Applied Thermal Engineering 91 (2015) 515–524

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Research paper

Experimental studies of direct contact heat transfer in a slurry bubble column at high gas temperature of a helium–water–alumina system

M.W. Abdulrahman

Faculty of Engineering and Applied Science, UOIT, Oshawa, ON, Canada L1H 7K4

HIGHLIGHTS

- Direct contact heat transfer is investigated experimentally in a slurry bubble column.
- Empirical equation of direct contact heat transfer Nusselt number is formulated.
- The volumetric heat transfer coefficient increases with superficial gas velocity.
- The volumetric heat transfer coefficient decreases with the static liquid height.
- The volumetric heat transfer coefficient decreases with the solid concentration.

ARTICLE INFO

Article history:
Received 17 July 2015
Accepted 18 August 2015
Available online 6 September 2015

Keywords:
Slurry bubble columns
Direct contact heat transfer
Volumetric heat transfer coefficient
Helium
Solid concentration

ABSTRACT

In this paper, the direct contact heat transfer is investigated experimentally for a helium gas at 90 °C injected through a slurry of water at 22 °C and alumina solid particles in a slurry bubble column reactor. This work examines the effects of superficial gas velocity, static liquid height, solid particles concentration and solid particle size, on the volumetric heat transfer coefficient and slurry temperature of the slurry bubble column reactor. These effects are formulated in forms of empirical equations. From the experimental work, it is found that the volumetric heat transfer coefficient and the slurry temperature increase by increasing the superficial gas velocity with a higher rate of increase at lower superficial gas velocity. In addition, the volumetric heat transfer coefficient and the slurry temperature decrease by increasing the static liquid height and/or the solid concentration at any given superficial gas velocity. Furthermore, it is found that the rate of decrease of the volumetric heat transfer coefficient with the solid concentration is approximately the same for different superficial gas velocities, and the decrease of the slurry temperature with the solid concentration is negligible.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

Slurry bubble column reactors (SBCRs) belong to the general class of multiphase reactors. In these reactors, a gas is dispersed through a sparger and bubbles through a slurry in a vertical cylindrical column. SBCRs are becoming more competitive due to their inherent advantages and are used in numerous industrial applications. The advantages are; better temperature control; lower pressure drop; and excellent heat transfer rates per unit volume of the reactor. Additional advantages include; higher values of effective interfacial areas; little maintenance required due to simple construction; and relatively cheap to construct and operate and require less floor space. Although SBCRs are simple in construction, the scale up analysis of such reactors is complex, because scale-up problems basically stem from the scale-dependency of the fluid dynamic phenomena and heat transfer properties. Most of the previous studies on heat transfer measurements in slurry bubble columns concerned the heat transfer of the wall-to-bed [1] and object-to-bed [2].

Direct-contact heat transfer in an SBCR is based on heat transfer between a primary flow (liquid) and a dispersed phase (bubbles). A direct-contact heat exchanger provides cost-effective heat transfer and has the capacity to operate at relatively smaller temperature differences. The main idea underlying this process is to exploit the large interfacial area developed by the dispersed phase, while the absence of a solid wall between the two phases optimizes heat transfer without increasing pressure losses.

Direct-contact heat exchangers were first investigated by Wikle et al. [3] and have since been the topic of numerous works. They

E-mail address: mo-wassef@hotmail.com.

http://dx.doi.org/10.1016/j.applthermaleng.2015.08.050
1359-4311/© 2015 Elsevier Ltd. All rights reserved.

have been recommended for water desalination [4], crystallization [5], energy recovery from industrial waste [6], thermal energy storage [5] and ice-slurry production [7]. Direct-contact gas–liquid heat transfer, in which a gas is injected into a stagnant pool of liquid, involves a complex phenomenon of bubble formation and gas motion through the liquid layer. Ghazi [8] presented results of experiments on direct-contact heat transfer between stagnant water maintained at a constant temperature and air bubbling through the water. He found a correlation for the Nusselt number and the overall heat transfer between the water and air. Boulama et al. [9] studied heat and mass transfer between gas and liquid streams in direct contact within a duct. The study was based on the assumptions of constant heat and mass transfer coefficients and the existence of a thin saturated layer between the two streams. They investigated the effects of different entry conditions and adiabatic or non-adiabatic walls on the performance of evaporators and condensers with parallel or counter-flow arrangements.

Jassim [10] carried out an experimental and theoretical investigation of three phase direct contact heat transfer by evaporation of refrigerant drops in an immiscible liquid. Refrigerant R12 and R134a were used for the dispersed phase, while water and brine were the immiscible continuous phase. A numerical analysis has been presented to predict the temperature distribution throughout the circular test column radially and axially. Experimental measurements of the temperature distribution have been compared with the numerical result. A comparison between the experimental and theoretical results has shown acceptable agreement and applicability of the derived equations.

Mahood [11] presented a semi-analytical approach to study the transient heat transfer of a single volatile drop evaporation in an immiscible liquid with bubble nucleation inside the drop. The solution was based on the energy equation included both convection and conduction heat transfer from the continuous liquid to the bubble with the concentric spheres model. The radius of the growing bubble had been found and the effects of Prandtl number, Stanton number, initial radius, initial velocity and ratio of density have been examined. The Nusselt number has been derived as a function to the drop velocity. His results have been compared well with the available data.

Sheoran et al. [12] proposed a direct contact heat exchanger for high temperature thermal storage for solar power generating plants. They used high pressure gas as the working fluid in the solar plant. The gas was circulated through solar receivers and was then bubbled through an immiscible molten salt solution, which acted as the thermal storage media. High heat transfer rates could be achieved between the gas and the molten salt. A higher heat exchange rate between the working fluid of the solar power system and the thermal storage media was of paramount importance to maximize the thermal efficiency of the power plant. They studied in details a preliminary computer model developed for describing the fluid and heat transfer characteristic of gas–molten salt storage systems.

Blanco et al. [13] described the study and implementation of an experimental solution that optimizes the emptying of CO_2 cylinders in a power plant, thereby making a considerable saving because of their better exploitation. Their method that involved the use of spraying water at ambient temperature for exposing the cylinders of CO_2 to natural convection, has been proven to be a suitable procedure for optimizing resources.

Jiang et al. [14] conducted experimental study to investigate the effect of packing on performance of direct contact evaporative heat transfer for n-pentane and water operated in a bubble column with concurrent upward flow. The optimal column height and volumetric heat transfer coefficient with and without Dixon rings were examined and compared under the conditions of different flow velocity ratios of n-pentane to water, temperature differences between water and n-pentane and distributor apertures. It was found that packing enables optimal column height to decrease significantly. Besides, back mixing observed in the experiment was demonstrated, and its significant influence on evaporative heat transfer performance was also analyzed.

It can be concluded from the direct contact heat transfer literature survey, that there is no general model that can be used to predict the volumetric heat transfer coefficient. Because of the direct dependence of heat transfer on hydrodynamic studies and because of the complexity of the bubble behavior, empirical equations from experimental studies are important to describe the direct contact heat transfer. The basic parameters that can affect the heat transfer rates in the SBCR, are the design parameters (e.g., reactor geometry, sparger design, etc.) and operating variables (e.g., reactor pressure and temperature, gas and slurry flow rates, solid particles size and loading, etc.) along with phase properties and kinetics. These, in turn, impact the reactor performance, operation, and its design and scale-up. However, due to the complex interaction among the various phases, the direct contact heat transfer in the SBCR has not yet been well understood.

In spite of the different systems and parameters that were investigated in the studies of direct contact heat transfer, most of these studies, as well as empirical correlations for predicting volumetric heat transfer coefficient, were limited to air/water. In the literature, no work has been reported regarding detailed studies of direct contact heat transfer in SBCR with high temperature helium gas. Therefore, this lack motivates the present work, which seeks to fill this gap by investigating experimentally the SBCR using alumina–water slurry at 22 °C and helium gas at 90 °C. The importance of using helium gas lies in being a perfect fluid for transferring heat because of its high thermal conductivity and specific heat as well as being inert and safe to use. The high value of the helium gas thermal conductivity (which is about six times that of the air) is especially important, because it will help reduce the gas side thermal resistance in the direct contact heat transfer. It is well known that the gas density plays an important role in the heat transfer of bubble columns. Since the density of the helium gas at 90 °C is less than that of air at ambient temperature by more than 9 times, the use of previous literature results and correlations for predicting volumetric heat transfer coefficient of a high temperature helium gas in SBCR can be risky.

The other point that distinguishes the experimental work of this paper from previously published work is that, the previous empirical equations of volumetric heat transfer coefficient were mainly related to the thermo physical properties of the gas and slurry. In this paper, the empirical equation of the volumetric heat transfer coefficient is formulated in terms of the bubble column design parameters only, such as the reactor dimensions, superficial gas velocity, and solid concentration.

2. Experimental work

2.1. Experimental setup

The schematic of the SBCR setup is illustrated in Fig. 1. All experiments were conducted in a stainless steel column with 21.6 cm inner diameter and 91.5 cm height. The diameter of the reactor was chosen to be larger than 15 cm to minimize its effect on hydrodynamic studies. The reactor consisted of four sections provided with flanges for easy construction and flexibility and also for easy installation and removal for cleaning purposes. The reactor was provided with two Jerguson site-windows, located in the middle of the second section from the bottom of the reactor. These windows were placed in opposite directions to allow the light to penetrate through one of the windows in order to enable a clear vision for the

Download English Version:

https://daneshyari.com/en/article/645096

Download Persian Version:

https://daneshyari.com/article/645096

Daneshyari.com