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The effect of temperature on the distributor design in bubbling fluidized beds

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ABSTRACT

In this paper the effect of the temperature on the distributor pressure drop ratio is studied. There is a lack of information in the literature concerning the effect of the temperature on the performance of the distributor plate, and its possible role on non-uniform gas distribution. The effect of temperature on the distributor pressure drop has been experimentally established for the first time for two different air distributor plates, multiorifice and tuyere. The distributor pressure drop curves were obtained at different temperatures by means of pressure measurements. The well-known orifice equation was used to predict the distributor pressure drop at different temperatures and a good agreement with the experimental data was found. A methodology to obtain the distributor open area as a function of the bed temperature for different bed aspect ratios was developed. It was found that when operating at higher temperatures the distributor pressure drop decreases for the same gas velocity due to the decrease in the gas density. The resulting decrease of the distributor to bed pressure drop ratio shows that gas distributor plates have to be designed at the operating temperature instead at the ambient temperature to avoid non-uniform gas distributions and to save cost in manufacturing and operation.

1. Introduction

Bubbling gas–solid fluidized beds (BFBs) are broadly applied in industry, particularly in thermochemical energy conversion processes such combustion and gasification. The fluidization process offers a high heat transfer rate, good gas–solid mixing and solid handling, and provides a uniform and controllable temperature. Moreover, its ability to process low grade fuels with low pollutant emission makes the use of BFBs a very promising technology for the valorization of biomass and wastes in energy conversion processes. According to that, a better understanding of the fluidization hydrodynamics during operation is needed to enhance the reactor design and scale-up processes. Many authors have reported experimental results of biomass gasification in bubbling fluidized bed pilot-plants and lab-scale facilities [1–8]. However, in these works there is a lack of information concerning technical facility details, especially about the distributor design, and it is not clear if the operating temperature has been taken into account on the design of the distributor plate. Some operational problems found in combustors and gasifiers such as dead zones, hot spots and ash sinterization might be attributed to an incorrect design of the distributor plate.

The performance of a fluidized bed reactor depends primarily on the satisfactory design of the gas distribution system. The design of the gas distributor often determines the success or failure of a fluidized bed [9]. The gas distributor plate must ensure the uniform distribution of the gas in a fluidized bed. Non-uniform distributions can lead to poor conversion rates in reactions, formation of dead zones and, in case of sticky or aggregative solids, agglomeration problems and defluidization of the entire bed [10]. Several authors have studied the design and performance of different types of gas distributors for fluidized beds, and also its effects on the segregation and distribution of bed solids. Most of these studies are focused on the ratio, R, of the distributor pressure drop, ΔP_{dist}, to the bed pressure drop, ΔP_{bed}, and it is generally assumed that the value of this ratio ranges from 0.015 to 0.4 [11–15]. Karri and Werther [16] assumed that this ratio should be larger than 0.3 to ensure a uniform velocity distribution. If a very large value is chosen for design, it will be, in many cases, wasteful in terms of the energy required to pump the fluidized gas through the distributor plate. However, if a lower value is chosen there is a risk of maldistribution.

Sathiyamoorthy and Rao [17] reported that the stable operation (i.e. no maldistribution present) of a fluidized bed can be achieved when all the orifices or tuyeres of the distributor are operating at the same time and additionally, when there is a uniform distribution of gas and solids without any channeling in the bed. As previously reported by Whitehead [13], the number of operating orifices or tuyeres depends on the gas flow rate, the bed aspect ratio, the bed material and the open area of the distributor. The authors [17] showed that there is a superficial gas velocity, U_M, at which all the orifices of the distributor became operative, related to a critical value of R that defines the

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boundary between stable and unstable operation and proposed a correlation to estimate it. However, Thorpe et al. [18] have cast doubt on the use of R to predict maldistribution and therefore the utility for distributor design. The authors also found that the correlation of Sathiyamoorthy and Rao [17] is too conservative in the predictions of R. Accordingly, a more recently work of Thorpe et al. [19] rejects the use of R as a parameter for distributor design.

Besides, novel measurement techniques reported in recent studies, such as magnetic resonance imaging [20–22], gamma ray tomography [23,24] and electrical capacitance tomography [25,26], have shown to be very useful in the characterization of the hydrodynamics of fluidized beds and the study of the bottom zone region close to the distributor plate.

Even though there are several works related to gas distributor design available in the literature, to the author's best knowledge, there are no previous published investigations comparing the performance of gas distributor plates at elevated temperature. The knowledge of the effect of temperature on the distributor performance is of particular interest in industrial applications such as FB combustors and gasifiers, since industrial and pilot-scale plants operate at high temperature and the distributor plate design directly affects the bed hydrodynamic.

In this work, two different gas distributor plates, multiorifice and tuyere, operating at high temperature are compared using experimental pressure drop measurements. The effect of the temperature on the distributor pressure drop is established. Moreover, the variation of the distributor open area with temperature to satisfy a given value of R is studied, and a methodology to obtain the distributor open area as a function of the bed temperature for different bed aspect ratios is provided.

2. Experimental setup

Experiments were carried out in a biomass bubbling fluidized bed gasifier (BFBG), sketched in Fig. 1. The column was made of stainless steel and it has a total height of 2.5 m divided into two sections, the bed section of 0.134 m inner diameter (D) and the freeboard region of 0.25 m inner diameter. The air flow was measured with a set of two mass flow meters, with ranges of 0–500 L/min and 150–3000 L/min and with an accuracy of 1% of full-scale span (FSS). The fluidizing air passes through an air preheater to heat up the air stream before entering the fluidized bed.

Two different solids were used as bed material, silica sand particles with 2645 kg/m^3 density and 725 μm mean diameter and sepiolite (clay) particles (SG36) with 1551 kg/m^3 density and 450 μm mean diameter. Both bed materials are type B according to Geldart's classification [27]. The main physical properties of the two solids are summarized in Table 1, including experimental values of minimum fluidization voidage, ε_{mf}, and minimum fluidization velocity, U_{mf}, at ambient temperature, which were determined using pressure measurements. Taking into account the experimental values of minimum fluidization velocity and minimum fluidization voidage, the particle sphericity, ϕ, was calculated by means of the Carman–Kozeny equation (Eq. (12)) for each type of particle studied in this work.

Two piezo-electric pressure transducers (*Kistler type 5015*) and two absolute pressure sensors (*Honeywell SPT Series*), with an accuracy of ±0.01% of FSS, were used to measure the pressure fluctuations in the plenum chamber and at 55 mm above the distributor plate. Pressure fluctuation signals were used to obtain the minimum fluidization

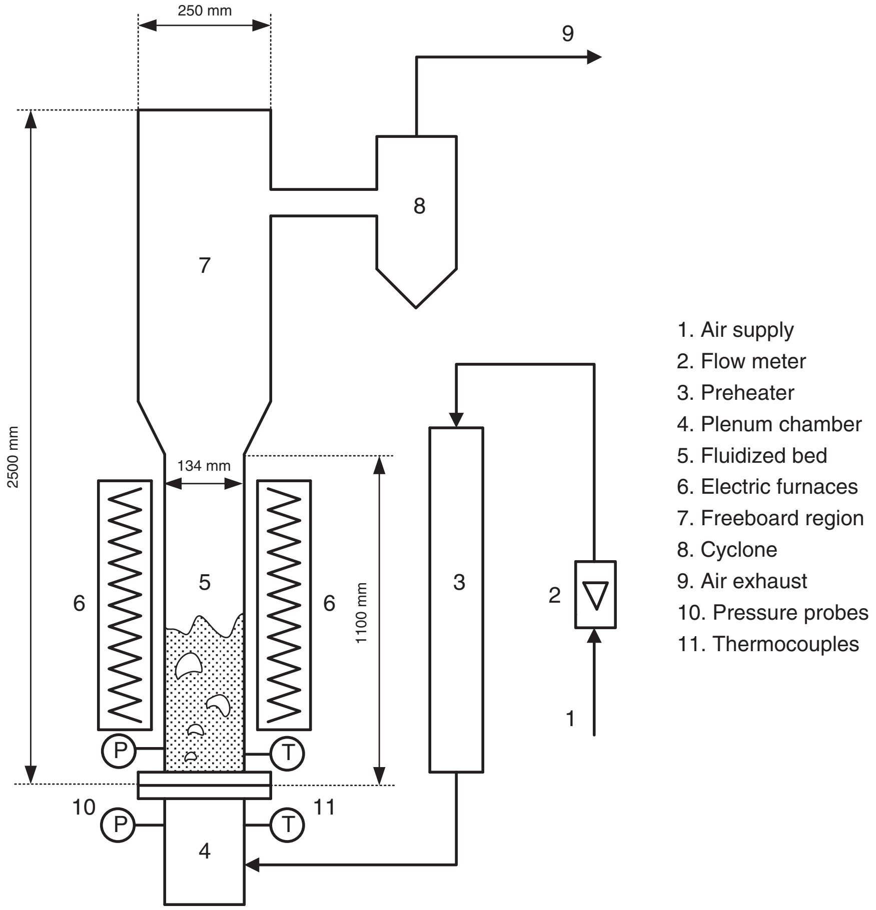

Fig. 1. Schematic diagram of the experimental setup.