CFD simulation of the hydrodynamics in a novel spouted bed with swirling flow

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This study reports a numerical simulation of the effect of swirling flow on gas-solid two phase flow behavior in three-dimensional spouted bed

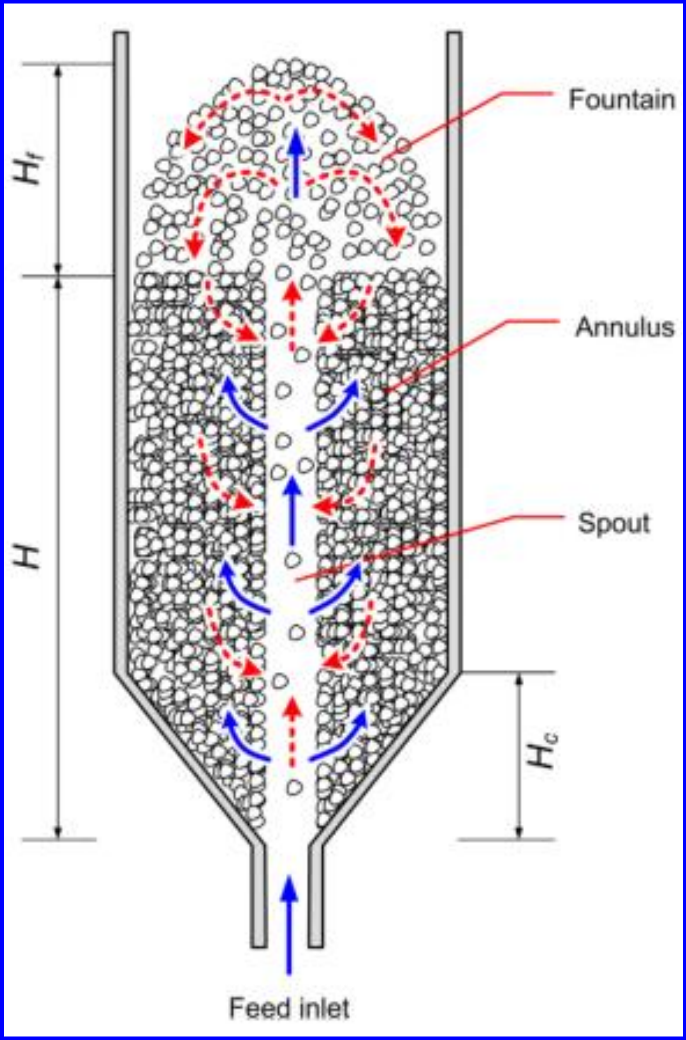
- **Introduction**
- **Physical model**
- **Numerical method**
- **Results and discussion**
- **Conclusions**

1. Introduction

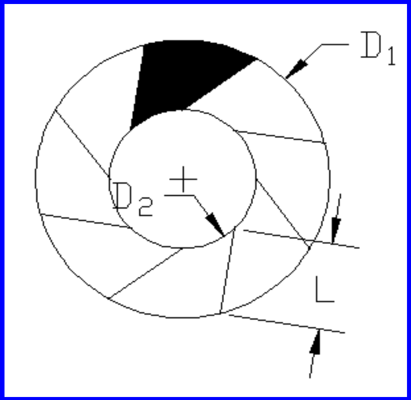
- The spouted bed technique has been used extensively in petro-chemical, chemical and nuclear engineering industries
- such as drying, nuclear fuel coating, granulation, gasification due to their high gas-solid contacting efficiency

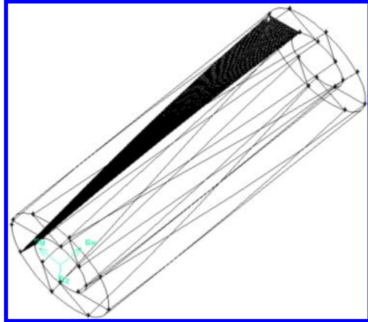
1. Introduction

- Cylindrical spouted beds are gas particle contactors in which the gas is introduced through a single nozzle at the center of a conical of flat base.
- A conventional spouted bed typically has three distinct regions: a central spout, a fountain region, an annulus region
- Disadvantage appears when the three regions formed in spouted bed, the radial mixing of gas and particles in central spout and annulus regions is not sufficient.



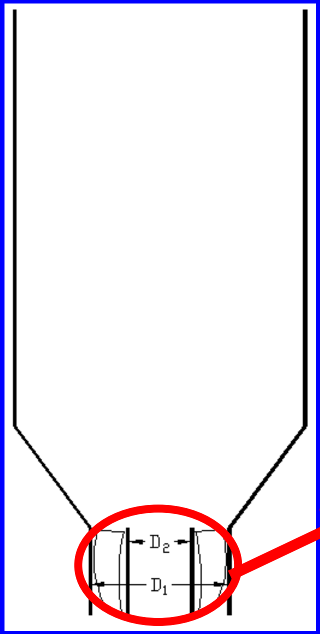
- **In order to make more effective use of cylindrical spouted beds in industrial applications, swirling flow technique is used to improve the radial mixing of gas and particles in the spouted bed**

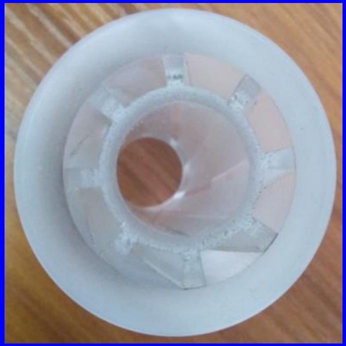




- **The aim of this study is to investigate the improvement of gas-solid mixing in the spouted bed under swirling flow effect**

Integral swirling blade nozzle (ISBN)





◆The main objective of this work is to investigate the improvement of gas-solid radial mixing in the spouted bed with an integral swirling blade nozzle (ISBN)

◆Three dimensional gas-solid two phase flow behaviors in a spouted bed under the swirling flow effects was numerically studied

◆ The flow behavior of gas and particles in a conventional spouted bed was compared to that in a spouted bed with ISBN and detailed analyses were carried out

2. Physical model

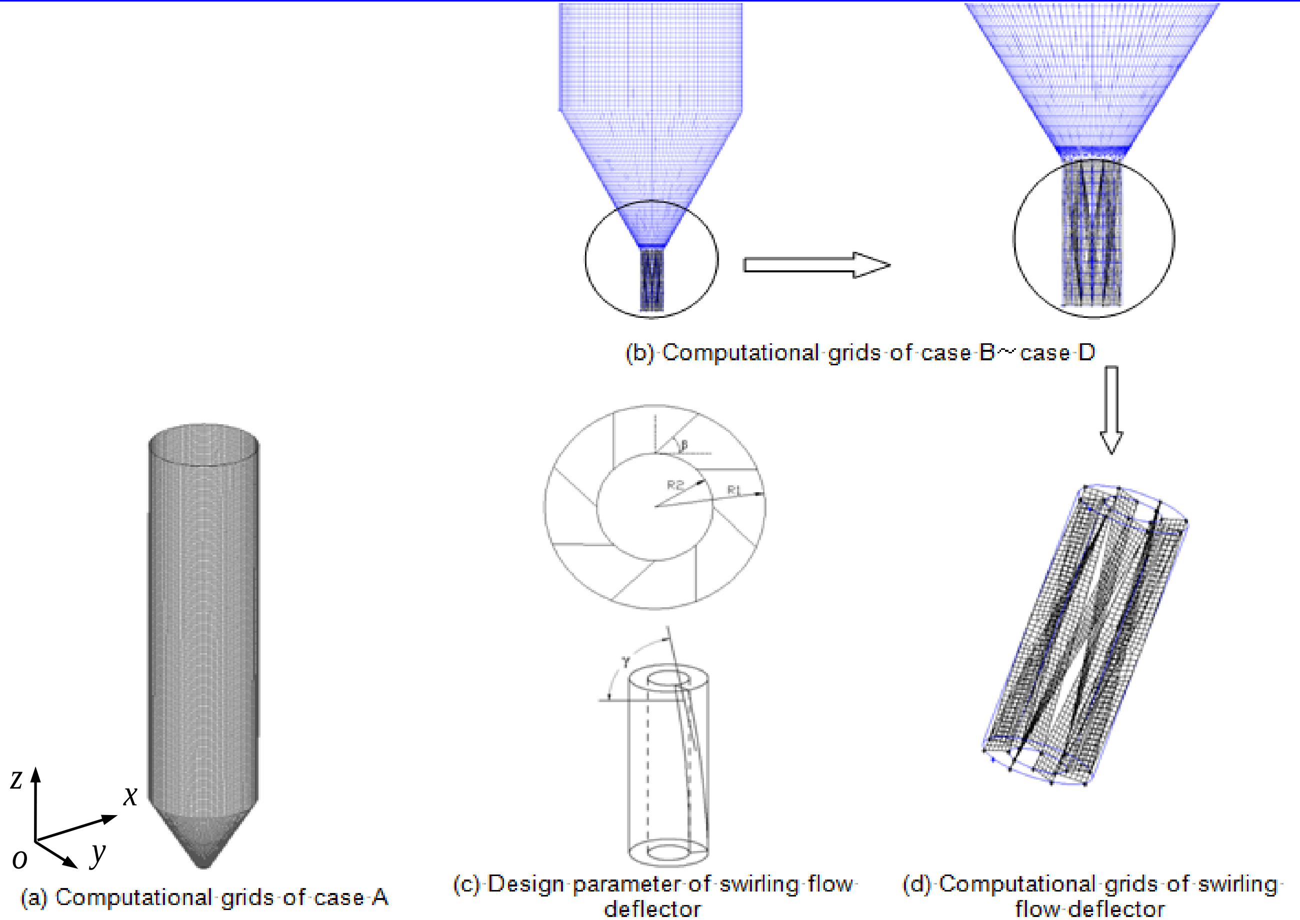


Fig. 2 Geometry, grids and design parameter of spouted bed with integral swirling blade nozzle

- **The number of grid is set as about 450 thousand and hybrid grid is used in the calculation domain**
- **The simulation model has been validated by literature Wu et al**

F. Wu et al, Numerical analysis of gas-solid flow in a novel spouted bed structure under the longitudinal vortex effects, Chemical Engineering Journal, 334 (2018) 2105–2114.

3. Numerical method

◆The set of governing equations is solved by **CFD code(Fluent 15)**. The phase-coupled PC-SIMPLE algorithm is used for the pressure-velocity coupling.

◆ A second-order upwind discretization scheme is used for momentum, turbulence kinetic energy and turbulence dissipation rate equations

◆Transient simulations are performed with a constant time step of 0.00001s with 30 iterations per time step. The convergence criterions for the solution are that all variable residuals such as velocity are less than 0.001

3. Numerical method

Table 1 Parameters and simulation settings in present work

Description	Experiment	Computer run
Particle density	2503 kg/m^3	Same
Gas density	1.225 kg/m^3	Same
Particle diameter	1.41 mm	Same
Maximum solid volume fraction	0.588	Same
Gas superficial velocity	0.54 m/s	Same
Particle-particle restitution coefficient	/	0.94
Diameter of the spout gas inlet	19 mm	Same
Diameter of the bed	152 mm	Same
Static bed depth	325 mm	Same
Length of swirl nozzle (L)	/	50 mm
Outer diameter of swirl nozzle (D_1)	/	19 mm
Inner diameter of swirl nozzle (D_2)	/	10 mm
Number of swirling blades	/	8
Width of swirling blades (L_i)	/	6.4 mm
Thickness of swirling blades (L_i)	/	0.5 mm
Inlet angle of swirl blade (β)	/	45°
Inclination angle of swirl blade (γ)	/	80°

3. Numerical method

Table 2 Boundary conditions for numerical simulation

Initial and boundary conditions	Parameter
Inlet	The turbulent velocity distribution, spouting inlet gas velocity U, ($m \cdot s^{-1}$), turbulence kinetic energy is k=2% No particles enter for solid phase
Outlet	Uniform velocity distribution for fluid phase No particle exits for solid phase
Wall	No slip for fluid phase Zero shear stress for solid phase

4. Results and discussion

4.1 Effect of swirling flow on particle concentrations

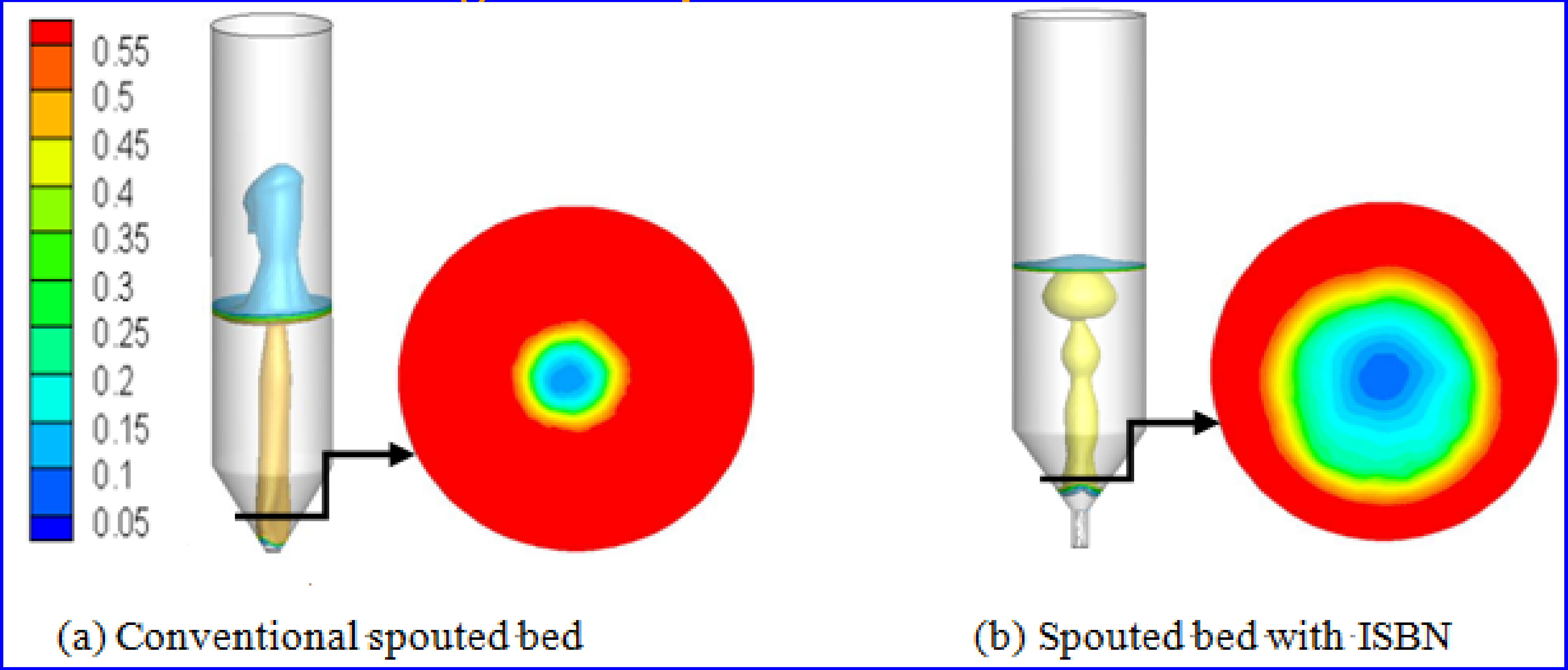
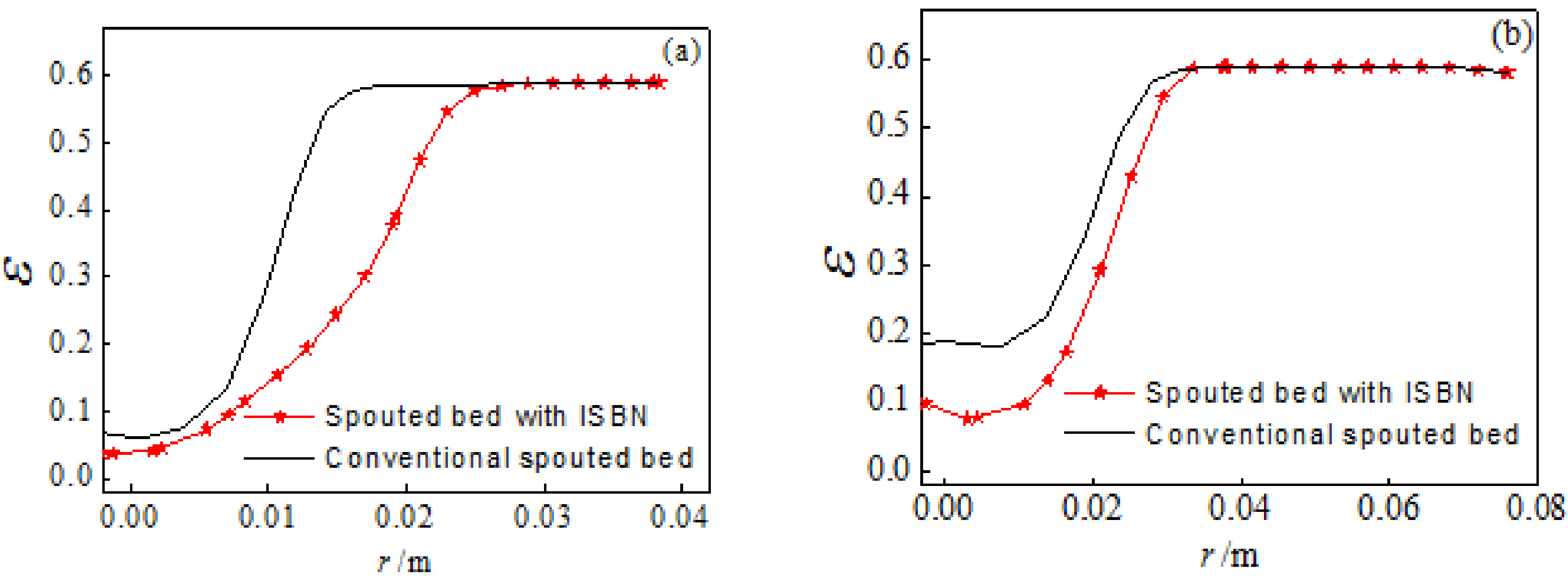


Fig.3 Particle volume fraction distribution in spouted bed (t=15 s)

➢ **It can be seen that swirl flow of gas phase in spouted bed can effectively eliminate the accumulation of particles in the cone region, and expand the influence range of the spout region at the low bed.**

4.1 Effect of swirling flow on particle concentrations



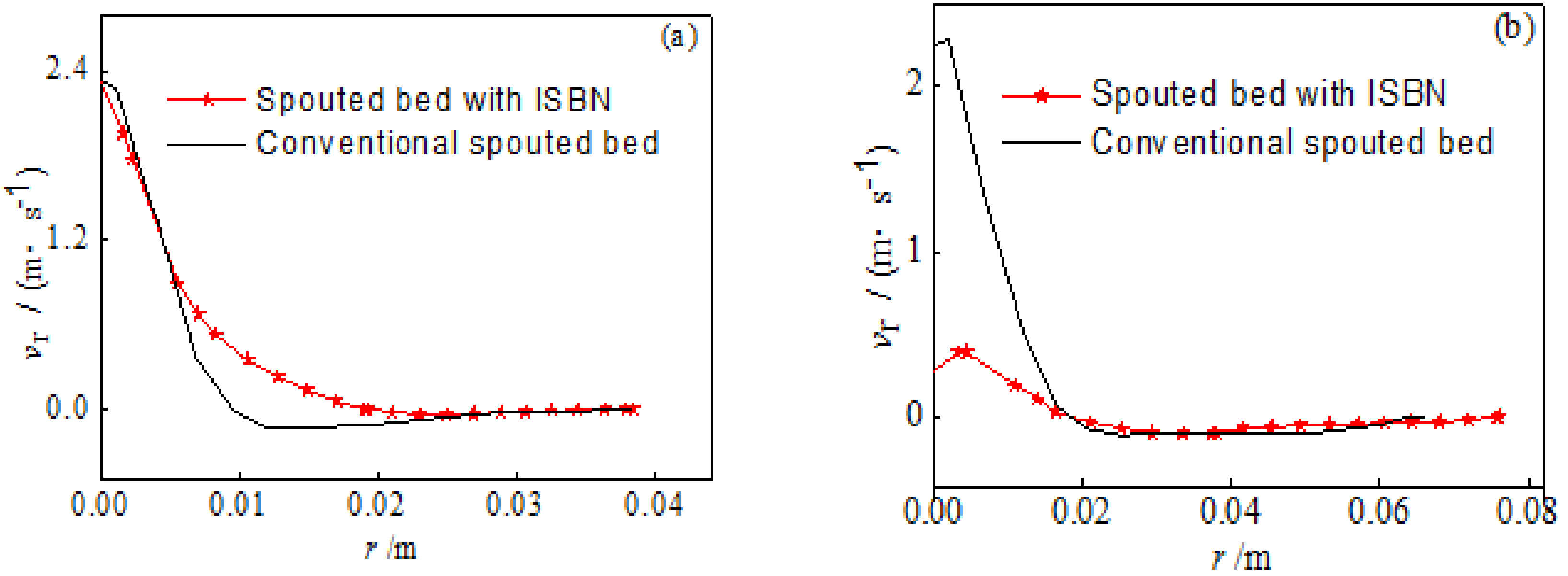
(a) z=0.05m (b) z=0.15m

Fig.4 Comparison of particle volume fraction in two kinds of spouted beds

- ➢It can be seen that the particle volume fraction near the annulus, especially near the **cone region,** decreases significantly because of the emergence of **radial swirling flow of gas phase** in spouted bed

- ➢ The maximum decrease of particle volume fraction near **cone region** is 72 %

4.2 Effect of swirling flow on flow of gas and particles

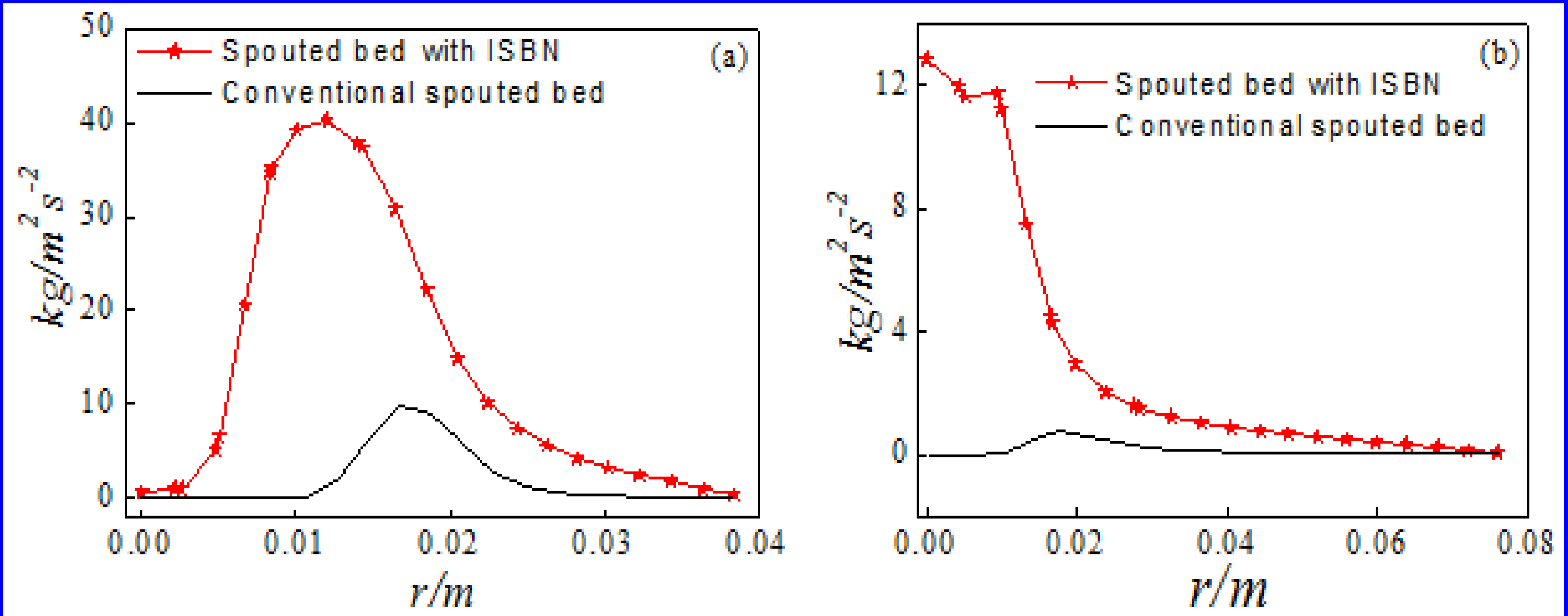


(a) z=0.05m (b) z=0.15m

Fig.5 Particles radial velocity distribution of two kinds of spouted beds

- **The radial velocity of particles is increased in both the cone and the spout region of spouted bed, and the strengthening degree of particles' radial velocity by ISBN decreases with the increase of the spouted bed height (z)**
- **It reveals that the swirling flow of gas leads to a large energy dissipation of gas phase flow in the cone region, which results in a sharp decrease of the swirling effect of gas on particles in the high bed**

4.2 Effect of swirling flow on flow of gas and particles

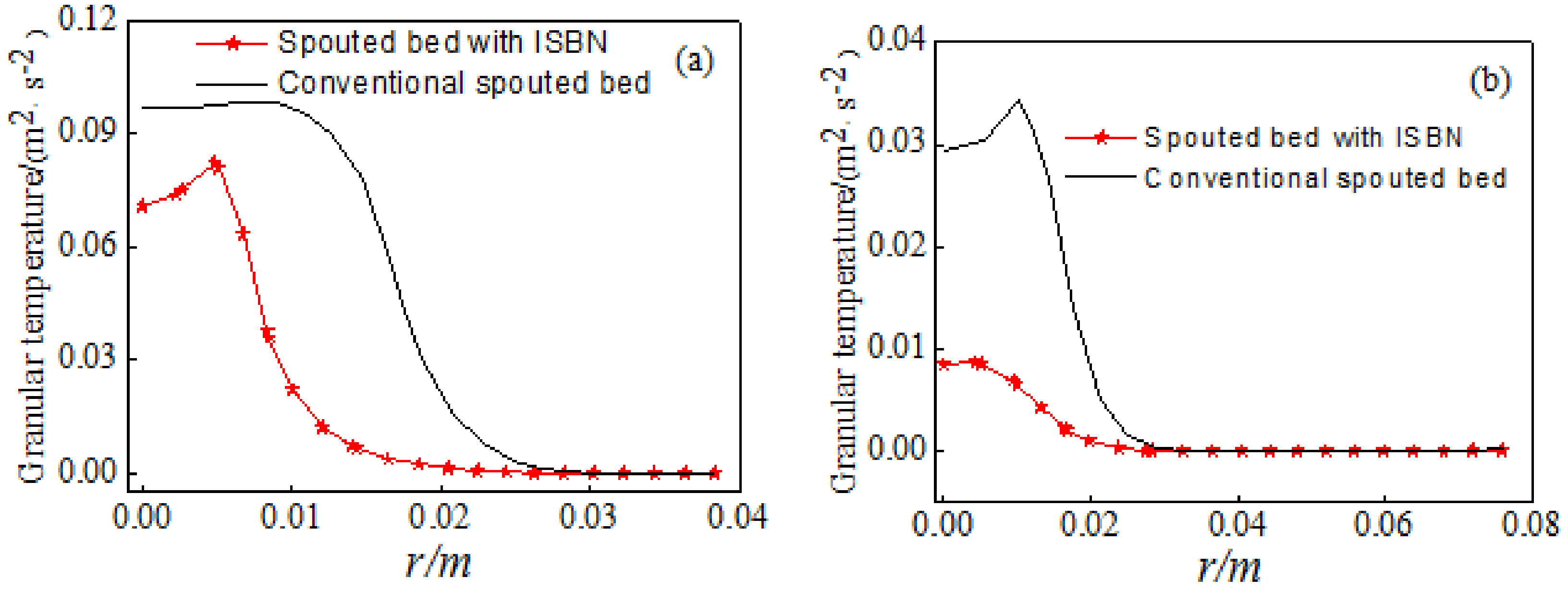


(a) z=0.05m (b) z=0.15m

Fig.6 Turbulent kinetic energy profile of gas phase distribution of two kinds of spouted beds in same height

➢ **It is seen that, compared with conventional spouted bed, the values and ranges of turbulent kinetic energy of gas phase in spouted bed can be enhanced significantly by ISBN, especially in the column cones region, wich is helpful in improving radial mixing between particle and gas phasses in spouted bed**

4.2 Effect of swirling flow on flow of gas and particles



(a) z=0.05m (b) z=0.15m

Fig.7 Granular temperature distribution of two kinds of spouted beds

- **The value of granular temperature decreases in spout region under the effect of ISBN**

4.2 Effect of swirling flow on flow of gas and particles

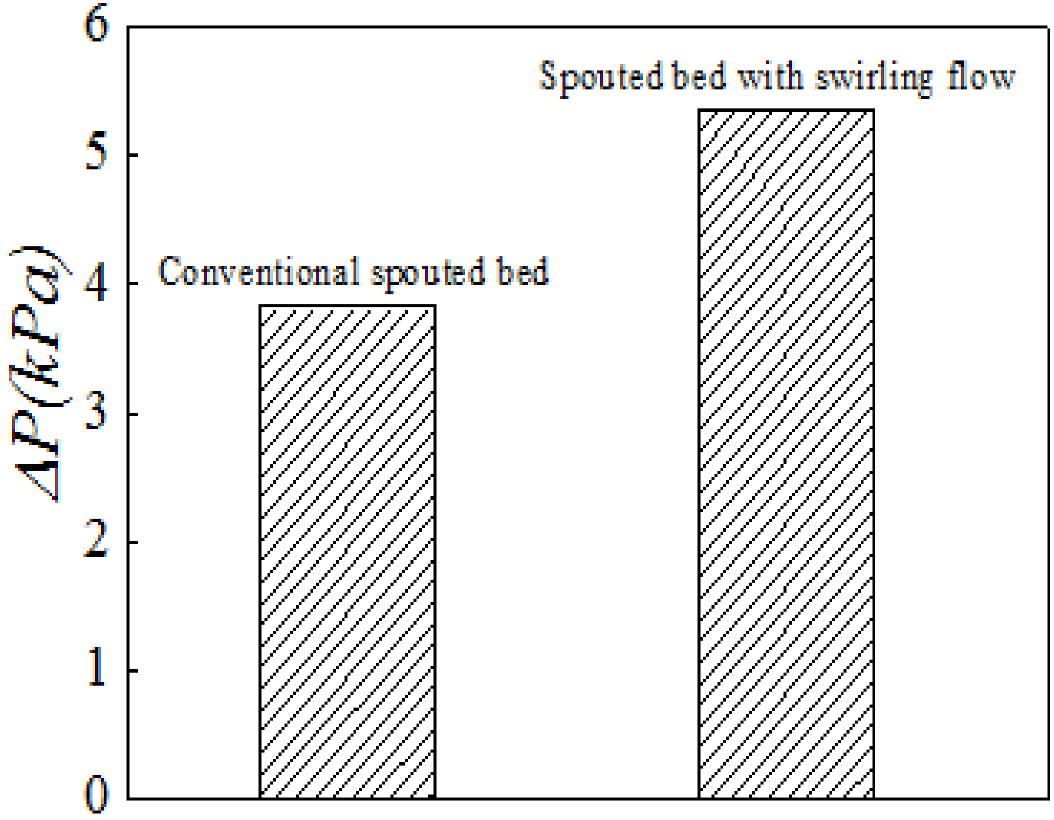


Fig.8 Comparison of pressure drop in two kinds of spouted beds

- **Pressure drop in spouted beds increases when adding the inner device of ISBN, which reveals that the dissipation of gas swirling flow can increase the pressure drop of spouted bed to a certain extent**

5. Conclusions

- An increasing energy dissipation due to swirling flow of gas leads to a decrease of the fountain height, and the value of particle volume fraction near the annulus region can be reduced by ISBN
- The radial velocity of particles and the turbulent kinetic energy of gas phase in spouted bed can be enhanced significantly by ISBN.
- The value of granular temperature decreases in spout region under the effect of ISBN, and Pressure drop in spouted beds increases when adding the inner device of ISBN

Acknowledgement

This work is supported by National Natural Science Foundation of China (Grant No. 21878245)

Thank you very much

for your attention