IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

CPFD Simulations of Gas-Solid Fluidization in Fluidized Beds with Different Shapes of Cross Sections

To cite this article: Jiangtao Jin *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **223** 012054

IOP Conf. Series: Earth and Environmental Science 223 (2019) 012054 doi:10.1088/1755-1315/223/1/012054

CPFD Simulations of Gas-Solid Fluidization in Fluidized Beds with Different Shapes of Cross Sections

Jiangtao Jin[1], Xiaofei Li[2,*], Fangzhou Zhu[2], Xiaolong Lv[2] and Zhichao Qu[2]

[1]College of Automation and Electronic Engineering, Qingdao University of Science and Technology, Qingdao, Shandong, 266061, China
[2]College of Sino-German Science and Technology, Qingdao University of Science and Technology, Qingdao, Shandong, 266061, China

[*]E-mail: lixiaofeide126@126.com

Abstract. In order to study the influence of shape of cross section on hydrodynamics of gas-solid fluidization in the fluidized bed, five fluidized beds with the shapes of cross sections of circle, regular hexagon, square, rectangle and regular triangle were proposed. The fluidization characteristics and pressure drops in the fluidized beds with different shapes of cross sections were numerically investigated by Computational Particle-Fluid Dynamics (CPFD) models. The simulation results show that the shapes of cross sections affect strongly the particles distributions and the fluidized gas distributions due to strong wall effects, but affect slightly the pressure distributions and the pressure drops in the fluidized beds.

1. Introduction

Structure design of fluidized bed is an important research field. The shape of fluidized bed affects not only the volume of the bed, but also the performance of the bed. Therefore, it is necessary to study the influence of bed shape on fluidization characteristics of the fluidized bed. Numerical simulation can describe the interaction between gas phase and particle phase more directly than experiment study [1].

Computational Particle-Fluid Dynamics (CPFD) is a new pattern way to model fluidized beds, such as circulating fluidized bed with annular combustion chamber [2], chemical looping combustors [3], downer reactors [4], compact micro fluidized beds reactor [5], and oblique micro fluidized bed [6]. Thapa et al. studied the flow pattern of the dual fluidized bed system by simulation, the numerical and experimental results are in good agreement with each other [7]. Liang et al. used CPFD to improve understanding of gas velocity and particles distribution characteristics in the fluidized beds [8]. Lim et al. simulated the pressure distributions in the bubbling fluidized beds using CPFD, the simulation results are in good agreement with the experimental results [9].

Many researches focus on the fluidization characteristic of fluidized bed with circular cross section. There is few study on flow characteristics and pressure drops of the fluidized beds with different shapes of cross sections. In this paper, the flow characteristics and pressure drops in the fluidized beds with different shapes of cross sections were simulated by CPFD.

2. Model description

2.1. Governing equations

In CPFD, the continuity and momentum transfer equation for the gas phase are [10]:

$$\frac{\partial \theta_{\mathrm{f}} \rho_{\mathrm{f}}}{\partial t} + \nabla \cdot \left(\theta_{\mathrm{f}} \rho_{\mathrm{f}} u_{\mathrm{f}} \right) = 0 \tag{1}$$

$$\frac{\partial \left(\theta_{\mathrm{f}} \rho_{\mathrm{f}} u_{\mathrm{f}} \right)}{\partial t} + \nabla \cdot \left(\theta_{\mathrm{f}} \rho_{\mathrm{f}} u_{\mathrm{f}} u_{\mathrm{f}} \right) = -\nabla p + \nabla \cdot \left(\theta_{\mathrm{f}} \tau_{\mathrm{f}} \right) + \theta_{\mathrm{f}} \rho_{\mathrm{f}} g - F \tag{2}$$

Where θ_{f} and τ_{f} are the gas volume fraction and the gas stress tensor.

The particle acceleration is given by

$$\frac{du_{\mathrm{p}}}{dt} = D\left(u_{\mathrm{f}} - u_{\mathrm{p}} \right) - \frac{1}{\rho_{\mathrm{p}}} \nabla P + g - \frac{1}{\theta_{\mathrm{p}} \rho_{\mathrm{p}}} \nabla \tau_{\mathrm{p}} \tag{3}$$

Where u_{p} and D are the particle velocity and the drag coefficient, respectively.
Particle normal stress is given by

$$\tau_{\mathrm{p}} = \frac{P_{\mathrm{s}} \theta_{\mathrm{p}}^{\beta}}{\max\left[\left(\theta_{\mathrm{cp}} - \theta_{\mathrm{p}} \right), \varepsilon \left(1 - \theta_{\mathrm{p}} \right) \right]} \tag{4}$$

Where P_{s} is the default 1 Pa. ε is 10^{-8} and β is 3.

2.2. Simulation setup

For the investigation of the effects of the shapes of cross sections on hydrodynamics of gas-solid fluidization in fluidized beds, five fluidized beds with the shapes of cross sections of circle, regular hexagon, square, rectangle, regular triangle, and the fluidized beds are called C-FB, RH-FB, S-FB, R-FB and RT-FB in short respectively were modeled. The areas of those cross sections are the same 314.0 mm^2. The sizes of the C-FB, RH-FB, S-FB, R-FB and RT-FB are listed in Table 1. The geometries and meshing of the fluidized beds are shown in Figure 1.

Table 1. The sizes of the C-FB, RH-FB, S-FB, R-FB and RT-FB

	Parameter	Length (mm)
C-FB	Diameter	20.0
RH-FB	Side	11.0
S-FB	Side	17.7
R-FB	Length & Width	43.6 & 7.2
RT-FB	Side	26.9

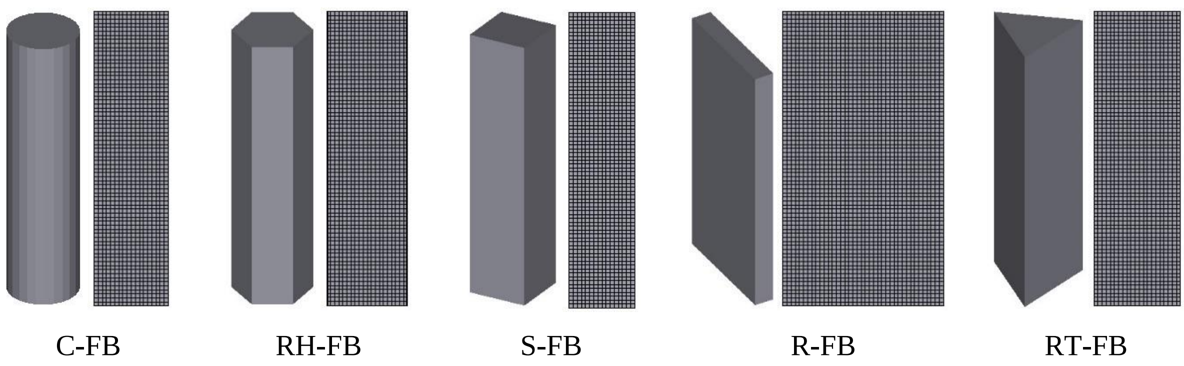


Figure 1. The geometries and meshing of the C-FB, RH-FB, S-FB, R-FB and RT-FB

Performances of the C-FB, RH-FB, S-FB, R-FB and RT-FB were simulated by the CPFD models with FCC particles. The initial particles fraction was the same 0.6. The initial bed height was the same

40 mm. The gas used in the simulation was air which gas velocity is 0.16 m/s. Key properties of gas and particles in the C-FB, RH-FB, S-FB, R-FB and RT-FB are listed in Table 2.

Table 2. Key properties of gas and particles in the C-FB, RH-FB, S-FB, R-FB and RT-FB

Gas		Particle	
Gas density/(kg/m^3)	1.25	Particle density /(kg/m^3)	1200
Viscosity coefficient/(kg/m s)	1.85^{-5}	Bulk density /(kg/m^3)	680
Superficial velocity/(m/s)	0.16	Particle diameter /μm	150-200

A uniform inlet flow boundary condition is applied to all the cells at the bottom of the domain. A constant pressure boundary condition with atmospheric pressure was applied for the outlet. Relevant simulation parameters are presented in Table 3. The boundary conditions of the C-FB, RH-FB, S-FB, R-FB and RT-FB models are shown in Figure 2.

Table 3. Simulation parameters

	Parameter
Drag model	WenYu
Particle-to-particle interaction	Close-pack volume fraction: 0.6 Maximum momentum redirection from collision: 40% Pressure constant, Ps: 1 Pa Non-dimensional exponent, β: 3 Non-dimensional constant, ε: 10^{-8}
Particle-to-wall interaction	Normal-to-wall retention coefficient: 0.3 Tangent-to-wall retention coefficient: 0.99 Diffuse bounce: 0
Boundary conditions	Constant-velocity gas inlet Dynamically balanced pressure gas outlet Gas wall: free-slip
Time settings	Initial time step: 0.001 s Total time 30 s Start time for average 5 s

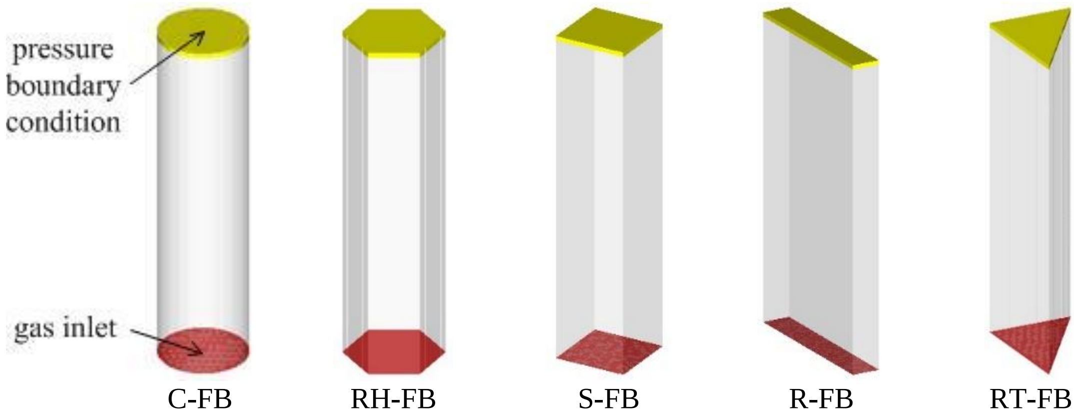


Figure 2. The boundary conditions of the C-FB, RH-FB, S-FB, R-FB and RT-FB models

IOP Conf. Series: Earth and Environmental Science 223 (2019) 012054 doi:10.1088/1755-1315/223/1/012054

3. Simulation results analysis

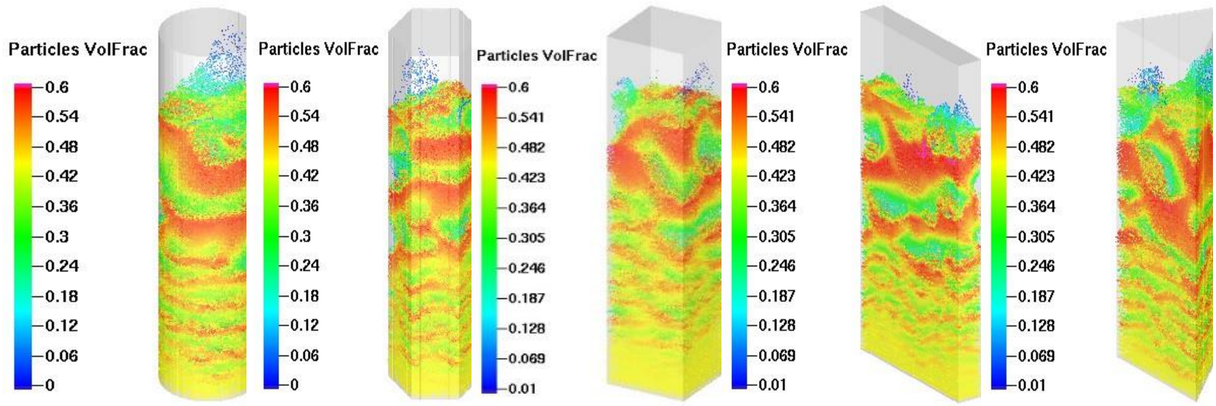
3.1. Effect of Cross sections on fluidization characteristics in the fluidized beds

The simulation results of the gas-solid fluidization in the C-FB, RH-FB, S-FB, R-FB and RT-FB are shown in Figure 3, where the particles distributions in the upper parts are more dense than in the lower parts of the C-FB, RH-FB, S-FB, R-FB and RT-FB. There have less and smaller bubbles, more uniform particles distributions, better gas-solid fluidization, and superior gas-solid contact in the C-FB, RH-FB, S-FB and R-FB than in the RT-FB due to small angles between adjacent bed walls and strong wall effects.

The simulation results of the particle volume fractions in the C-FB, RH-FB, S-FB, R-FB and RT-FB are shown in Figure 4. The particle volume fractions in the C-FB, RH-FB, S-FB and R-FB are even. But the particle volume fractions in the RT-FB is very uneven. The particle volume fractions between adjacent bed walls are much smaller than in the middle region of the RT-FB due to strong wall effects. The particle volume fractions in the lower part regions of the C-FB, RH-FB, S-FB, R-FB and RT-FB all show alternating distributions of large- and small-fraction layers.

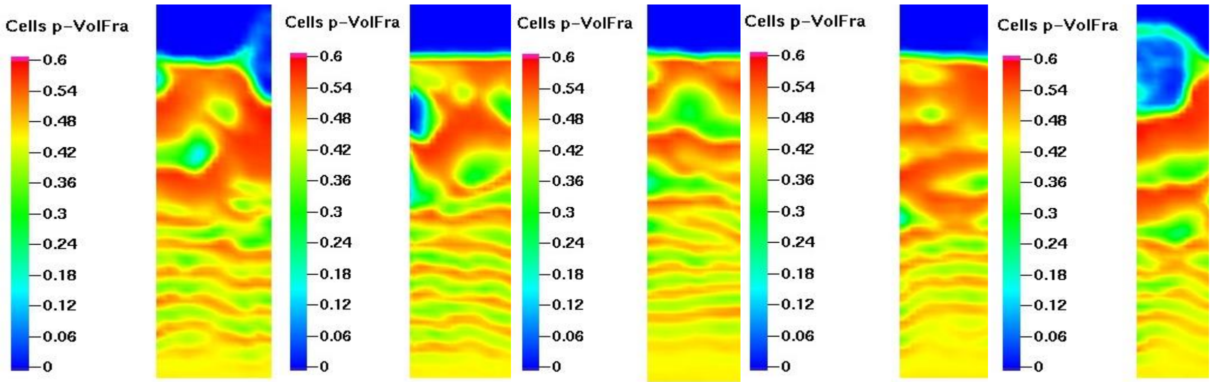
The simulation snapshots of the gas velocities in the C-FB, RH-FB, S-FB, R-FB and RT-FB are shown in Figure 5. The gas superficial velocities in the C-FB, RH-FB, S-FB and R-FB distribute much more uniformly and equivalently than in the RT-FB. The vector magnitudes of gas superficial velocities in the regions near the walls are much higher than the middle regions in the upper parts of the C-FB, RH-FB, S-FB, R-FB and RT-FB due to dense particles distributions. There are many regions of maximum or minimum gas superficial velocities in the RT-FB due to the nonuniform particles distribution in the bed.

Figure 6 displays the simulation results of the pressure distributions in the C-FB, RH-FB, S-FB, R-FB and RT-FB, which indicates that the pressures all decrease from the bottom to the top of the beds gradually, and the decreasing ranges reach the maximum values at the bottom zones of the beds. The pressures at the same height positions in the C-FB, RH-FB, S-FB, R-FB and RT-FB distribute uniformly. The maximum pressures have close magnitudes in the fluidized beds with different shapes of cross sections. Consequently, the shapes of cross sections nearly have no influence to the maximum pressures in the fluidized beds.



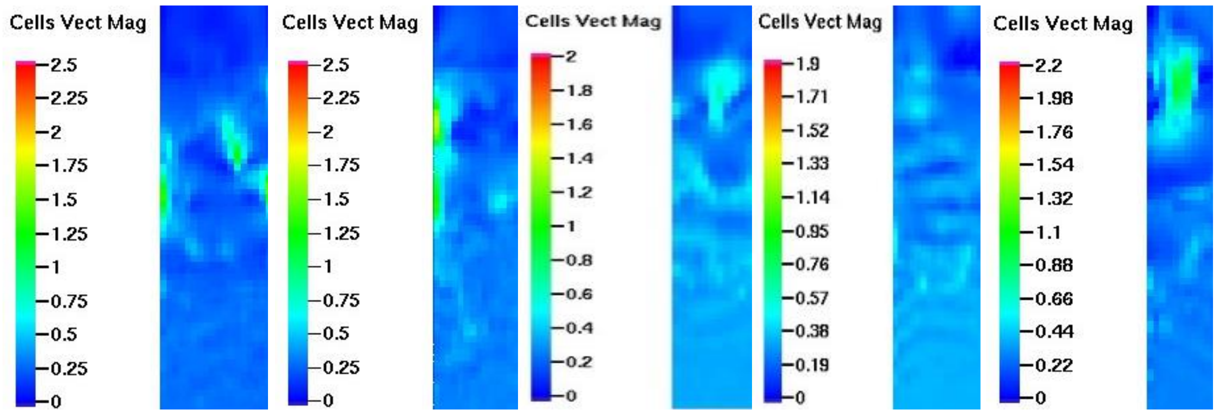
C-FB RH-FB S-FB R-FB RT-FB

Figure 3. Particles distribution in the C-FB, RH-FB, S-FB, R-FB and RT-FB



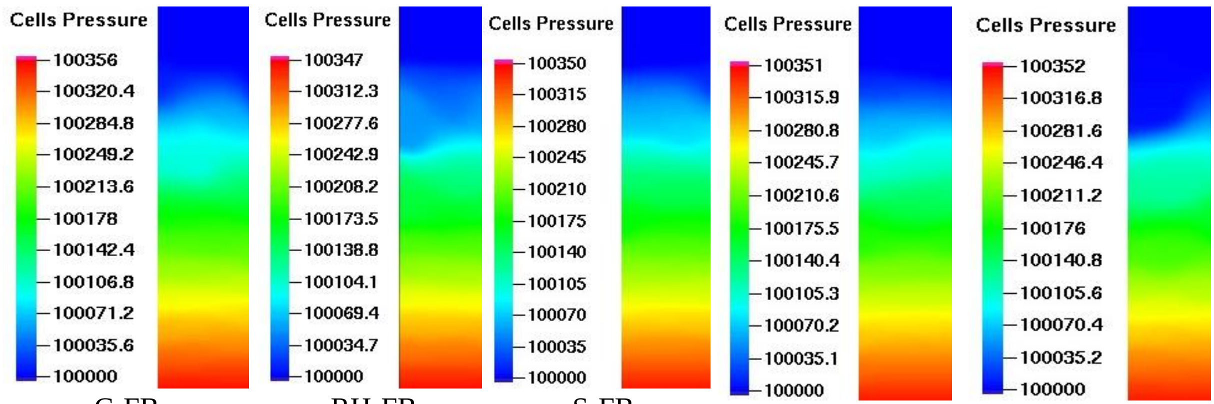
C-FB RH-FB S-FB R-FB RT-FB

Figure 4. Particle volume fractions in the C-FB, RH-FB, S-FB, R-FB and RT-FB



C-FB RH-FB S-FB R-FB RT-FB

Figure 5. Gas velocities in the C-FB, RH-FB, S-FB, R-FB and RT-FB



C-FB RH-FB S-FB R-FB RT-FB

Figure 6. Pressure distribution in the C-FB, RH-FB, S-FB, R-FB and RT-FB

3.2. Effect of Cross sections on Pressure Drops in the fluidized beds

Figure 7 shows the pressure drops in the C-FB, RH-FB, S-FB, R-FB and RT-FB with different shapes of cross sections. The pressure drops in the C-FB, RH-FB, S-FB, R-FB and RT-FB are 354 Pa, 353 Pa, 355 Pa, 353 Pa and 356 Pa respectively, and the pressure drop values almost equal. The reason may be that the shapes of cross sections nearly have no influence to the pressure drops in the fluidized beds, and the C-FB, RH-FB, S-FB, R-FB and RT-FB have the same particles mass and the same static bed height of 40 mm.

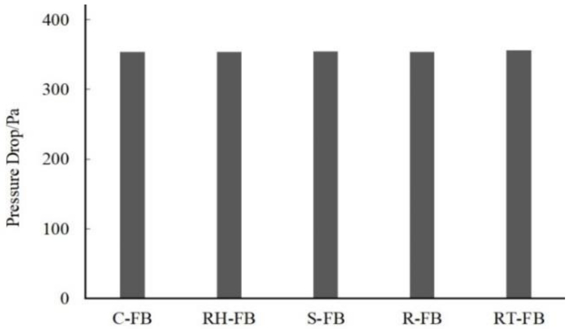


Figure 7. The pressure drops in the C-FB, RH-FB, S-FB, R-FB and RT-FB

4. Conclusions

In this paper, the effects of the shapes of cross sections on the fluidization characteristics and pressure drops in the C-FB, RH-FB, S-FB, R-FB and RT-FB were investigated. Small angles between adjacent bed walls can lead to strong wall effects which result in nonuniform particles distributions, uneven particle volume fractions, nonuniform gas superficial velocities, bad gas-solid fluidization, inferior gas-solid contact in the fluidized beds. But the shapes of cross sections have very slight influences on the pressure distributions and the pressure drops in the fluidized beds.

Acknowledgments

This work was supported by the Key Research and Development Project of Shandong Province under Grant no. 2017GSF17120.

References

[1] CHEN Cheng, WERTHER Joachim, HEINRICH Stefan, et al. CPFD simulation of circulating fluidized bed risers[J]. Powder Technology, 2013, 235, 238-247.

[2] QIU Guizhi, YE Jiamin, WANG Haigang. Investigation of gas-solids flow characteristics in a circulating fluidized bed with annular combustion chamber by pressure measurements and CPFD simulation[J]. Chemical Engineering Science, 2015, 134, 433-447.

[3] SU Mingze, Zhao Haibo, Ma Jinchen. Computational fluid dynamics simulation for chemical looping combustion of coal in a dual circulation fluidized bed. Energy Conversion & Management, 2015, 105, 1-12.

[4] ABBASI A, ISLAM M A, EGE P E, et al. CPFD flow pattern simulation in downer reactors[J]. Aiche Journal, 2013, 59(5), 1635-1647.

[5] LI Xiaofei, WANG Lei, JIA Lei, CAI Wenjian. Numerical and Experimental Study of a Novel Compact Micro Fluidized Beds Reactor for CO_2 Capture in HVAC[J]. Energy and Buildings, 2017, 135, 128-136.

[6] LI Xiaofei, WANG Lei, JIA Lei, CAI Wenjian. Design and performance of oblique compact micro fluidized bed for low-concertration CO_2 capture[J]. Journal of Southeast University, 2016, 46(4), 770-775.

[7] THAPA R K, PFEIFER C, HALVORSEN B M. Modeling of reaction kinetics in bubbling fluidized bed biomass gasification reactor[J]. International Journal of Energy & Environment, 2014, 5, 35-44.

[8] LIANG Yongshi, ZHANG Yongmin, LI Tingwen, et al. A critical validation study on CPFD model in simulating gas-solid bubbling fluidized beds[J]. Powder Technology, 2014, 263(263), 121-134.

[9] LIM J H, BAE K, SHIN J H, et al. Effect of particle–particle interaction on the bed pressure drop and bubble flow by computational particle-fluid dynamics simulation of bubbling fluidized beds with shroud nozzle[J]. Powder Technology, 2016, 288, 315-323.

[10] SNIDER D M, CLARK S M, O'ROURKE P J. Eulerian-Lagrangian method for three-dimensional thermal reacting flow with application to coal gasifiers [J]. Chemical Engineering Science, 2011, 66(6), 1285-1295.