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Parametric study of gas-solid flow characteristic by using integration computational fluid dynamics and dynamic simulation

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Abstract. The multiphase gas-solid in the FCC Riser system is a complex flow. The particle flow influenced by superficial velocity. Some researchers showed that it needs a method to solve the advanced analysis in solid-particle characteristics, for example, Reynold number particle, the difference of height fluidization, coefficient of drag, and particle forces. This research gives an alternative method by integrating the CFD method and dynamic simulation method. We used EES as dynamic simulation software. The simulation data need some data such as average fluid velocity, average solid velocity, a maximum height of fluidization, and void fraction. The mathematical model is performed and the simulation data is copied to EES to analyst the gas-solid flow characteristic. This parametric study has been carried out with several superficial velocity 0.35 m s^{-1}, 0.45 m^{-1}, 0.5 m^{-1}, and 0.7 m s^{-1}. The results show that there are fluctuations in the forces received by the particles due to changes in the superficial velocity. However, the tendency of fluctuation trend to be directly proportional to the increase in the superficial velocity. The dynamic simulation calculations have a good agreement compare to literature studies and basic theory for solid flow behaviour in bubbling regimes.

Keywords: superficial velocity, fluidization, solid-gas flow, FCC, CFD, dynamic simulation

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1. Introduction

The fluid characteristics in Circulating Fluidized Bed and Fluidized bed are complex turbulent included fluidization, combustion, and heat transfer processes. Previously, the basic parameter design to optimize the performance of CFB by increasing the superficial velocity, however, this has a negative impact such as overheat of wall heating surface and erosion of wall tube [1]. Some research showed that superficial velocity control could reduce overheating and erosion in-wall tubes, electricity consumption, and NOx [2]. The experimental method showed that the initial velocity influenced the blower specification [3]. Recently, some research has been designed and reverse engineering used computational fluid dynamics method rather than experimentally method because of the limitation of measuring tools and cost [4]. Furthermore, the CFD method could be predicted and visualized the fluid behaviour, in X-Y plots, vector plots, contour plots, animation, data reports, and output [5][6][7]. However, in complex fluid characteristics, engineers or researchers need some parameters to calculate. The calculation of the drag coefficient of the gas-solid flow particle has been done by R. Mabrouk et al. by using the fourth-order Runge-Kutta Method [8]. F. Hernández-Jiménez verified the simulation results by calculating the minimum value of superficial velocity based on the Ergun, Wen & Yu, Carman-Kozeny, and Grace equations [9].

The novelty of this study provides an alternative method of analysing the results of particle flow simulations by integrating CFD and dynamic simulation. The analysis focused on the effect of superficial velocity on particle flow characteristics such as Reynold number, coefficient of drag, gravity, buoyancy force, and drag force.

2. CFD Parameter

The modeling method of Hydrodynamics Fluidization used simulation reference from (10). The simulation parameter shows in Table 1. The validation of the model has been done against measurement data from the apparatus of fluidization and heat transfer unit H692. The result of the pressure drop can be seen in Figure 1. Simulation results and pressure drop measurement showed an increase in pressure drop during fixed bed conditions, after achieving minimum fluidization the pressure drop fluctuation is not significant. It has good agreement with some researchers [10-12].

Table 1. Simulation parameter

Parameter	Value
Chamber dimension	0.4 m height x 0.1 m width x 0.1 m thickness
Model	2 D
Grid size	100 x 200 (total 20000 grid)
Initial bed height	0.08 m
Initial volume fraction	0.46
Solid	alumina (Al_2O_3)
Motive fluid	Compressed air
Alumina diameter	320 µm
Particle density	3770 kg m^{-3}
Time set	0.0005 s
Multiphase	Euler-Euler

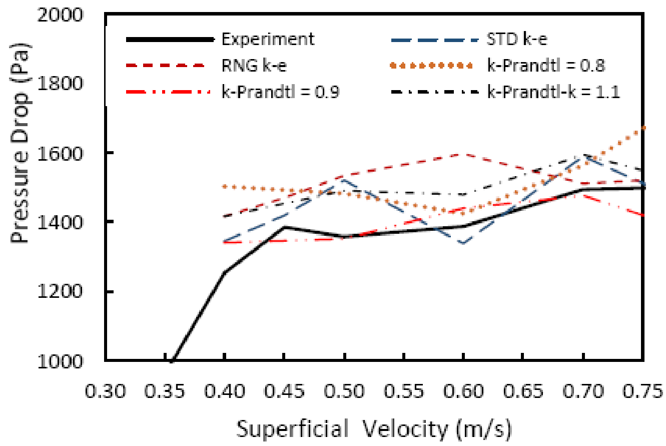

Figure 1. Bed pressure drop at superficial velocity of 0.4 m s^{-1} to 0.75 m $^{-1}$

3. Dynamic simulation procedure

This research used EES® as Dynamic simulation. Mathematical models build on the equation window and the simulation results input on the parametric table. Data input in this study has not integrated with C ++. Thus, the simulation data copies to the parametric table. Superficial velocity is a motive fluid in particle flow. Jieng Feng He et al. stated that the forces acting on the particles consist of inter-particle force (F_p), buoyancy force (F_b), gravity force (F_g), and drag force (F_D). This study neglected the forces between particles. The particle force diagram can be seen in Figure 2 [8].

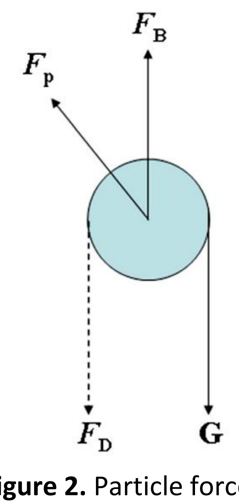

Figure 2. Particle force diagram

The movement of particles in the gas-solid flow include Reynolds number particle, gravitational force, buoyancy force, drag force, and total force as described in equation 1 to equation 7. Reynold number particle [13]

$$Re_p = \frac{d_p u_o \rho_g}{\mu} \tag{1}$$

Coefficient of drag [8]

$$CD = \alpha Re_p{}^{-\beta} \tag{2}$$

Forces [14]

$$\rho_f = (1-\varepsilon)(\rho_s - \rho_g) \tag{3}$$

$$F_B = \rho_f V_p g \tag{4}$$

$$F_G = mg \tag{5}$$

$$F_D = \frac{1}{8}\pi C_D \rho_f (u_f - u_p)^2 \tag{6}$$

$$F = F_b + F_g + F_D \tag{7}$$

4. Result and discussion

Based on equation 1 to 7 above, a program made in the equation window shown in Figure 3. Data and calculation results shown in Table 2. The parametric table consists of two-color, black and blue. The black-colored was simulation input data include superficial velocity, the maximum height of fluidization, particle velocity, and, average fluid velocity. While the blue-colored was a calculation result of EES, which are Reynolds number of particles, Buoyancy Force, Gravity Force, coefficient of drag, Drag Force, Composite Force, and Air fraction. The graph of gas-solid particle behavior showed in Figure 4.

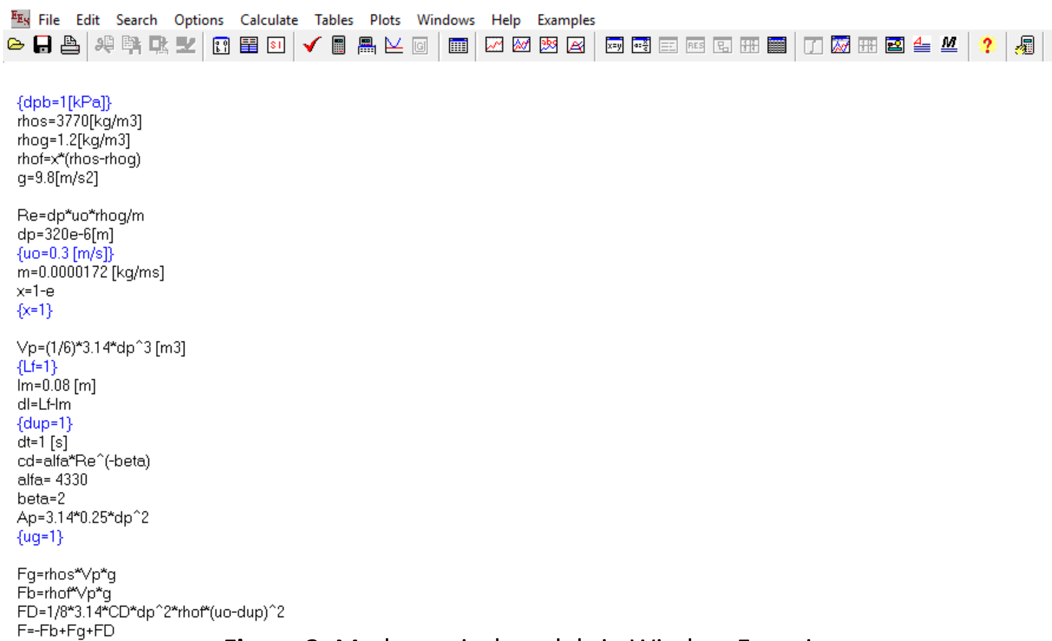

Figure 3. Mathematical models in Window Equation

Table 2. Parametric table

1..4	dl	Re	uo	Lf	dup	Fb	Fg	cd	ug	FD	F	x
Run 1	0.05	7.814	0.35	0.13	0.1397	4.769E-07	6.336E-07	70.92	0.4535	0.0003577	0.0003579	0.753
Run 2	0.076	10.05	0.45	0.156	0.18	4.887E-07	6.336E-07	42.9	0.5494	0.0003655	0.0003657	0.7716
Run 3	0.084	11.16	0.5	0.164	0.223	4.953E-07	6.336E-07	34.75	0.5887	0.0003158	0.000316	0.782
Run 4	0.104	15.63	0.7	0.184	0.24	5.118E-07	6.336E-07	17.73	0.8503	0.0004592	0.0004593	0.808

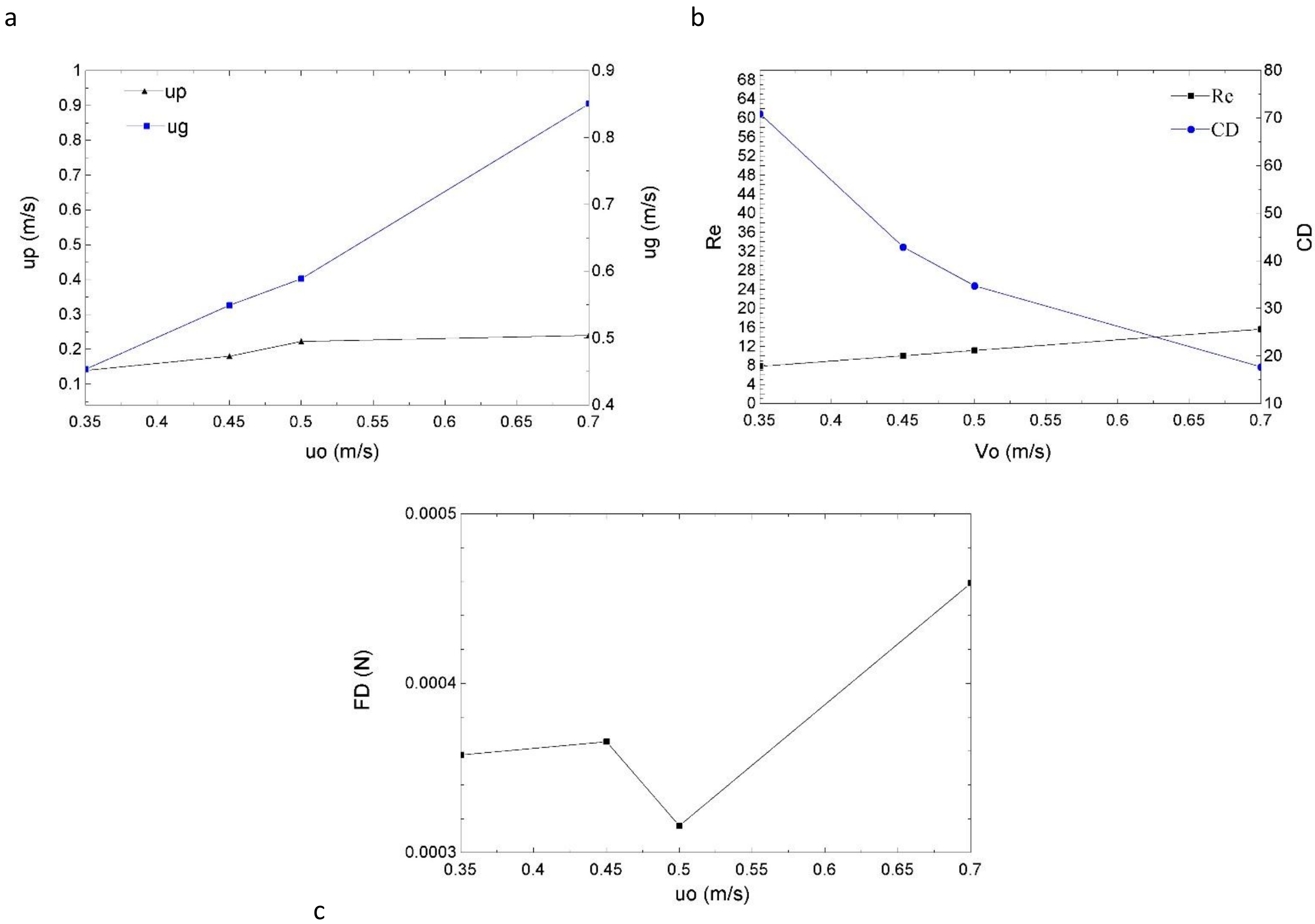

Figure 4. The particle flow characteristics of a) particle velocity and fluid velocity b) Reynold number and coefficient of drag c) drag force are affected by the superficial velocity

Figure 4 shows superficial velocity affects particle velocity and fluid velocity in the chamber. An increase in superficial velocity causes a tendency to increase the average air velocity and particle velocity in the gas-solid flow. Particle velocity increases between 0.14 m s^{-1} and 0.24 m s^{-1} while fluid velocity has a range of 0.45 ms^{-1} to 0.85 ms^{-1}. Increased particle velocity causes the particle inertia force is higher than the viscous force, so the particle Reynold number also rises. Because of the particle inertia increases, the coefficient of drag of the particles decreases. However, the decrease in the coefficient of resistance is not as large as the square of the difference between the velocity of the fluid and the velocity of the particle, so the drag force tends to increase. This

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phenomenon has a good agreement with the experimental drag force measurement that has been done by Ana Mosquera Gomez [15].

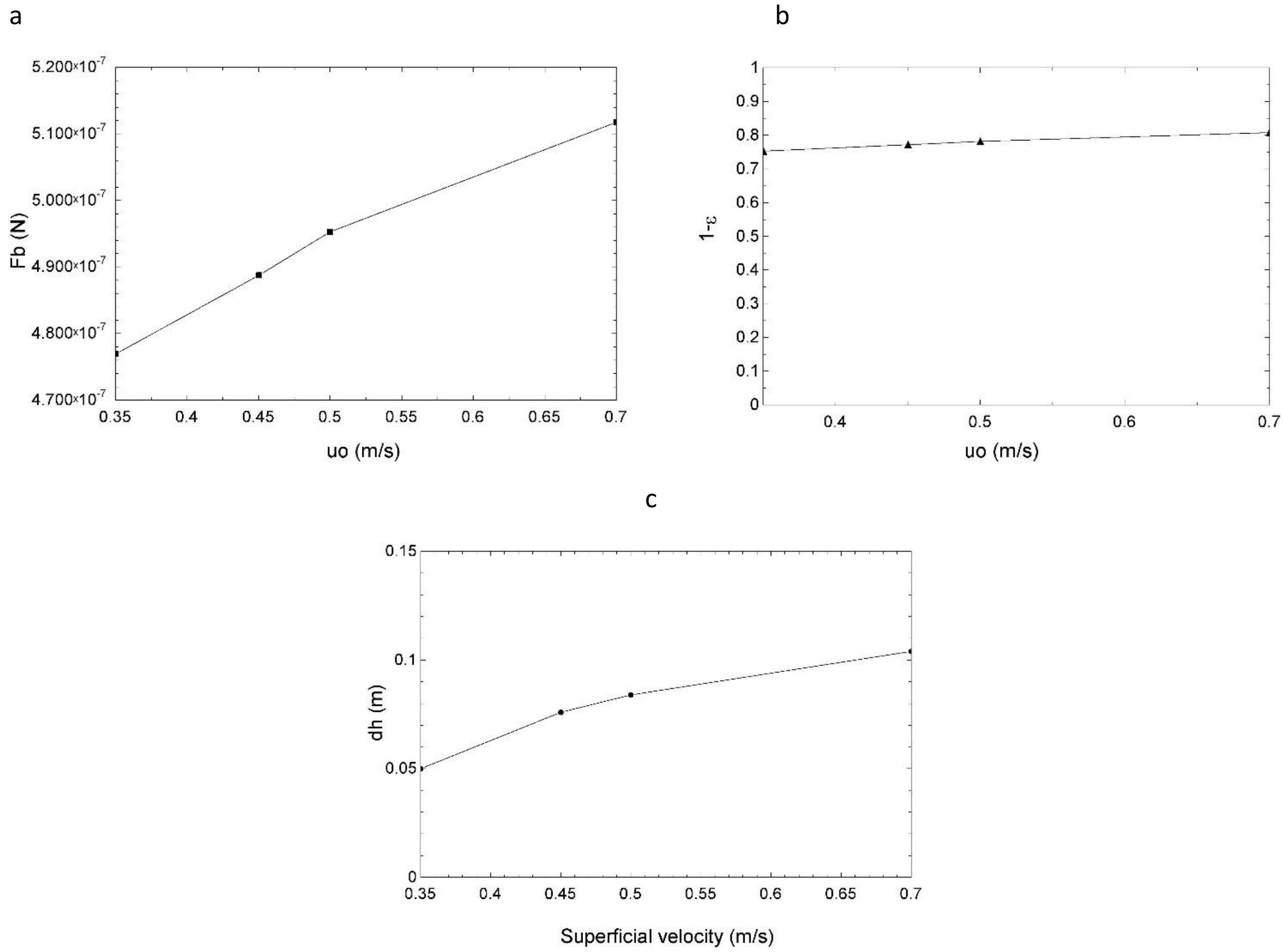

Figure 5. The particle flow characteristics of a) buoyance force b) fraction of fluid c) additional height of fluidization are affected by the superficial velocity

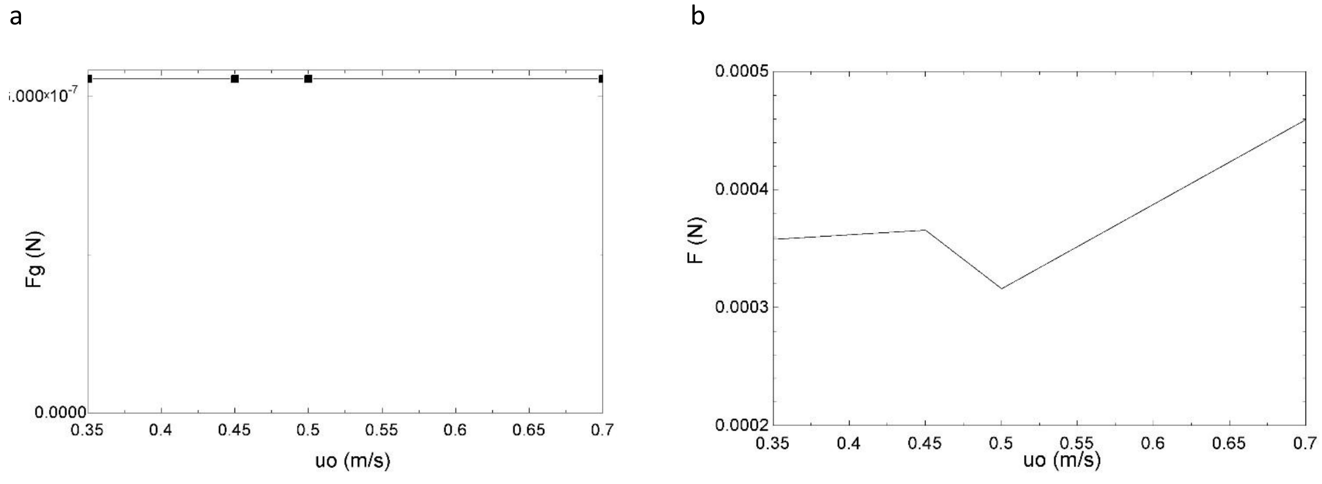

Figure 6. The particle flow characteristics of a) gravity force b) composite force are affected by the superficial velocity

The increase in superficial velocity causes the mass of air in the reactor to expand. This causes the buoyancy force to increase so that the height of the fluidization higher. This phenomenon has good agreement with the results of research conducted by Musango Lungu [16]. Therefore, the flow of particles spreads in a larger chamber volume; consequently, the air volume fraction is increasing. The gas-solid flow in this study is isothermal and no particles enter and exit, so the fluid density remains, therefore the gravity force particle is constant. It shows that the superficial velocity influences the particle flow significantly. This phenomenon makes the composite force of particle increasing. This result has a good agreement with research conducted by Jingfeng He *et al.* [17].

5. Conclusion

The alternative method for analyzing particle flow characteristics in the bubbling regime has been carried out by integrating the CFD method and the dynamic simulation method. The advantage of the integration of these two methods is a unified calculation that is systematic and easy to do. The calculation results show that superficial velocity influenced significantly to the gas-solid characteristics. Besides that, the calculation result also has good agreement with the experiment that has been done by researchers.

Nomenclature

Cd = coefficient of drag
d_p = particle diameter (mm)
F_B = buoyance force (N)
F_D = drag force (N)
F_G = gravity force (N)
F = total force ($F_B+F_D+F_G$)
g = gravity (ms^{-2})
m = solid mass (kg)
Re_p = Reynolds number particle based upon superficial velocity
Vp = volume of particle (m^3)
u_o = superficial velocity
u_p = average velocity of solid (ms^{-1})
u_f = average velocity of fluid (ms^{-1})
ε = void fraction
μ = fluid viscosity ($kgm^{-1} s^{-1}$)
ρf = fluid density
ρ_g = gas density (kg m^{-3})
ρ_s = solid density (kg m^{-3})

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