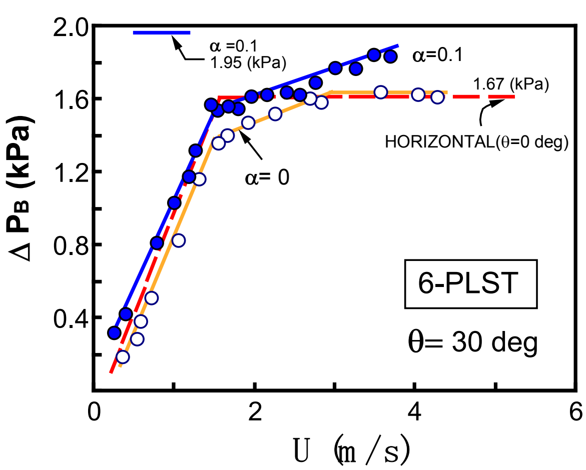


Fig.11 ΔP_B-U diagram of 6 mm-PLST particle bed with inclined (30 deg) distributor for dry and wet conditions

Fig.12 Solid circulation in wetted binary solids fluidized bed with inclined distributor.

Figure 13 shows results for fluidization of a binary mixture with an inclined distributor. ΔP_B was lowered around U_{mf} and then increased linearly with U. The extent of the increase was larger than for a single-species wet bed, probably due to wetted small high-density particles.

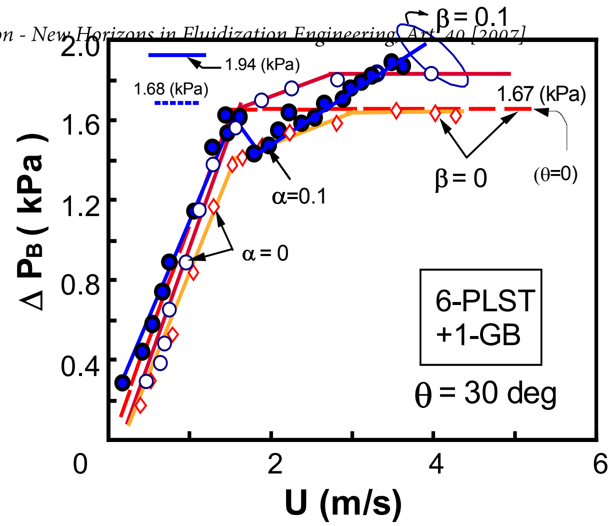


Fig.13 ΔP_B-U diagram for binary solids fluidized bed for dry and wet conditions, (30° -inclined distributor, with 6-PLST+1-GB)

CONCLUSIONS

From pressure drop measurements and video analysis, no severe segregation was experienced, except at low velocities. Fluidization enhancement by addition of water was not significantly weakened by adding small high-density particles, at least for liquid volume fractions less than or equal to 10%. Inclining the distributor plate was helpful for completely wetted beds in which $U/U_{mf}<1.2$, with even an angle of 10° to the horizontal being sufficient to discharge small high-density particles.

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