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Heat Transfer Study of Binary Mixture of Group B Particles in the Gas – Solid Fluidized Bed using Acoustic field.

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Abstract

The behavior of binary mixture of similar size and density of group B particles (Sand and Clay with mean diameter 200 µm) and the heat transfer coefficient between immersed horizontal heating tube in the gas-solid fluidized bed in presence of an acoustic field was studied. Two types of data are investigated as function excess air velocity and sound pressure level for the average and local heat transfer coefficient for binary system. The experimental result showed that acoustic energy at sufficient intensity and sound pressure level improves the quality of fluidization in binary system.

Keyword: Fluidization, SPL, Sound wave, Heat transfer, Binary particle.

Introduction

Most of the published research on heat transfer in sound assisted fluidized bed is focused on mono component system, while there is little information available on heat transfer to multi component system. The Morse [1] found that the fluidization quality of group C particles could be improved by the application of sufficient sonic energy generated by loudspeakers located at the bottom of bed. Recently, Nowak and Hasatani [2] reported significant improvement observed in the quality of fluidization when low frequency acoustic energy of sufficient intensity was introduced,. Sound pressure level (SPL) greater than 100 dB were found to decrease in minimum fluidization velocity and increase in the heat transfer coefficient. Derezynski *et al* [3] studied the effect of sonic energy on fluidization and heat transfer of fine particles which belong to group C powders. Authors reported that the extent of bed expansion varies greatly raise accordingly the frequency of the sound and the highest increase in heat transfer coefficient is at low frequencies and at secured resonance. Chirone et al [4] studies the effect of acoustic field on fluidization of cohesive powders. Their observation showed that homogeneous bubble free fluidization of ultra fine particles was obtained when operated in an acoustic field with appropriate combination of bed weight, sound intensity and resonant frequency. Leu and Chen [6] used the speaker at top of the bed powered by an audio amplifier to investigate the primary effect of sound intensity on the fluidization of group B particles, and observed that the minimum fluidization velocity decreases with increase in intensity.

Experimental studied of heat transfer in a fluidized bed with a horizontal tube with group B particles Grewal and Saxena [7] demonstrated that heat transfer coefficients are related to the volumetric capacity of the particles, the particle diameter and the thermal conductivity of fluidizing gas. Chandran and Chen [8] reported that local heat transfer coefficient were strong function of angular positions, particle size, system pressure and gas flow rate. Author measured steady state heat transfer coefficient for particle sizes 125 – 1580 µm by specially instrumented tube with thermocouples and heat generation from an electrical inconel foil. McKain and Atkinson [9] investigated instantaneous heat transfer coefficient values of which varies from 200 – 500 w/m^2k for 250 µm Sand particle with horizontal tube. Olsson and Almsted [10] investigated the influence of excess gas velocity on the local instantaneous and time average heat transfer in a fluidized bed. The bubble caused a rapid mixing in the bed which led to high heat transfer rates between the bed and immersed surface and between the gas and particles. Author demonstrated that the correlation between the heat transfer coefficient the local bubble frequency reflected to a large extent the coupling between the frequency with which the particles near the tube surface were being placed by fresh, thermally unaffected particles. Kim *et al* [11] reported the effect of gas velocity on average and local heat transfer coefficient between a submerged horizontal tube and a fluidized bed heat exchanger of silica sand particles. They found that average heat transfer coefficient increases with increase in gas velocity and local heat transfer coefficient was maximum at the sides of the tube. The bubble frequency increased and emulsion contacting time decreased with increasing gas velocity. Huang and Levy [12] studied the heat transfer and bubble behavior in a sound assisted fluidized bed with horizontal tube. Author reported that bubble frequency increases with an increase in excess air velocity, the sound pressure level, the packet residence time and the fraction of the packet contact time at the tube surface decreased with increased in excess air velocity and decreased with an increased in sound pressure level. They also found that a gas film is present in the vicinity of the tube surface. The gas film increased slightly with increased excess air velocity and decreased with an increase in sound pressure level. The convective heat transfer coefficient between the tube surface and the bed material is strongly affected by the existence of the gas film between the heated surface and the emulsion phase.

In fluidized bed particle mixing, not only the particle segregation but also the temperature segregating may occurs under particular conditions. Gu and Satoh [13] experimentally examined the particle and temperature segregations in fluidized bed of binary particle mixtures. It was found that the temperature segregation results mainly from low heat transfer coefficient through the interface layers, which exists in between the floatsom and jetsom – rich layers, and that the heat transfer coefficient increases rapidly with increasing the excess gas velocity. Gu [14] further showed that the particle exchange rate of the interface layer increases with excess gas velocities, and the heat transfer coefficient which is dependent upon the volume exchange rate of the particles also increases. It was shown that the heat transfer coefficient or the thermal conductivity in the interface layer is influenced by the densities and specific heat capacities of the particles. Chongdian and Guo [15] studied the fluidization behaviors of binary mixtures of biomass and quartz sand for the investigation in an acoustic bubbling fluidized bed. Two kinds of biomass particles, sawdust and wheat stalk, were employed in this test. The experiment indicated that the addition of quartz sand can improved the fluidization quality of biomass. The minimum fluidization velocity of the mixtures increased with increasing biomass content in the mixtures. A new correlation was developed for predicting the minimum fluidization velocity of different binary mixtures. The minimum fluidization velocity decreased with increasing sound pressure level at the same sound frequency. Moreover, the minimum fluidization velocity has a maximum value over the sound frequency range of 100 – 200 Hz. Such an acoustic fluidized bed operated in a stable or unstable fluidization regime depending on the operating conditions.

In this paper fluidized bed subject to acoustic field behavior of binary mixture, the particle motion in the segregated fluidized bed, heat transfer coefficients, was experimentally studied by using acoustic field with immersed horizontal heating tube, and its effect on the behavior of fluidization and heat transfer in the fluidized bed were discussed.

Experimental:

The experimental apparatus used for the fluidization experiments is schematically illustrated in fig. 1. It consists of fluidized bed is a 115 mm i. d. and 610 mm high Plexiglas column, with a porous polymer plate used as a gas distributor, and a horizontal heating cylinder of copper material. Experiments were performed with compressed air and the flow rate was monitoring by a rotameter (Eureka of uncertainly 3 % of full scale reading). The bed materials used were group B binary mixture of Sand and Clay with mean size of 200 µm in all experiments.

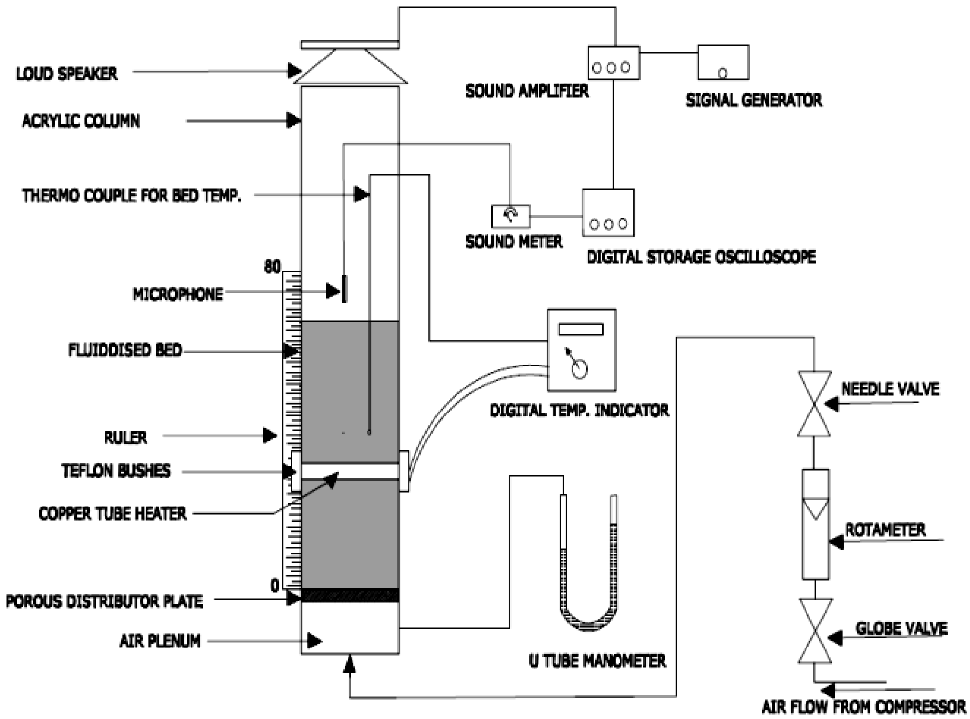

Figure 1: Schematic diagram of the experimental set up of sound assisted fluidized bed system.

In 8" diameter loud speaker (4 Ω impedance) installed at the top of the fluidized bed column was used to generate sound as the source of the acoustic field. A signal generator was used to obtain a sine wave signal, which was amplified by a 50 W amplifier. The sound pressure level (SPL) was measured just above the free surface of the fluidized bed using sound measuring system is connected with microphone (Bruel and Kjaer – model 4944). The sound pressure level (SPL) is commonly defined by [16]

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Where is the effective sound pressure level and is the reference sound pressure, which are obtained by the sound measuring system.

A heating cylindrical element of 25 mm i. d. was installed horizontally through the center of the bed at 80 mm above the distributor, and extended on two sides by Teflon bushes to minimized heat losses, used to determine the heat transfer coefficient. Four K – type wire thermocouples were fixed in grooves made on the heater tube at 90^0 intervals to measures the surface temperature and bed temperature was measured with K – type wire thermocouple placed parallel to the heater tube at radial distance of 2.5 cm from the center of the bed as shown in fig. 2.

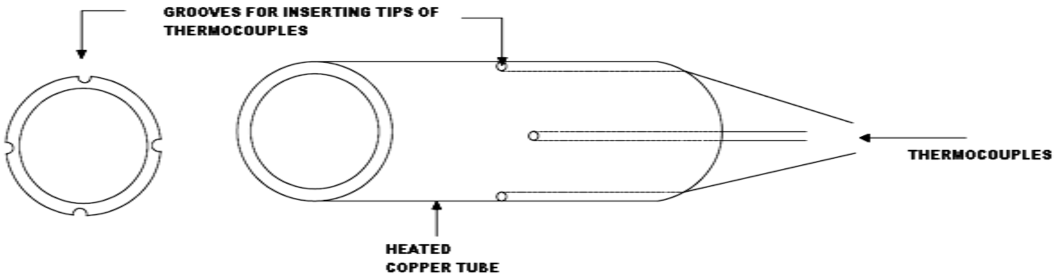

Figure 2: Layout of configurations of the heated tube.

Heat transfer coefficient were obtained from equation,

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where, is the convective heat transfer coefficient (w/m^{2}k), *I* is the current (amperes), *R* is the resistance (Ω), is the surface area of the element, is the surface temperature (k) and is the bed temperature (k).

Result and discussion:

The heated tube was tested for the heat transfer measurement at specific sound pressure level (SPL) and acoustic frequency in a fluidized bed of binary mixture of group B particles Sand and Clay with mean particle diameter 200 µm. Addition of assisting particles like Sand 200 µm to an acoustic fluidized bed increases the fluidization. The mixing of binary system at the beginning of a fluidization experiments can be charged into the column in different ways i.e. well mixed assembly of particles and two completely segregated layers of each component behaves like a fixed-bed arrangement reported by Formisani et al. (17).

Fig. (3) shows the plot of local heat transfer coefficient (h_{local}) for the mixture of group B particles at different locations of heated tube along the circumference at 90 Hz and at twice the velocity of umf. The local heat transfer coefficient increases from 120 dB to 140 dB. However, the local heat transfer coefficient decreases after 140 dB. The fluidization behavior of particles is significantly affected by acoustic field and hence there is a major effect on local heat transfer coefficient Nowak *et al* (2). An increase in gas velocity in absence of sound intensity, voidage in the bed increases with rise in bed height. Due to increases in bed voidage particle to particle and particle to surface contact is minimal and thus the heat transfer coefficient is observed less value than the acoustic fluidization heat transfer. The effect of increased in gas velocity shown in figure (4). The bubble increased with increasing gas velocity that led to increase in local heat transfer coefficient is reported by Kim *et al* (11). Maximum local heat transfer coefficient observed shown in figure (3) at sides of the wall $\theta = 270^0$ directly affect by both bubble motion with sliding motions of solids as reported by Sundersan (18), Kim *et al* (11). In the top region of the heated tube θ = 180^0,h_{local}, attained low values since solid particles reside for longer on the top of the tube with low bubble frequencies. In the bottom region of the heated tube θ = 0^0, h_{local}, exhibits higher value compare to θ = 180^0. Vigorous bubbling occurs at bottom of the heated tube having high frequency since solid particles resides short time in spite of low emulsion fraction or solid holds up (11). However, with increased in sound pressure level (SPL) more than 140 SPL, voidage decreases markedly, the packets do not get sufficient contact time to carry from heated wall and as an effect, h_{local}, reduces.

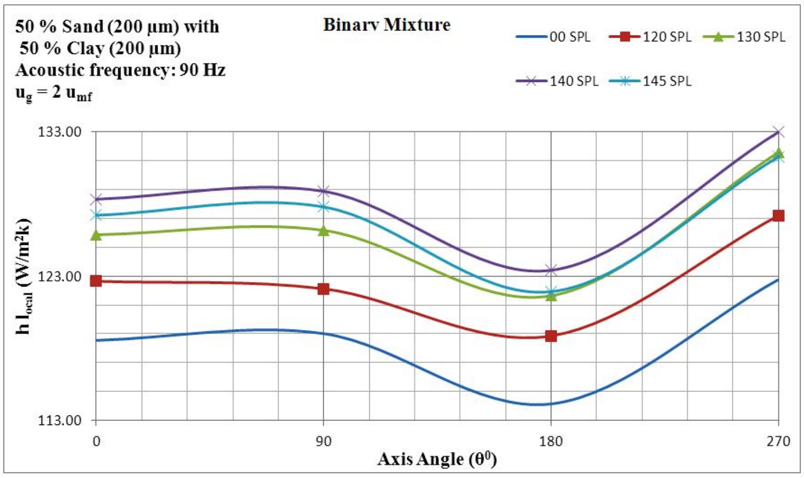

Fig. (3): Effect of SPL on the local heat transfer coefficient.

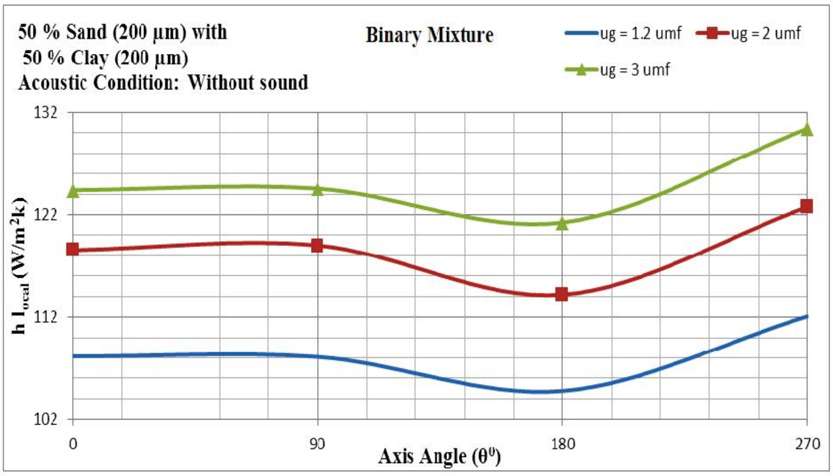

Fig. (4): Effect of u_g on the local heat transfer coefficient at without acoustic condition.

The relationship between SPL and the average heat transfer coefficient (h_{avg}) is shown in figure 5 for binary mixture of group B particles. As can seen, h_{avg}, increases with an increase in SPL upto 140 dB leads to increase in replacement rate of solid packets and solid mixing in the bed. Thefluidization behavior of binary mixture particles is significantly affected by acoustic field and hence increases in average heat transfer coefficient.

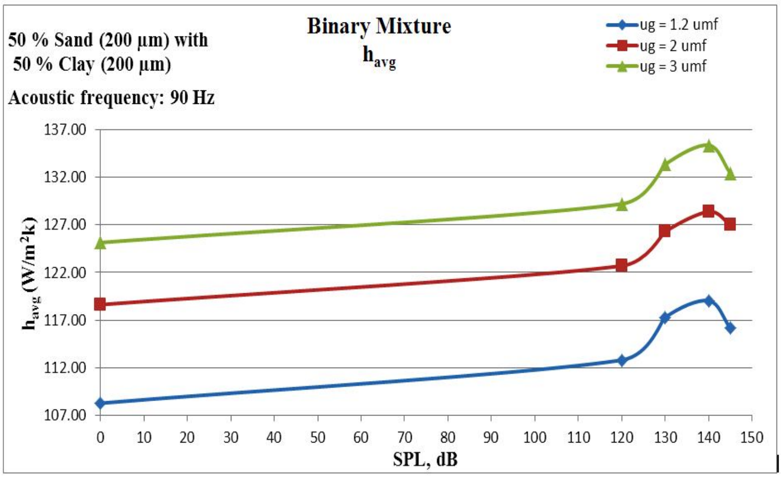

Fig. (5): Effect of SPL and u_g on the average heat transfer coefficient.

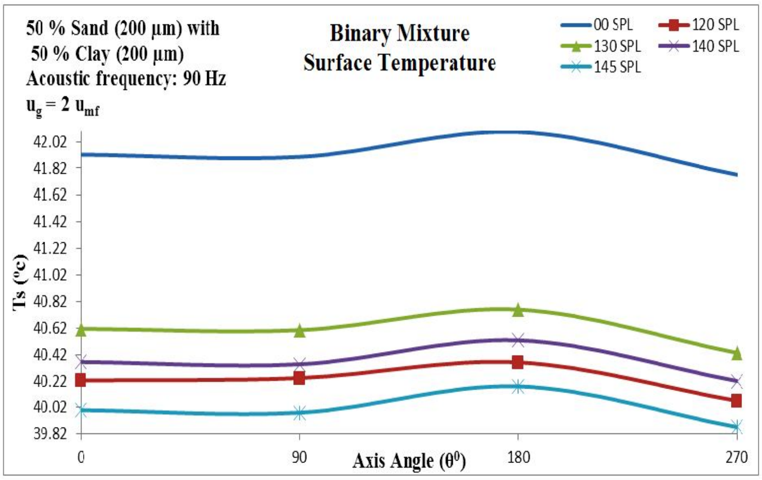

Fig. (6): Effect of SPL on the behavior of temperature variation along the circumference of the heated tube.

The variation of surface temperature values can be recorded in fig. (6) with angular positions along the circumference of the heated tube binary mixture. The heat transfer rate of the heated tube is governed by the frequency of deterioration of the stagnation zone and the fresh particle packets extract heat from heated tube and replacing the older hotter particles. At $\theta = 180^0$ indicates the lack of temperature variation sensed by thermocouple. This is due to a stagnation zone is located on the top surface of the heated tube. Thermal activity rate is highest at the sides of heated tube $\theta = 90^0$ and $\theta = 270^0$ due to continual replacement of fresh particle packets and is slightly lower at the bottom surface $\theta = 0^0$. The scenario of temperature variations with angular position along the circumference of the heated tube is shown in fig. (6) at different sound pressure level.

The field of heat conduction has been of great interest to researchers, since the fluidized bed is characterized by high heat conductivity. Mixing of particles and the frequency of sand particle collisions increases, which enhances more intensive diffusion of heat and thus increases the heat transfer coefficient of the fluidized bed.The thermal conductivity of the fluidizing sand (200 µm) is more as compare to clay (200 µm) that increases, h_{local}, with increased in SPL upto 140 dB.

Conclusion:

The experimental result indicates that acoustic field can improve the fluidization quality of mixture. The fluidization behavior of binary mixture of particles at the same size and same density is strongly influence by the thermal conductivity of the fluidizing Sand.

The heat transfer data showed that the average heat transfer coefficient increased with increasing gas velocity. It also found that as sound pressure level of acoustic field increases, local heat transfer coefficient increases.

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