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Research Article

Mass Transfer Studies in Three-Phase Stirred Fluidized Bed using Nanofluids

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Abstract Fluidization has wide industrial applications, particularly in the chemical, physical and biological process where contact between solid liquid and gas phase is required. It helps to achieve high heat and mass transfer. Due to these advantages, fluidized beds are used in the wastewater treatment process, food process industries. In the present day, nanofluids have a variety of applications in chemical industries. This circumstance makes to do studies on a fluidized bed with nanofluid at different varying parameters such as airflow rate (4,6 & 8 lpm) liquid height (50, 60 & 70 cm) nanofluid volume (100&200 ml) and stirrer speed (1000, 1200 & 1400 rpm). It was observed that the volumetric mass transfer coefficient increases when the nanofluid level increases with increasing the stirrer speed in the fluidized bed.

Keywords Fluidization, Nanofluids, mechanical stirring, volumetric mass transfer coefficient

Introduction

Fluidization is used to describe the conditions of fully suspended particles like solid acts as a fluid. A fluidized bed is a gas-solids and liquid-solids system in which the solid particles are placed under appropriate conditions to cause a solid/fluid mixture to behave as a fluid by the co-current flow of gas or liquid stream moving through the bed containing solid particles. In the fluidized bed, the fluids are continuously mixed by the stirrer with nanofluids instead of nanoparticles because there are no agglomerates formed [1]. Nanofluid is used to increase the surface area of the bed. The fluidized bed classification depends on its flow behaviour, which is bubbling bed, circulating fluidized bed, vibrating fluidized bed, etc. [2, 3]. It has many advantages which are high contracting space, high heat, and mass transfer rate, etc. [4]. It has a variety of applications such as wastewater treatment process, vapour compression refrigeration, food process industries, adsorption process, petroleum industries and several other processes [5]. For efficient fluidization, aeration is essential. But too much aeration will cause bubble formations and slugging. The implementation of mechanical stirring can achieve the efficiency of fluidization.

Response Surface Methodology and experimental methodology helps to understand that controlling biofilm thickness in the biological wastewater treatment process by Inverse fluidized bed which plays a major role in this treatment process. Haribabu et al. studied [6] that the mass transfer coefficient is determined by the effect of liquid, gas velocity, solid loading, and concentration of xanthan gum. The above study in mass transfer, superficial liquid velocity had a poor effect but in non-Newtonian fluid, the mass transfer is positively affected by gas flow rate. At minimum gas velocity, the bed fails to expand fully when the increase in liquid velocity and solid loading. The mass transfer coefficient is decreased with an increase in particle concentration when the gel diameter is minimum [7]. Due to the density change, the mass transfer coefficient is partially affected. The recent work is centralized the mass transfer studies in the stirred fluidized bed using the air-water system. It shows good heat and mass transfer rate, proper mixing, and uniform temperature gradient. The application of the three-phase fluidized bed is wastewater treatment, hydrocarbon cracking, etc. Stirrer helps to increase the efficiency of the bed because of its proper mixing. This work includes the investigation of the effect of bed.

Materials and Methods

The experimental setup is shown in Figure (1). The set up consists of a transparent acrylic column of inside diameter 50mm and outer diameter 60mm. The column is 1000 mm high. A stirrer is fixed in the bed for promoting the mixing. The stirrer is made up of stainless steel which has 6 impeller blades of 7 mm diameter. Impellers employed are roustion turbine -1 number, pitched blade downflow 45°- 4 number pitched up-flow – 1 number. The Rotameter is fixed to measure the liquid flow rate and airflow rates such as 0-5 LPM for liquid and 0-10 LPM for air. The compressor is equipped to supply the compressed air into the system.

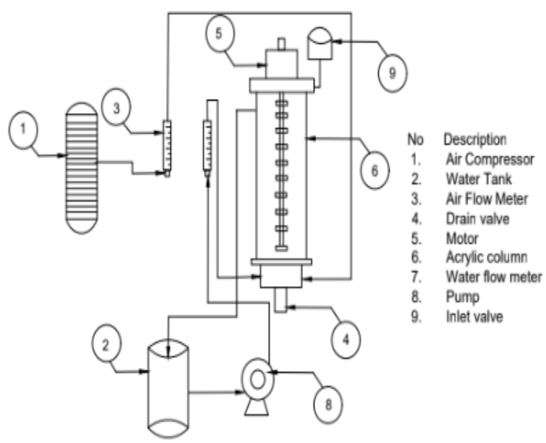

Figure 1: Stirred fluidized bed

Preparation of nanofluid

Nanofluid preparation is one of the important steps in this experiment. In the present work, Al_2O_3-water nanofluids [8] with a volume percentage of 6% were prepared by using the two-step method. The demineralized water is used to prepare the Al_2O_3-water nanofluid by using an ultrasonicator which is generating an ultrasonic pulse of 180 W and 40 Hz. The nanofluid is kept under sonication for 6 hrs [9] which helps to get uniform mixing and attains high stability.

Method

Water is pumped into the bed and is filled with the desired level. Compressed air allowed into the column at the bottom of the bed. Prepared Nanofluid is added into the water. A digital tachometer is attached to measure the speed of the impeller. The dissolved oxygen probe is used to measure the oxygen concentration of the water. Initially, the dissolved oxygen concentration is noted down for the bed height of 50 cm, 60 cm, and 70 cm. Airflow rate varies as 4 LPM, 6 LPM, and 8 LPM. Stirrer speed varies from 1000 rpm, 1200 rpm, 1400 rpm. Nanofluid is added as 100 ml and 200 ml.

Measurement of overall volumetric mass transfer coefficient in three stirred fluidized beds by using a dynamic method:

The mass transfer performance of gas-liquid and gas-liquid-solid reactors is characterized by the volumetric mass transfer coefficient, k_{La} [10]. The concentration gradient of the liquid helps to find out the volumetric mass transfer coefficient.

$$dC_L/_{dt} = K_{La}[C* - C_L] \quad (1)$$

where C_L and C^* are the instantaneous and saturation concentration, respectively, the Dissolved Oxygen in the liquid $C_L = C_{LO}$ at t = 0 and $C_L = C_L$ at t = t, yields

$$\ln[C* - C_{Lo}]/[C* - C_L] = K_{La}t \quad (2)$$

The coefficient k_{La} was obtained from the plot a graph of $\ln(C^* - C_{LO}) / (C^* - C_L)$ vs t.

Results & Discussion

Effect of airflow rate on mass transfer coefficient at the nanofluid of 100ml for different liquid height at the unstirred condition

From the observance of this study, volumetric mass transfer coefficient values were obtained at room temperature for three-phase systems at different conditions. For 100 ml of nanofluid addition, Figure (2) shows the effect of airflow rate vs volumetric mass transfer coefficient for different bed height at the unstirred condition. In this study, it is observed from the graph; the mass transfer coefficient is increased with an increase in airflow rate at unstirred conditions. The mass transfer coefficient decreases with an increase in bed height because oxygen concentration of water is reduced due to increasing bed height.

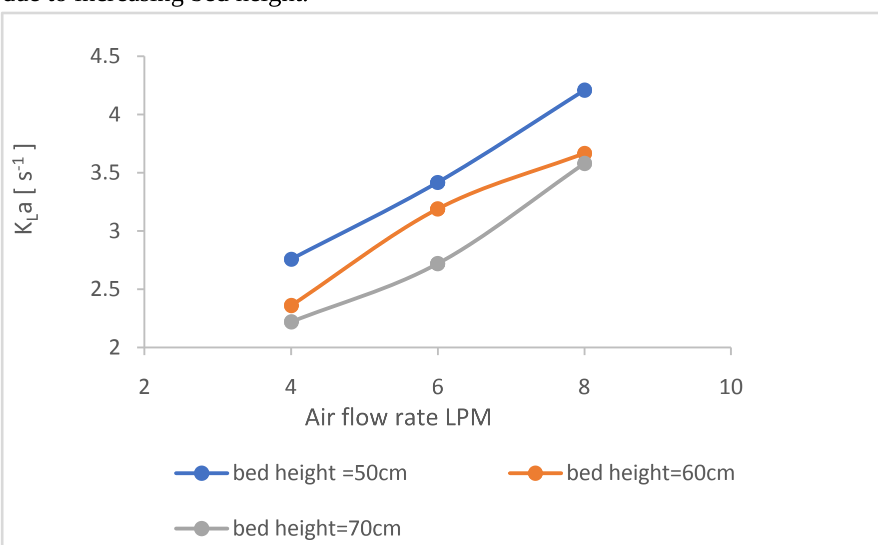

Figure 2: Effect of airflow rate on mass transfer coefficient at the nanofluid of 100ml for different liquid height at the unstirred condition

Effect of airflow rate on mass transfer coefficient at the nanofluid of 100ml for different liquid height at the stirred condition

While comparing with the stirred bed column at the same condition, the volumetric mass transfer coefficient is comparatively increased. It happens because high stirrer speed increases the mass transfer rate in the bed. The higher mass transfer coefficient is reached for a stirred condition for higher impeller speed and higher airflow velocity. The unstirred bed has a low mass transfer coefficient proving that the mass transfer is enhanced when stirring and velocity are higher in the column.

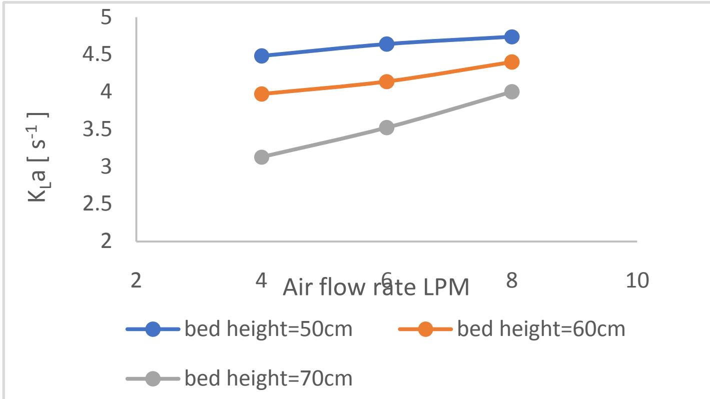

Figure 3a.

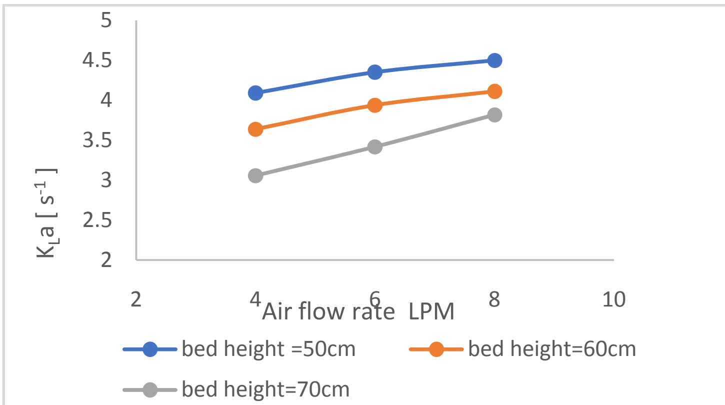

Figure 3b.

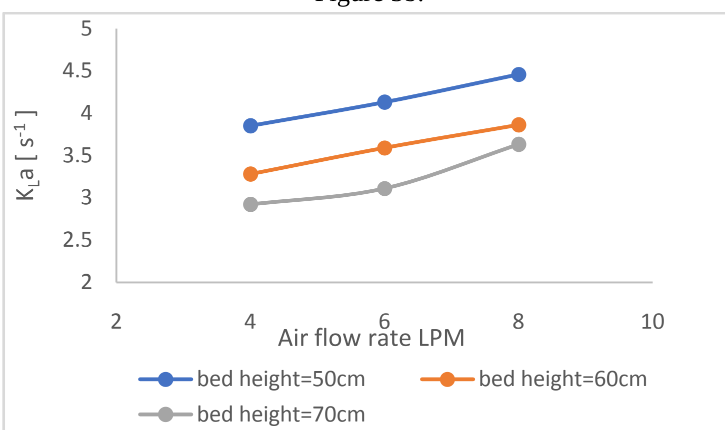

Figure 3c.

Figure 3a, 3b. 3c: Effect of airflow rate on mass transfer coefficient at the nanofluid of 100ml for different liquid height at the stirred condition

Effect of airflow rate on mass transfer coefficient at the nanofluid of 200ml for different liquid height at the unstirred condition

Further study, 200 ml of nanofluid is taken, and the studies are carried out in the same condition. The variables considered are the impeller speed, airflow rate, and bed height. For unstirred conditions, while gradually increasing the airflow rate, the Mass transfer coefficient is gradually increased. Whether increasing the bed height, it affects the K_La value.

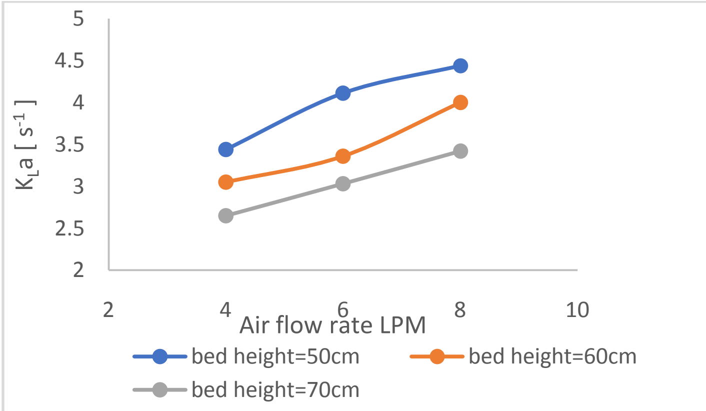

Figure 4: Effect of air flow rate on mass transfer coefficient at the nanofluid of 200ml for different liquid height at the unstirred condition

Effect of airflow rate on mass transfer coefficient at the nanofluid of 200ml for different liquid height at the stirred condition

For stirred conditions, the speed of the stirrer and airflow rate increases, the K_{La} value is high compared to unstirred conditions. It promotes the mass transfer coefficient because it creates turbulence inside the bed. So, it influences the parameter and affects the mass transfer coefficient. The higher stirrer speed and high volume fraction of nanofluid enhance oxygen distribution into the water. So, the mass transfer coefficient is highly influenced. The maximum value of the mass transfer coefficient is achieved at a higher volume fraction of nanofluids, higher impeller speed, higher airflow velocity, and lower bed height.

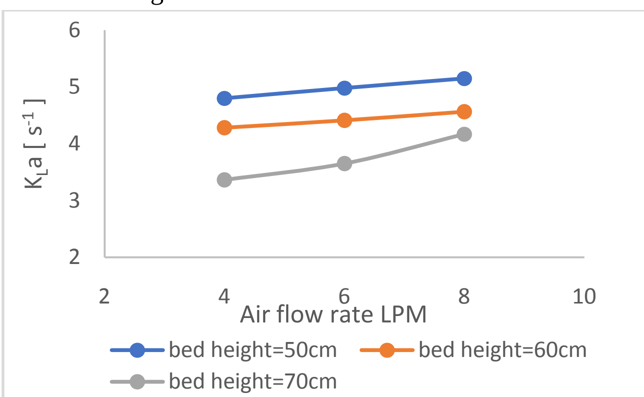

Figure 5a.

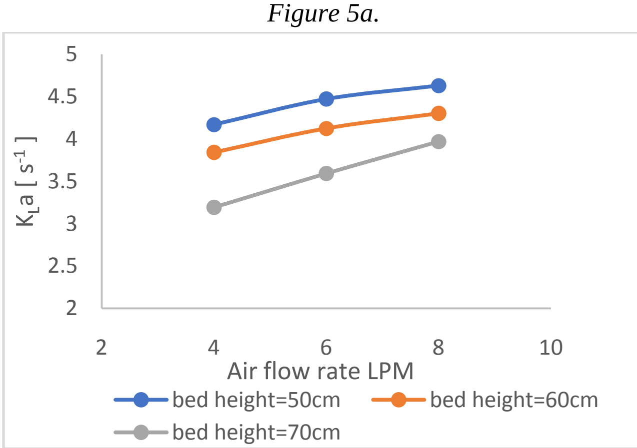

Figure 5b.

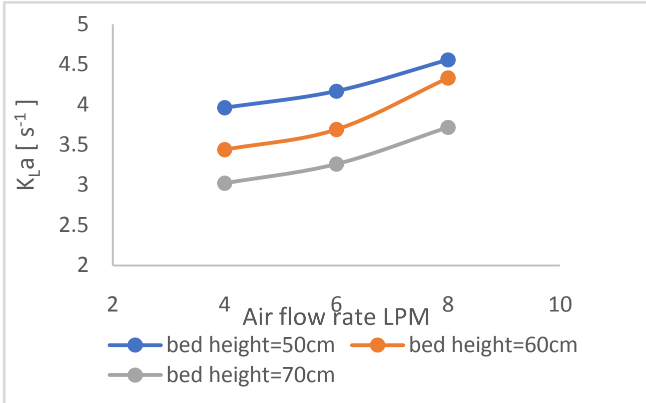

Figure 5c.

Figure 5.a, 5.b, 5.c: The effect of 200ml of airflow rate on mass transfer coefficient at the nanofluid of 200ml for different liquid height at the stirred condition

Effect of Bed height

The mass transfer coefficient is lower when the nanofluid absence and unstirred bed condition because of low turbulence, absence of impeller motion and low surface area of interaction. As compared to the previous study shows that better mass transfer coefficient is achieved at a high-volume fraction of nanofluids, high impeller speed, high airflow velocity, and minimum bed height.

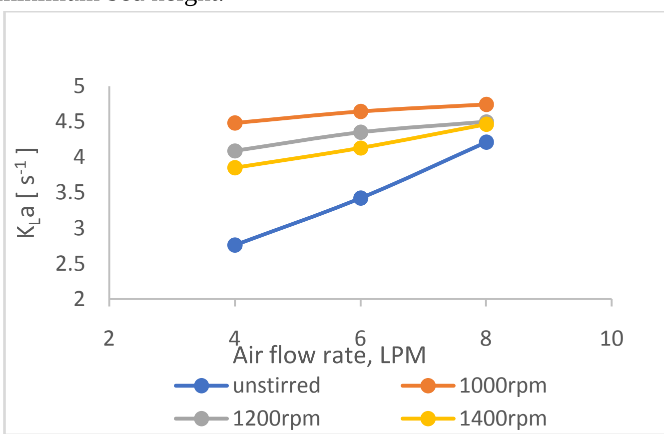

Figure 6a.

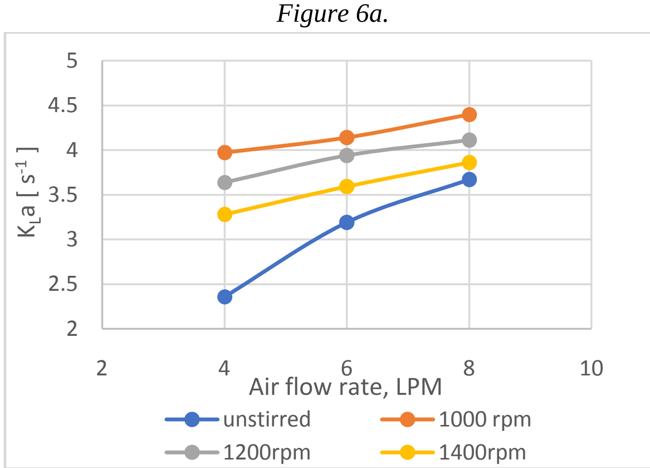

Figure 6b.

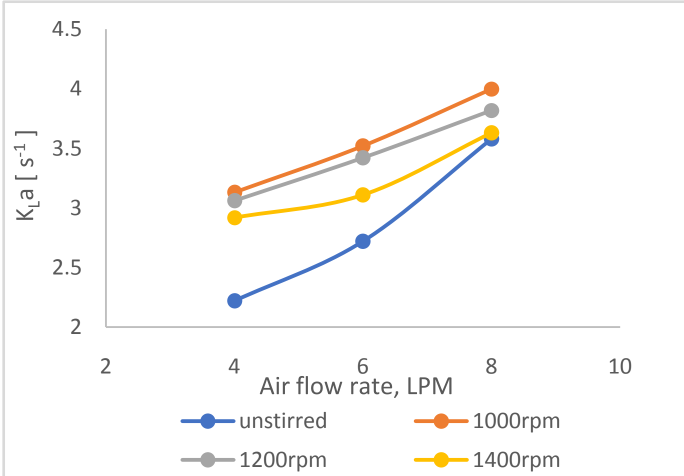

Figure 6c.

Figure 6a, 6b, 6c: Effect of Bed height on volumetric mass transfer coefficient

Conclusion

The volumetric mass transfer coefficient studies were carried out in a stirred fluidized bed column. It is observed from the results that a better mass transfer coefficient is achieved at a high-volume fraction of nanofluids, high impeller speed, high airflow velocity, and minimum bed height. So, it is suggested to have a minimum height of the liquid bed and adding a high-volume fraction of nanofluid for a higher mass transfer coefficient.

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