INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 41 (2016) 15859–15867

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

Numerical research on flow features of gas–solid flow of cylindrical particles

Jie Cai [a,b,*], Zhulin Yuan [a,**], Xiaobao Zhao [b], Zhongzhu Gu [b]

[a] Key Laboratory of Energy Thermal Conversion and Control of Ministry of Education, Southeast University, Nanjing 210096, PR China

[b] School of Energy and Mechanical Engineering, Nanjing Normal University, Nanjing 210042, PR China

ARTICLE INFO

Article history:
Received 26 March 2016
Accepted 27 April 2016
Available online 19 May 2016

Keywords:
Gas–solid flow
Cylindrical particles
Two-way coupling
Interaction between cylindrical particles
Rheological properties

ABSTRACT

The flow features of gas–solid flow of cylindrical particles are essential. In the present work, a three-dimensional two-way coupling model was established for the gas–solid flow of cylindrical particles. Discrete Element Method (DEM), rigid dynamics and RNG $\kappa - \varepsilon$ model were applied. Meanwhile, the force and motion model was established based on DEM and rigid dynamics, respectively. The two-way coupling correlation between cylindrical particles and turbulent flow was considered, which was established based on the correlation between Lagrangian time scales and $\kappa - \varepsilon$ model. The interaction between cylindrical particles was taken into account using the rigid dynamics and the modified Nanbu method. The model was verified by a cold-state fluidization experiment of gas–solid flow of cylindrical particles in a riser. In addition, some rheological properties of gas–solid two-phase turbulent flow such as pressure distribution, velocity distribution and turbulent kinetics along the axis of the riser were investigated using the model.

© 2016 Hydrogen Energy Publications LLC. Published by Elsevier Ltd. All rights reserved.

Introduction

The gas–solid flow of cylindrical particles is widely used in industries such as direct combustion of biomass straws, molding and drying of cylindrical pills, and molding and machining of composite materials of short fibers.

One method on gas–solid flow of cylindrical particles is slender-body theory, which was initiated by Burgers and developed by Tuck, Tillett, Batchelor, Cox, et al. [1–6]. Slender-body theory analyzes the force of a cylindrical particle in a flow field using a set of equations deduced by Batchelor [5]. But for slender-body theory, there is an inherent fault on handling the coupling correlation between cylindrical particles and flow field.

DEM was firstly used by Tsuji in numerical study of gas–solid flow of spherical particles [7]. By far it has advanced to gas–solid flow of irregularly-shaped particles. DEM approximatively treats a irregularly-shaped particle as the geometric assembling of finite discrete elements. A cylindrical particle is the assembling of finite discrete elements along its axis.

Fan et al. simulated a turbulent solid–liquid flow of cylindrical particles in a stirred tank with standard Rushton turbines using the improved inner-outer iterative method and standard $\kappa - \varepsilon$ model [8]. Zhong et al. simulated a cylinder-

* Corresponding author. Key Laboratory of Energy Thermal Conversion and Control of Ministry of Education, Southeast University, Nanjing 210096, PR China.
** Corresponding author.
E-mail addresses: caijie@njnu.edu.cn (J. Cai), zlyuan@seu.edu.cn (Z. Yuan).

http://dx.doi.org/10.1016/j.ijhydene.2016.04.183

0360-3199/© 2016 Hydrogen Energy Publications LLC. Published by Elsevier Ltd. All rights reserved.

Nomenclature

A_{axis}	height position, m
υ_g	viscosity, s/m^2
$\boldsymbol{v}_s$	velocity of cylindrical particle, m/s
ω_s	angular velocity of cylindrical particle, rad/s
ρ_s	density of cylindrical particle, kg/m^3
dt	time step, s
H_{riser}	height of riser, m
W_{riser}	width of riser, m
Θ	notation angle, °
Ψ	precession angle, °
Φ	spin angle, °
$\mathbf{M}_f$	torque acting on the centroid of a cylindrical particle in the fixed reference frame, N·m
$\boldsymbol{v}$ (s_i)	the velocity of discrete element i of a cylindrical particle, m/s
J	the rotary inertia tensor of a cylindrical particle, mr^2
ρ_g	Density of gas, kg/m^3
$\boldsymbol{v}_g$	Velocity of flow, m/s
L_r	slender ratio
ϕ_g	Volume fraction of turbulent flow, %
p	the pressure of flow field, Pa
μ	the dynamic viscosity of fluid, Pa·s
μ_t	the turbulent viscosity, Pa·s
$\boldsymbol{f}_{sg}$	interaction force between phases, N
K_{sg}	the momentum exchange coefficient, kg/s
L_t	the length scale of turbulence vortex, m
ϕ_s	volume fraction of solid particles, %
F(s)	the force acting on unit length on the interval [−1, 1], N/m
$F_i(s_i)$	the component of force acting on discrete element i, N
$\mathbf{M}_b$	the torque acting on the centroid of the cylindrical particle in the body axes, N·m

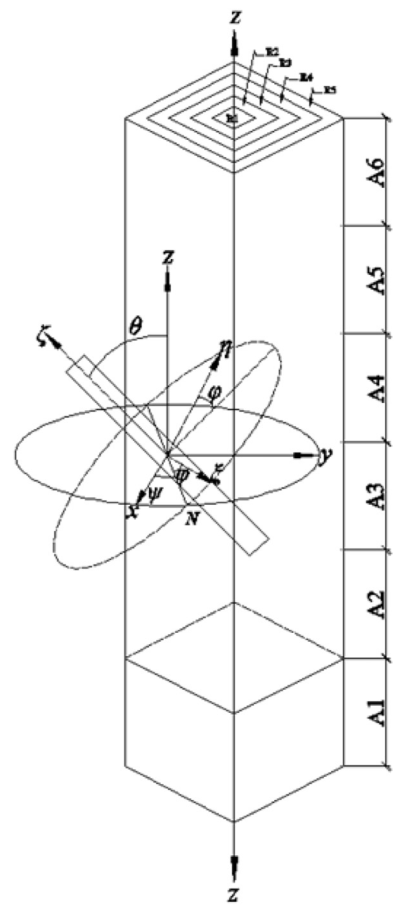

Fig. 1 – Nutation angle between the body axes and the fixed reference frame.

shaped particle flow in a gas–solid fluidized bed based on DEM [9]. But DEM can not in detail track the rotation of a cylinder-shaped particle. Time-averaged N–S model has been widely used in diffusion study of spherical particles in a turbulent flow in recent years, but seldom in that of irregularly-shaped particles [10,11].

Rigid dynamics studies the movement of a rigid-body under the external force. As shown in Fig. 1, rigid dynamics consists of two reference frames, one is the body axes of which 3 axes are ξ-axis, η-axis and ζ-axis, and the other is the fixed reference frame of which 3 axes are x-axis, y-axis and z-axis. A rigid-body is fixed in the body axes, and its motion attitude is tracked by 3 Euler angles, precession angle (ψ), nutation angle (θ) and spin angle (φ). If a cylindrical particle's centroid overlaps the origin of the body axes and its axis is along the ζ-axis, its nutation angle (θ) is just the angle between the axis of the cylindrical particle and the z-axis of the riser. Yin et al. proposed a model of motion of cylindrical particles in a non-uniform flow based on rigid dynamics [12]. Renner et al. presented a model of tracing the rotation of a cylindrical particle [13]. Kodam et al. established a model of cylindrical object contact detection based on rigid dynamics [14]. Cai et al. proposed a three-dimensional one-way coupling model of gas–solid flow of cylindrical particles based on standard $\kappa - \varepsilon$ model, rigid dynamics and DEM [15].

As shown above, by far there is no efficient two-way coupling model of gas–solid flow of cylindrical particles. But Hsu et al. indicated that even though for dilute flow, the existence of cylindrical particles would affect the flow field evidently [16].

In this paper, a three-dimensional two-way coupling model of gas–solid flow of cylindrical particles was proposed. First, the force and motion modeling was established according to DEM and the rigid dynamics respectively. The two-way coupling correlation was taken into account between the cylindrical particles and turbulent flow. Meanwhile, the coupling correlation between Lagrangian time scales and $\kappa - \varepsilon$ model was put into use. The interaction between cylindrical particles was based on the rigid impact dynamics and the modified Nanbu method. The model was verified by a cold-state experiment of gas–solid flow of cylindrical particles. In the end, some rheological properties of gas–solid two-phase turbulent flow such as pressure distribution, velocity distribution, and turbulent kinetics along the axis of the riser were studied using this model.

Download English Version:

https://daneshyari.com/en/article/1270314

Download Persian Version:

https://daneshyari.com/article/1270314

Daneshyari.com