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Experimental investigation of heat transfer in gas–solid packed fluidized bed

D. Mandal [a,c,*], D. Sathiyamoorthy [b], M. Vinjamur [c]

[a] Chemical Engineering Division, Bhabha Atomic Research Centre, Trombay, Mumbai 400085, India
[b] Powder Metallurgy Division, Bhabha Atomic Research Centre, Vashi, Sector 20, Navi Mumbai 400705, India
[c] Department of Chemical Engineering, Indian Institute of Technology Bombay, Powai, Mumbai 400076, India

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ABSTRACT

Packed fluidization is a novel technique, in which small particles are allowed to fluidize in the interstices of relatively large and stationary packing to enhance heat transfer rates of a unary packed bed of same size pebbles. In the present study, heat transfer in unary packed bed and binary packed fluidized bed were investigated and compared in terms of the effective thermal conductivity. In the experimental works, large pebbles (size: 3–10 mm) of two different materials viz. lithium titanate and alumina and small particles (size: 231–780 μm), also of two different materials viz., lithium titanate and silica were used. It was found that the heat transfer in unary packed bed is enhanced due to the packed fluidization and in terms of the effective thermal conductivity; the enhancement was up to 260%. It was found that the volume fraction of small particles, operating gas velocity, particle to pebble size ratio and the type of materials have a significant effect in enhancing the effective thermal conductivity and heat transfer rates. It was also found that 60% (v/v) of small particles in the interstitial voids of packing pebbles can give much improved effective thermal conductivity keeping all other operating parameters same. Possible mechanism for heat transfer enhancement due to packed fluidization has been proposed. Based on the results for different particle and pebble sizes, materials and process variables viz. particles to pebble size ratios, operating gas velocity ratios, volume fraction of small particles in the interstices and bed wall temperatures, we could arrive at optimum conditions for determining effective thermal conductivity and a correlation to estimate the same.

1. Introduction

Fluidization is often employed to enhance the rate of heat and mass transfer in various process applications, involving gas–solid operations dealing with small particles [1–3]. Fluidization leads to an isothermal condition due to the vigorous and uniform gas solid mixing. However, fluidization technique is not well established for small particles with high density. Bubbles normally produce during the fluidization of small particles of size (d_p) range, 100 μm < d_p < 500 μm and with a density (ρ_p) higher than 2500 kg m^{-3} i.e., particles fall under Geldart B class [4] and especially when the operating gas velocity exceeds the minimum fluidization velocity [5]. It may be noted that the minimum fluidization velocity of small particles is defined as the minimum superficial gas velocity at which the pressure drop through the bed is equal to the bed weight divided by the cross sectional area of the bed and all the particles start to fluidize. Due to high particle density, the minimum fluidization velocity of Geldart B class particles is quite high. In many process applications high operating gas velocity as well as the bubbling are not desirable [6]. Moreover, slugging occurs during the fluidization of Geldart B class particles, especially when fluidized in a bed of high aspect ratio [5,6]. Sometimes bubbles occupy the entire cross-section of the bed, which affects the heat transfer as well as mass transfer rates in fluidized bed. From their experimental study, Mickley et al. [7] found that due to slugging, the heat transfer coefficient decreases with increase in bed height.

To prevent the formation of bubbles in fluidized bed, Sutherland et al. [8] introduced stationary solid materials of different shapes and sizes which they called packing. They found that due to the presence of packing in a fluidized bed of small particles, bubbling and slugging are completely eliminated. They also found similar results even for small particles of high density. Zeigler and Brazelton [9] studied radial heat transfer in packed fluidized bed of glass beads with stationary packing and compared the heat transfer rate to that of a packed bed of spherical pebbles. They found a significant improvement in the rate of heat transfer in packed fluidized bed.

Packed fluidization is useful, when particles need to be fluidized cannot be divided into very small sizes, so that they can be fluidized at low velocity [9]. Also, if an exothermic reaction is carried out in a packed catalyst bed, hot spots could be created, which are detrimental to the catalyst. The packed fluidized bed offers better control for heat transfer and uniform bed temperatures [10–13]. This is due to the

* Corresponding author at: Chemical Engineering Division, Bhabha Atomic Research Centre, Trombay, Mumbai 400085, India. Tel.: +91 22 25594937; fax: +91 22 25505151.
E-mail addresses: dmandal@barc.gov.in, dmandal10@gmail.com (D. Mandal).

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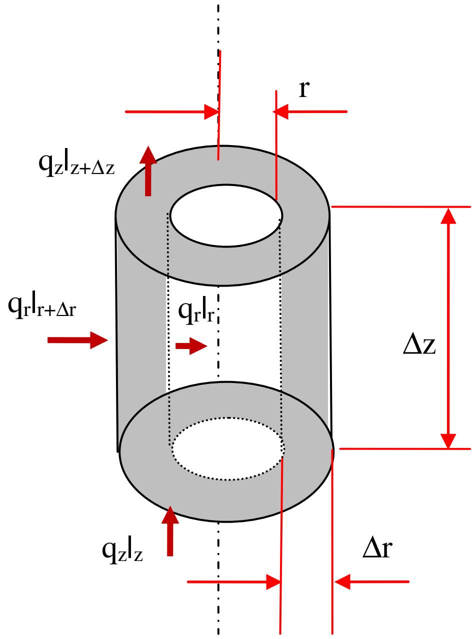

Fig. 1. Elemental volume in packed fluidized bed, filled with stationary packing pebbles (volume fraction: ε_P), small fluidized particles (volume fraction: ε_f) and flowing gas i.e., dry air (volume fraction: ε_{pfb}) which has been considered for energy balance.

uniform distribution of voidage in packed fluidized bed which produces homogeneous fluidization [14]. Compared to a packed bed, the additional mode of heat transfer in a packed fluidized bed is the heat transfer by convection of the fluidized particles [15]. Packed fluidization enhances heat transfer rates in the voids; these rates are low in packed beds where the voids are filled with gas only. The advantages of both packed bed and fluidized bed can be exploited if the bed is operated as a packed fluidized bed, where small particles are fluidized in the interstitial void space of relatively large and stationary pebbles of a pebble bed [15].

The works of Sutherland et al. [8], Zeigler and Brazelton [9] and later by many others [10–13] were primarily focused to break the gas bubbles into small sizes in order to improve the homogeneity of fluidization and which in turn improves the transfer rates. In all the previous studies, packed fluidized bed was essentially a gas fluidized bed, in which a stationary packed bed was immersed and the previous studies are not in principle the same as packed fluidized bed, which we have defined in the present studies. In the present studies, small particles were allowed to fluidize in the interstitial voids of relatively large spherical packing pebbles (henceforth also called pebbles) only and the expansion of the fluidized bed above the top surface level of stationary pebble bed was not allowed, that is a fluidized bed of small particles was immersed in a bed of large size stationary pebbles. Hydrodynamic behavior of such packed fluidized bed was investigated recently by Mandal et al. [16]. Variation of void fraction in packed fluidized bed with the ratio of small particle to packing pebbles has also been discussed by Mandal et al. somewhere else [17].

An experimental setup was designed and fabricated to study the heat transfer in packed and packed fluidized bed and heat transfer in both these beds was compared in terms of the effective thermal conductivity. Axial and radial temperature profiles were measured at different bed wall temperatures and the measurements were used to estimate the effective thermal conductivities. The beds were operated at various volume fractions of particles in the interstitial voids and at velocities above the minimum fluidization velocity of the particles in the voids of packing. Like conventional fluidization, minimum fluidization velocity in packed fluidized bed is defined as the minimum superficial gas velocity at which the small particles start to fluidize in the interstitial voids of stationary pebbles [16]. Effects of different process

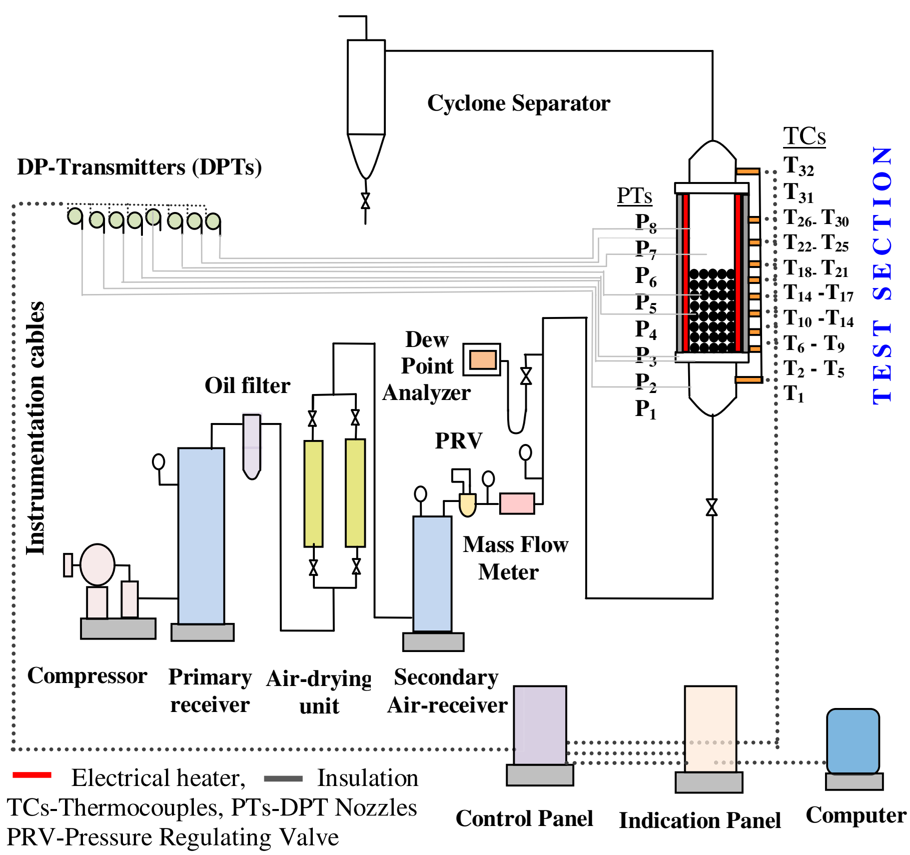

Fig. 2. Schematic diagram of the experimental setup, used to study heat transfer in packed and packed fluidized beds [15,18].