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Numerical study on heat transfer in a conical fluidized bed combustor considering particle elasticity

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ABSTRACT

Numerical simulations of conical fluidized bed combustors were carried out to estimate the effect of collision elasticity, parameterized by the particle-to-particle and particle-to-wall coefficients of restitution, upon the combustor's hydrodynamics and heat transfer. The Eulerian–Eulerian two-fluid model was used to simulate the hydrodynamics and heat transfer in the combustor, and solid phase properties were calculated by applying the kinetic theory of granular flow (KTGF). Sand of size 560 μm was used as a bed material and air was used as a fluidized gas, introduced at the velocity of 3 m/s at the combustor inlet. In the simulations, increasing the particle-to-particle restitution coefficient increased the bed pressure drop and caused significant changes to other hydrodynamics parameters. Oppositely increasing the particle-to-wall coefficient of restitution decreased the bed pressure drop. Changes to either the coefficients studied had little effect on heat transfer.

1. Introduction

Traditional energy sources based on oil, coal, and natural gas have proven to be highly effective in driving of economic progress, but at the same time damaging to the environment and to human health. The potential of renewable energy sources is enormous as they can in principle meet the world's energy demand many times over. There are many renewable energy sources such as biomass, solar, wind, hydropower, and geothermal. Biomass can be converted into three main products: two related to energy (heat generation and transportation fuels) and chemical feedstocks. Biomass such as forest, agricultural and organic processing residues can be converted to commercial products via either biological or thermochemical processes. Among thermo-chemical conversion techniques, four process options are available: combustion, pyrolysis, gasification and liquefaction [1–3]. Fluidized bed combustion technology is known to be the most efficient and environmentally friendly technology for conversion of energy from practically all solid fuels including biomass. The gas solid fluidized bed reactor has been used extensively because of its capability to provide effective mixing and highly efficient transport processes. Understanding the hydrodynamics and heat transfer of these reactors is essential for designing them properly and for choosing the correct operating parameters that will allow efficient operation. Use of the conical fluidized bed combustor (FBC) seems to be the most suitable fluidized bed combustion technique for testing new bed materials. The conical fluidized bed has been applied in various industrial processes such as biological treatment of waste water, biofilm immobilization reactions, incineration of waste materials, coating of nuclear fuel particles, coal liquefaction and gasification, catalytic polymerization, and fluidization of cohesive powder [2]. Compared with a columnar FBC, the conical FBC exhibit some apparent benefits, such as its relatively small amount of bed material, shorter combustor start up time, and lower pressure drop across the fluidized bed; all of these reduce operating costs. In the meantime, as with any fluidized bed combustion system of a cylindrical or prismatic shape, the conical FBC ensures high combustion efficiency and acceptable levels of gaseous emissions when burning various biomasses as found by [4–6].

Some correlations are used in modeling of hydrodynamics and heat transfer in fluidizing bed. However, they remain to be empirical or semi-empirical. As a consequence, the model and its

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Nomenclature

C_D	drag coefficient
C_P	specific heat, J/(kg K)
d_s	diameter of the sand particles, μm
e_s	particle to particle coefficient of restitution
e_w	particle to wall coefficient of restitution
H	enthalpy, J
h	heat transfer coefficient, W/(m^2 K)
h_s	static (minimum) bed height, m
I	identity tensor
k	thermal conductivity, W/(m K)
q	diffusive flux
Pr	Prandtl number
g	gravitational acceleration, m/s^2
g_o	radial distribution function
Nu	Nusselt number
$\boldsymbol{n}$	unit normal vector
p	pressure, Pa
Re	Reynolds number
t	time, s
U	inlet gas as velocity, m/s
$\vec{v}$	velocity vector
Z	height above air inlet, m

Greek symbols

ε	volume fraction
β	interphase exchange coefficient
μ	viscosity
Θ	granular temperature, m^2/s^2
ρ	density, kg/m^3
$\bar{\bar{\tau}}$	stress tensor
φ	exchange of energy between phases
$\emptyset$	specularity coefficient

Subscripts

avg	average
col	collision
g	gas
kin	kinetic
max	maximum
m	mixture
s	solid
pen	penetration

parameters must be validated against experimental measurements obtained for similar scales and configurations. Numerical modeling techniques such as computational fluid dynamics (CFD) are important tools to understand hydrodynamics and heat transfer in fluidized beds. Despite the modeling challenges, there has been continual development in the application of CFD to model fluidized bed hydrodynamics and heat transfer, owing to its many advantages including design optimization and scale-up of such systems. Increases in computing capabilities have allowed non-invasive simulations of complex phenomena in realistic geometries that otherwise requires experiments under difficult measurement conditions [7].

Restitution coefficients characterize the amount of the energy dissipated due to inelastic collisions. Such dissipation can affect the granular conductivity, viscosity and granular temperature. By convention, coefficients of restitution range from zero for fully inelastic collisions to one for fully elastic collisions. They have been utilized to account for energy loss due to collision of particles, which is not considered in the classical kinetic theory [7]. The restitution coefficient charactering the interaction between solid particles and a wall can be used to account for the dissipation of the solid particle's fluctuating kinetic energy as they collide with the wall. The value of restitution coefficient between solid particles and a wall varies from zero to one. A value of zero would means that a significant amount of the solid's fluctuating kinetic energy is dissipated, whereas a value of one would means that no solid fluctuating kinetic energy is dissipated [8].

From literatures, it is found that the research related to the study of heat transfer in a conical FBC is very limited comparing to those in other types of FBC. Therefore, in this study, both hydrodynamics and heat transfer in a conical FBC were simulated using the Eulerian–Eulerian approach with the. To evaluate the role of the elasticity of particle collision, different values of the coefficients of restitutions were used in the simulations. The influence of particle-to-particle restitution coefficients (e_s) and particle-to-wall restitution coefficients (e_w) upon hydrodynamics and the bed to wall heat transfer were studied at the superficial air velocity of 3 m/s which lies between the minimum fluidizing velocity and the terminal velocity in the fluidizing bed combustor.

2. Numerical simulations

2.1. Model setup

The simulations were implemented using the two-dimensional conical fluidized bed as illustrated schematically in Fig. 1. The combustor consisted of two parts, a conical part of inlet diameter 0.2 m, outlet diameter 0.4 m and height 0.4 m, and a cylindrical part 0.4 m in both diameter and height. Sand of average size 560 μm was used as a bed material, and air was used as fluidized gas. Sand was chosen because it was cheap, easy to find and has a good thermal properties. Air inlet velocity at the bottom of the cone part was uniform at 3 m/s. Air was introduced at the inlet at the temperature of 450 K while the initial temperature of both wall and sand

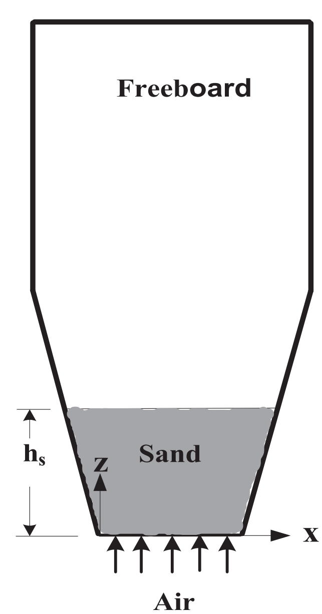

Fig. 1. Schematic of a conical fluidized bed combustor.