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Heat transfer process in gas–solid fluidized bed combustors: A review

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ABSTRACT

In recent decades, more emphasis has been given to produce clean energy from wastes and other renewable sources due to the rise in crude oil price and greenhouse gas emission. Fluidized bed combustors (FBC) are becoming the core of 'clean wastes technology' for power production, owing to their efficient and clean burning of coal and other solid fuels including biomass and other wastes, in an environment friendly manner with reduced pollutants. It is important to understand the mechanism of heat transfer and the effect of operating parameters on the heat transfer process for proper design of fluidized-bed reactors and for control the temperature at desired value. The scope of this paper is reviewing the heat transfer process in different types of fluidized bed combustors as well as the important operating conditions affecting the process. This paper covers both experimental and numerical studies related to the heat transfer process in different types of fluidized bed combustors.

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Contents

1. Introduction

Nowadays, energy is considered as a main key in discussions of sustainable development. Sustainable development requires a sustainable supply of clean and affordable renewable energy sources those do not cause negative societal impacts. Energy sources such as solar radiation, wind, waves and tides are generally considered as renewable and sustainable over the relatively long term. Wastes and biomass fuels are usually viewed as sustainable energy sources [1]. A variety of waste sources like urban, agriculture, industrial sectors, vegetable markets, etc., generate huge quantities of solid wastes containing a sizeable proportion of biodegradable-organic matter [2]. Waste-to-energy technologies

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Nomenclature

A	area
d_i	internal diameter
d_m	the arithmetic mean diameter of two sieve aperture size, mm
d_o	outer diameter
d_p	particle diameter
g	gravitational acceleration
H	height between two pressure taps, horizontal direction
h	heat transfer coefficient
I	electrical current
L	surface length
P	pressure
Q	total heat
T	temperature
U	superficial velocity
V	vertical direction, voltage
x	mass fraction

Greek symbols

δ	fraction of time, Eq. (4)
ε	volume fraction
ρ	density

Subscripts

b	bed
f	fluid
g	gas
mf	minimum fluidizing velocity
p	particle
r	radiation
s	surface
sus	suspension
t	tube
V	vertical

consist of various methods for extracting energy from waste materials. These methods include thermo-chemical types such as combustion, gasification, and pyrolysis. Biological methods like digestion and fermentation are also used in the converting process [3].

Fluidized bed combustion (FBC) is well known as an effective technology for burning both conventional and renewable solid fuel. Fluidized bed combustors have the ability to burn a wide variety of solid fuels with low pollutant emissions, high combustion efficiency, having smaller combustor cross section, fewer feed points, good turndown and load capability. The flexibility of the fuels, the high combustion efficiency, and the low environmental impact are major advantages of FBC [4]. There are two main types of fluidized bed combustor, bubbling fluidized bed combustor (BFBC) and circulating fluidized bed combustor (CFBC). Fluidized bed combustors are environmental friendly applications due to in-bed sulfur capture, and relatively low NO_x emissions, which can be directly reflected in better combustion conditions. Operating either in the fast fluidization regime or in the transported bed regime, CFBCs have many advantages over the conventional bubbling or turbulent fluidized bed combustors, such as high gas–solid contact efficiency, high gas and solid throughput, and reduced axial dispersion of both gas and solid phases [5].

In many fluidized bed applications it is necessary to add or extract heat in order to maintain the operating temperature at a desired value. The heat transfer in fluidized beds has been an important part of many investigations in the past. The heat transfer in a fluidized bed is a wide topic. It usually includes several sub-processes: heat transfer between solid particles and fluidizing medium, which includes heat transfer between the gas and solid particles in emulsion phase and heat transfer between bubbles and solid particles; heat transfer between the bed and the surfaces (walls or immersed surfaces); and heat transfer inside the solid particles [6,7]. Computational fluid dynamic models and other numerical models of fluidized bed combustors encompass a great deal of simplifications from experimental setups and bed material characteristics, especially when the experiments deal with irregular particles such as biomass particles [8].

This review aims to present a brief overview on the heat transfer process involved in fluidized bed combustor, and the important operating parameters affecting on the heat transfer process. Moreover, the important numerical models available used to predict the heat transfer process in different types of fluidized bed combustors will be mentioned.

2. Heat transfer process in gas–solid fluidized bed combustors

2.1. Experimental studies

2.1.1. Heat transfer process in BFBC

Gas–solid fluidized beds offer a number of advantages such as good solids mixing and high heat and mass transfer rates which make them attractive for a number of industrial processes. These reactors are expected to play an important role in the area of sustainable energy technology especially with renewed interest in wastes conversion to gaseous and liquid fuels via combustion, gasification or pyrolysis. Efficient operation of these reactors would depend on a good understanding of local hydrodynamics and heat transfer [9].

Bubbling fluidized beds operate at gas superficial velocity that is moderately above the minimum fluidization velocity leading to formation of bubbles. A Bubbling fluidized bed essentially consists of a thin phase of bubbles and a dense phase of particles [10]. Bubbling fluidized beds are widely used in the coal and wastes combustion in the power generation, mineral and chemical processing industries. Bubbling fluidized bed combustion continues to emerge as an attractive technology that offers certain advantages with respect to high heat and mass transfer, low pollution gas emissions, uniform temperature distributions and scale-up potential over other combustion systems [11,12]. Finned tubes can be used in bubbling fluidized bed combustor to advantage for creating steam for electrical power generation. The rate of heat transfer is high hence heat exchangers within fluidized beds require relatively small surface area comparing with surfaces without fins. However, the heat transfer coefficient decreases with increasing the number of fins used [13–15].

In a number of fluidized bed processes in BFBC, particles properties change with time as a result of coating on their surfaces. For example, during biomass combustion ash forming elements may form coatings on the bed material particles, and as their melting temperatures are approached, particles agglomerate. The heat transfer coefficient may then change as the particle surfaces are coated, possibly leading to decreased heat transfer rate [16]. As a consequence, the coated particles showed lower heat transfer coefficients than uncoated ones [16,17].

Problems pertinent to bubbling fluidized beds such as gas bypassing, poor fluidization quality of fine particles and elutriation of the bed material have been well-documented. In order to overcome these limitations and improve their intrinsic performance,

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