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Effect of baffle on hydrodynamics in the air reactor of dual circulating fluidized bed for chemical looping process

Xuan Feng, Laihong Shen *, Lulu Wang

Key Laboratory of Energy Thermal Conversion and Control of Ministry of Education, School of Energy and Environment, Southeast University, Nanjing 210096, China

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ABSTRACT

The air reactor plays an important role in a dual circulating fluidized bed system for chemical looping process while the non-uniformity of solid distribution in the riser leads to a poor gas-solid contact and decreases the operation stability of the system. The aim of the study was to propose a novel baffle consisting of a ring-type baffle and a convergent pipe to improve the flow pattern and enhance the gas-solid contact. The effect of baffle on the system hydrodynamics was investigated based on CFD simulations. Three configuration parameters were studied: baffle opening ratio, baffle thickness and baffle number. The effect of baffle on radial solid distribution was evaluated through the standard deviation. Additionally, the radial non-uniformity index (RNI) of radial solid volume fraction was introduced to describe the axial change of radial solid distribution. The results showed that the baffle significantly affected the system hydrodynamics. The baffle opening ratio and the number of baffles were the key factors to decrease the standard deviation of radial solid volume fraction. The axial RNI profile showed that medium baffle thickness can effectively maintain a uniform radial solid distribution in the region away from baffle. Analysis of the simulation results revealed that the baffle increased the gas and solid velocities and it created turbulent eddies to eliminate the solid back-mixing near the wall.

1. Introduction

Chemical looping combustion (CLC) technology has emerged as a promising combustion technology with inherent CO_2 separation [1]. As schematized in Fig. 1, the design of two separate reactors, the air reactor and the fuel reactor [2,3], can sequester the fuel from air. Thereby, pure CO_2 can be readily obtained after H_2O condensation with low energy penalty [4–6].

The performance of CLC system depends on many different factors including the property of oxygen carrier, the type of fuel and the reactor design. Among these characteristics, a proper reactor design is significant for optimizing the performance of CLC. The published attempts in recent years have established that the design of two interconnected fluidized beds most suitable for CLC process [7]. Furthermore, successive efforts have been done on the fuel reactor design considering that the higher residence time for oxygen carrier particle to achieve complete conversion of fuel. Various type of fuel reactor including the bubbling bed [8–10], moving bed [11] and spouted bed [12] have been tested using different oxygen carriers and fuels. Apart from this, researchers from Vienna University of Technology proposed the dual circulating fluidized bed (DCFB) [13], in which the fuel reactor was operated in a turbulent regime rather than bubbling regime. Thereby. the possible gas bypass was avoided and the good gas-solid contact was achieved along the height of fuel reactor. In this configuration, a high solid circulation rate can be achieved by adjusting the flow in air reactor. Compared with these extensive studies on fuel reactor, the air reactor has received little attention. As for the air reactor, many researchers applied a high velocity riser [14–18] to oxidize the oxygen carrier and provide enough propulsion for circulation of oxygen carriers.

However, there have been several reports on the non-uniformity of solid distribution in both axial and radial directions in the riser [19–22]. The non-uniformity of solid distribution in both axial and radial directions is attributed to particle clusters and solid back-mixing inside the riser. On one hand, the clusters and solid back-mixing strongly decreases the efficiency of mass, heat transfer and chemical reaction conversion [23,24]. The stability of the solid circulation rate is also affected by the non-uniformity of solid distribution in riser [25] while a stable circulation rate is required to achieve the mass and heat balance in DCFB system for CLC process. Besides, the particle clusters and solid back-mixing is one of the reasons for the pressure fluctuation in the riser [26,27]. Consequently, the pressure balance in DCFB system can be affected and the operation stability is decreased.

Abbreviation: CLC, chemical looping combustion; DCFB, dual circulating fluidized bed; CFD, computational fluid dynamics; FCC, fluid catalytic cracking; RNI, radial non-uniformity index; KTGF, kinetic theory of granular flow; SIMPLE, semi-implicit method for pressure-linked equations.

* Corresponding author.
E-mail address: lhshen@seu.edu.cn (L. Shen).

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Nomenclature

Greek letters

A, B, C	configuration parameter of baffle [−]
C_{D0}	drag coefficient [–]
D	riser diameter [m]
d	particle diameter [μm]
e_{ss}	particle-particle restitution coefficient [−]
e_w	particle-wall restitution coefficient [−]
g	gravity acceleration equal to 9.81 [m/s^{-2}]
$g_{0,\ ss}$	radial distribution function [−]
H	riser height [m]
P	pressure [Pa]
Re_k	Reynolds number [−]
U_g	superficial gas velocity [m/s]
v	velocity [m/s]

Latin letters

β_{gs}	interphase momentum exchange coefficient [kg/m^3 s]
ε	volume fraction [−]
k_{Θ_s}	conductivity of granular energy [kg/m s]
γ_{Θ_s}	collisional dissipation of granular energy [kg/m s^3]
Θ_s	granular temperature [m^2/s^2]
ρ	density [kg/m^3]
μ	viscosity [kg/m s]
τ	stress tensor [Pa]
λ_s	solid bulk viscosity [kg/m s]
φ	specularity coefficient [–]
σ	standard deviation

Subscripts

g	gas phase
s	solid phase
col	collisional
kin	kinetic
fr	frictional
max	maximum

As summarized in Table1, various types of baffles were installed to modify the gas-solid flow pattern and improve the gas-solid mixing. Jiang et al.[28]investigated the effect of internal ring baffles on ozone decomposition experimentally and they concluded that the addition of internal ring baffles can make radial solid distribution profile more uniform at medium and high superficial velocity, thus increasing the gas-solid contact efficiency and reaction conversion. The influence of internal ring baffles with different opening space on flow structure in the riser was explored by Zhu et al. [29], revealing that internal ring baffles redistributed the solid radially. Bu et al. [30] observed that opening space of internal ring baffle strongly affects the axial pressure distribution. At the presence of internals, the axial pressure gradient distribution exhibited a zigzag type profile instead of regular exponential or S-shape profile. Guío-Pérez et al. [31] studied the solid distribution in a fluidized bed with the presence of internal wedged-shaped baffle. In their study, four parameters including the aperture ratio, the number of rings, the fluidization velocity and the solid circulation rate were discussed. The obtained results showed that the impact of baffle was associated with the fluidization velocity. With respect to aperture ratio, they summarized that a smaller aperture ratio improved the solid redistribution in upper regions at lower fluidization velocities. Wang et al. [32] reported the addition of internal baffle in a square circulating fluidized bed riser for flue gas desulfurization. They found that baffles were more effective in increasing the solid concentration in center region when they were positioned at different heights. However, owing to the limitation of measurement techniques, some gas-solid behaviors, such as solid velocity and inter-particle forces, were difficult to be obtained in experiment, making it hard to understand the influence of internal baffles on flow structure comprehensively.

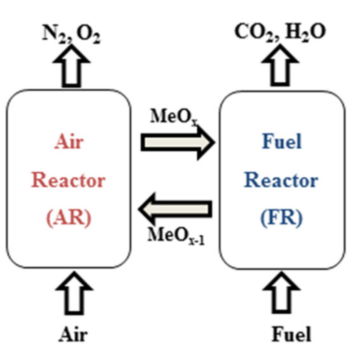

Fig. 1. Prototype of chemical looping combustion process.

Table 1
Reported baffles installed in risers with different size.

References	Riser size		Baffle type	Particle type
	D (m)	H(m)		
Jiang et al. [28]	0.102	6.32	Ring-type	Group A
Zhu et al. [29]	0.076	3.00	Ring-type	Group B
Bu et al. [30]	0.152	2.43	Ring-type	Group B
Guío-Pérez et al. [31]	0.054	0.74	Wedge-shaped	Group A
Wang et al. [32]	0.4(square)	3.94	Wedge-shaped	Group A
Therdthianwong et al. [33]	0.4	15.6	Ring-type	Group A
Samruamphianskun et al. [34]	0.2	14.6	Ring-type	Group A
Milinkumar et al. [35]	1	40	Ring-type	Group A
Vivien Rossbach et al. [36]	0.104	2.78	Airfoil-shaped	Group A

Computational fluid dynamics (CFD) modeling has been proven to be an effective tool for understanding multiphase flow characteristics in circulating fluidized bed. Therdthianwong et al. [33] used a two-dimensionalCFD model to study the conversion of ozone decomposition reaction in a circulating fluidized with installation of internal ring baffles. In their simulation, the addition of ring baffles enhanced radial gas-solid mixing and leaded to an increased ozone conversion by approximately 5-12%. The system hydrodynamics in a circulating fluidized bed reactor at the presence of internal baffles was investigated by Samruamphianskun et al. [34]. Simulation results indicated that the ring baffles could improve gas-solid mixing and eliminate the backflow near the wall. Milinkumar et al. [35] observed that the baffle promoted the radial dispersion of the catalyst and the heat transfer in a fluid catalytic cracking (FCC) riser. Regarding the shape of internal baffles, a novel airfoil-shaped internal baffle was proposed by Vivien Rossbach et al. [36]. They concluded that the airfoil-shaped baffle was able to improve the homogeneity of the gas-solid flow with a low pressure drop.

Most of the reported works on internal baffles were conducted with group A particles, mostly for FCC process. However, the system hydrodynamics of the riser changes considerably using different type of solid particles. In addition, the oxygen carriers used in CLC process belong to Group B particles, which can be directly separated from unburned solid fuel at fuel exit based on density and size difference [37]. Consequently, further studies should be conducted for reliable optimization and scale-up of baffles which can be installed in the riser for CLC process.

The aim of this study was to discuss the effect of a novel baffle on the system hydrodynamics in a lab-scale riser of DCFB system for CLCprocess, which was comprised of a ring-type baffle and a convergent pipe. CFD simulations were employed to investigate three configuration parameters, in terms of the baffle opening ratio, the baffle thickness and the number of baffles. The standard deviation of radial solid volume fraction was chosen to represent the uniformity of radial solid