Korean J. Chem. Eng., **28**(10), 2009-2011 (2011)
DOI: 10.1007/s11814-011-0091-8

Type transition in onset condition of turbulent fluidization

Jeong-Hoo Choi*,†, Ho-Jung Ryu, and Chang-Keun Yi****

*Department of Chemical Engineering, Konkuk University, Seoul 143-701, Korea
**Korea Institute of Energy Research, Daejon 305-343, Korea
(*Received 1 February 2011 • accepted 5 April 2011*)

Abstract−The type transition in onset condition of turbulent fluidization in gas fluidized beds was investigated to obtain the relation representing more precise roles of physical properties of gas and solid particles. The type transition in onset condition of turbulent fluidization occurs at Archimedes number of 20.87 by type transition of bubble breakup. The maximum stable bubble diameter (d_{bmax}) is greater than the equilibrium bubble diameter (d_{beq}) in the region, Ar<20.87, but $d_{beq}>d_{bmax}$ in the region, Ar>20.87. Therefore, the onset of turbulent fluidization is determined in the region, Ar<20.87, by d_{beq} and in the region, Ar>20.87, by d_{bmax} as the limit of bubble growth. The u_c decreases in the region, Ar<20.87, but increases in the region, Ar>20.87 as temperature increases.

Key words: Type Transition, Turbulent Fluidized Bed, Onset Velocity, Transition Velocity

INTRODUCTION

Bubble splitting or breakup is one of the important phenomena in gas fluidization that should be understood for making advances in fluidization of very fine particles.

The next to the bubbling or slugging regime is called turbulent regime in gas fluidization as gas velocity increases. The turbulent regime is often realized to represent a dramatic breakdown of bubbling or slugging, and the predominance of bubble breakup over bubble coalescence. The bubble size in bubbling or slugging bed is limited by the maximum stable bubble diameter (d_{bmax}) according to the study of Harrison et al. [1]. The bubble size in the bed of Geldart's group A particles is controlled additionally by equilibrium bubble diameter (d_{beq}) because bubble splitting occurs [2-4]. Chehbouni et al. [5] and Peeler et al. [6] have reported that two opposite trends exist in the effect of temperature on onset gas velocity of turbulent regime (u_c). Choi et al. [7] explain those opposite temperature effects on u_c with their model successfully. According to their model, one is that u_c decreases with an increase of temperature when d_{beq} is smaller than d_{bmax}. Another case is that d_{beq} is greater than d_{bmax}. Then u_c increases with temperature. They have shown that the onset of turbulent fluidization is caused by two different types of bubble breakup and discussed the transition condition between them by comparing d_{bmax} and d_{beq}.

However, precise roles of physical properties of gas and particle phase on the type transition of bubble breakup are unknown yet. Here we show that the type transition of bubble breakup in onset condition of turbulent regime can be represented by Archimedes number (Ar) that consists of physical properties of gas and solid particles.

THEORY

Choi et al. [7] represented the ratio of d_{beq} to d_{bmax} at the onset gas velocity of turbulent regime ($u=u_c$) as

$$\frac{d_{beq}}{d_{bmax}}=7953\frac{Re_{mf}^2}{Ar}\left\{\frac{\left(\frac{u_c}{u_{mf}}\right)-\left(\frac{u_c}{u_{mf}}\right)^{0.62}}{\left(\frac{u_c}{u_{mf}}\right)^{0.454}}\right\} \quad (1)$$

Re_{mf} is represented by the correlation of Wen and Yu [8]:

$$Re_{mf}=[(33.7)^2+0.0408\,Ar]^{0.5}-33.7 \quad (2)$$

At the condition $d_{beq}=d_{bmax}$, the onset velocity of turbulent regime [7] can be determined by

$$u_c=u_{mf}+0.5985\left(\frac{d_p(\rho_p-\rho_g)g}{\rho_g}\right)^{0.5} \quad \text{for the case } d_{beq}>d_{bmax} \quad (3)$$

or

$$\frac{u_c}{u_{mf}}=217.5 \quad \text{for the case } d_{beq}<d_{bmax} \quad (4)$$

Combining Eqs. (1) to (3), or Eqs. (1), (2) and (4) at the condition $d_{beq}=d_{bmax}$, gives Ar of 20.87 as the type transition condition in the onset condition of turbulent fluidization.

RESULTS AND DISCUSSION

Fig. 1 from the report of Choi et al. [7] confirms the present type transition condition in the onset condition of turbulent fluidization. The maximum stable bubble diameter (d_{bmax}) is greater than the equilibrium bubble diameter (d_{beq}) in the region, Ar<20.87, but $d_{beq}>d_{bmax}$ in the region, Ar>20.87. Therefore, the onset of turbulent fluidization is determined in the region, Ar<20.87, by the equilibrium bubble diameter (d_{beq}), and in the region, Ar>20.87, by the maximum stable bubble diameter (d_{bmax}) as the limit of bubble growth.

Fig. 2 with the data of Chehbouni et al. [5] and Peeler et al. [6] shows the same result. Eq. (3) for the case $d_{beq}>d_{bmax}$ agrees to the experimental data in the region, Ar>20.87 well, however, Eq. (4) for the case $d_{beq}<d_{bmax}$ agrees with the experimental data in the region,

†To whom correspondence should be addressed.
E-mail: choijhoo@konkuk.ac.kr

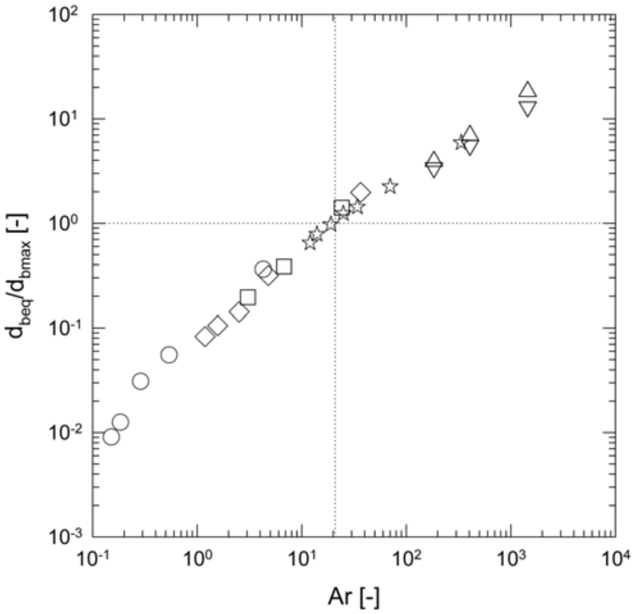

Fig. 1. d_{beq}/d_{bmax} versus Ar at u_c. Chehbouni et al. [5]: (□) FCC-air, 78 μm, 1,450 kg/m^3, d_t=0.2 m; (△) sand-air, 250 μm, 2,650 kg/m^3, d_t=0.2 m; (▽) sand-air, 250 μm, 2,650 kg/m^3, d_t=0.082 m. Peeler et al. [6]: (☆) sand-N_2, 130 μm, 4,400 kg/m^3; (◇) alumina-N_2, 70 μm, 2,800 kg/m^3; (○) alumina-He, 70 μm, 2,800 kg/m^3.

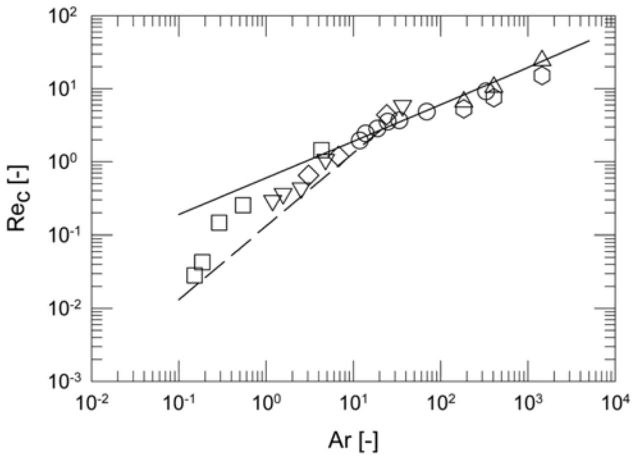

Fig. 2. Re_c versus Ar. Chehbouni et al. [5]: (◇) FCC-air, 78 μm, 1,450 kg/m^3, d_t=0.2 m; (△) sand-air, 250 μm, 2,650 kg/m^3, d_t=0.2 m; (⬡) sand-air, 250 μm, 2,650 kg/m^3, d_t=0.082 m. Peeler et al. [6]: (○) sand-N_2, 130 μm, 4,400 kg/m^3; (▽) alumina-N_2, 70 μm, 2,800 kg/m^3; (□) alumina-He, 70 μm, 2,800 kg/m^3. Correlations of Choi et al. [7]: (—) Eq. (3) for Ar>20.87 (d_{bmax}<d_{beq}), (---) Eq. (4) for Ar<20.87 (d_{bmax}>d_{beq}).

Ar<20.87 reasonably well. The u_c decreases in the region, Ar<20.87, but increases in the region, Ar>20.87 as temperature increases. As a result, the type transition in onset condition of turbulent fluidization occurs at Ar of 20.87 by type transition of bubble breakup. According to Peeler et al. [6], Ar of 20.87 is the upper limit of Geldart's group A/B transition.

This interpretation initially started to understand the published two opposite temperature effects on u_c [7]. However, the u_c data published with variation of temperature in the condition Ar<20.87 are unfortunately rare. Therefore, we could not add more experimental data. We thought that extending the meaning of the boundary value Ar more than present knowledge seemed improper at the moment because it might get into the wrong discussion. More discussion based on findings is needed in the future.

CONCLUSIONS

The type transition in onset condition of turbulent fluidization in gas fluidized beds was investigated to get the relation representing more precise roles of physical properties of gas and solid particles on the basis of the model of Choi et al. [7]. The type transition in onset condition of turbulent fluidization occurs at Ar of 20.87 by type transition of bubble breakup. The maximum stable bubble diameter (d_{bmax}) is greater than the equilibrium bubble diameter (d_{beq}) in the region, Ar<20.87, but d_{beq}>d_{bmax} in the region, Ar>20.87. Therefore, the onset of turbulent fluidization is determined in the region, Ar<20.87, by d_{beq} and in the region, Ar>20.87, by d_{bmax} as the limit of bubble growth. The u_c decreases in the region, Ar<20.87, but increases in the region, Ar>20.87 as temperature increases.

ACKNOWLEDGEMENT

This work was supported by the Energy Efficiency & Resources of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy (2008CCD11P030000).

NOMENCLATURE

Ar : Archimedes number, $(d_p^3\rho_g(\rho_p-\rho_g)g)/\mu^2$
d_{beq} : equilibrium bubble diameter [m]
d_{bmax} : maximum stable bubble diameter [m]
d_p : particle diameter [m]
d_t : column diameter [m]
g : gravitational acceleration, 9.8 [m/s^2]
Re_c : particle Reynolds number at the onset condition of turbulent fluidization, $(d_p u_c \rho_g)/\mu$ [-]
Re_{mf} : particle Reynolds number at minimum fluidization, $(d_p u_{mf} \rho_g)/\mu$ [-]
u : gas velocity [m/s]
u_c : onset velocity of turbulent fluidization [m/s]
u_{mf} : minimum fluidizing velocity [m/s]
ρ_g : gas density [kg/m^3]
ρ_p : solid density [kg/m^3]
μ : gas viscosity [PaÞs]

REFERENCES

1. D. Harrison, J. F. Davidson and J. W. de Kock, *Trans. Inst. Chem. Eng.*, **39**, 202 (1961).
2. S. Morooka, K. Tajima and T. Miyauchi, *Int. Chem. Eng.*, **12**, 168 (1972).
3. J. Werther, In *Fluidization Technology,* D. L. Keairns Eds., Hemisphere, 215 (1976).
4. J. Werther, In *Fluidization IV,* D. Kunii and R. Toei Eds., Engineer-

ing Foundation, New York, 93 (1984).
5. A. Chehbouni, J. Chaouki, C. Guy and D. Klvana, in *Fluidization VIII*, J. F. Large and C. Lagu'rie Eds., Engineering Foundation, New York, 149 (1995).
6. P. K. Peeler, K. S. Lim and R. C. Close, in *Circulating Fluidized Bed Technology VI*, J. Werther Eds., DECHEMA, Frankfurt, Vol. 1, 125 (1999).
7. J.-H. Choi, H.-J. Ryu and C.-K. Yi, *Korean J. Chem. Eng*., **28**, 304 (2011).
8. C. Y. Wen and Y. H. Yu, *AIChE J*., **12**, 610 (1966).