Formulation of experimental data based model for solid-liquid mass transfer enhancement in three phase fluidized bed using nanofluid

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1. Data description

Several models for solid liquid mass transfer in three phase fluidized bed have been proposed but to check the validity and usefulness of these models without reliable experimental data to compare with calculation is a difficult task. If general trends can be considered to be reasonably consolidated a definitive estimation of mass transfer coefficient is still not possible. Recently Rajendra P. Ugwekar et al.

https://doi.org/10.1016/j.dib.2019.104990
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(2016) proposed the mass transfer enhancement technique by using Zinc oxide nanomaterial in liquid-liquid extraction. It was shown with experiments that enhancement in mass transfer with increase amount of nanofluid [1]. L. Saeednia et al. (2015) examined the effect of nanomaterials on mass transfer coefficient in absorption process and found that nanofluid increases the mass transfer coefficient up to 78% [2].

In this work we applied the above concept to the measurement of mass transfer coefficient in three phase fluidized bed. We used Arachitol nano as nanomaterial spread over a bed of benzoic acid pellet in different volume percentage. Sample were taken in presence and absence of nanomaterial at varying operating conditions shown in Table 1. Sample consists benzoic acid in water with and without nanomaterial has taken at varying gas velocity, bed height, volume percent of nanomaterial, time. For mass transfer coefficient, Sherwood number, Reynold number, Schmidt number

Table 2 in supplementary data shows experimental and calculated values of Sherwood number ($Sh_{exp}$ and $Sh_{cal}$) and also shows the influence of operating parameters on mass transfer coefficient ($K$).

2. Experimental design, materials, and methods

The experiment was conducted using benzoic acid pellets as solid in stagnant liquid column with gas as a continuous phase in fluidized bed column. Arachitol nano is nanoparticles of Vit.D3, which is commercially available as (NDDS) novel drug delivery system [3,4] with a specific dosage was fed to the column and fully dispersed on the solid bed before liquid is charged into the column. Different sets for fixed size of benzoic acid pellets with varying operating conditions shown in Table 1 were used. By maintaining the gas phase flow rates constant for 15 min in stagnant liquid column by keeping the other parameters as constant, sample was collected from the top of column and analysed by volumetric titration method. The air flows were stopped at the end of the run and water was drained from the column in few sec. then all the solid pellets were removed from the test column and kept in desiccator and weighed. The weight of the solid pellets which was actually lost, was measured and calculation for mass transfer coefficient were done [5].
2.1. Correlation of experimental data

In three phase fluidized bed when liquid column is stagnant, mass transfer coefficient (K) is strongly influenced by the velocity of gas and eddies, so K can be represented by

\[ K \propto (Re_g)^a (Sc)^b \]  \hspace{1cm} (1)

Where Sc and Re\(_g\) are Schmidt and Reynolds number based on gas phase respectively. Since solid liquid contact occurs through gas bubbles [6] and transfer of mass of solid into liquid depends also on the size of particles in three phase fluidized beds, the Reynolds number can be replaced by particle Reynolds number based on gas phase as

\[ K \propto (Re'_g)^a (Sc)^b \]  \hspace{1cm} (2)

Sherwood number (Sh) can be defined as \( K^*d_p/D_{ab} \) where \( d_p \) is diameter of particle and \( D_{ab} \) is the diffusivity.

Sherwood number can also be represented in terms of Schmidt number (Sc) and Reynolds number (Re\(_g\))/particle Reynold number (Re\(_g'\)) based on gas velocity.

\[ Sh = n(Re_g)^a (Sc)^b \]  \hspace{1cm} (3)

\[ Sh' = n(Re'_g)^a (Sc)^b \]  \hspace{1cm} (4)

where \( n, a \) and \( b \) are correlation constant and exponents which were estimated from nonlinear optimization technique in MATLAB.

Tables 3 and 4 show the regression value of mathematical model \( (R^2) \) which denotes the satisfactory fit between \( Sh_{cal}/Sc \) vs \( Re_g \) and \( Sh_{cal}'/Sc \) vs \( Re'_g \) respectively for different bed heights. The values of correlation constant and exponents for different bed heights and different nano fraction in each bed height, for \( Re_g \) and \( Re'_g \) respectively, also shown in the tables. The value of exponent \( b \) has constant value for all range of varying parameters. Based on these, the equations (3) and (4) can be reduced into equations (5) and (6) respectively.

\[ \ln Sh_{cal}/Sc = \ln n + a \ln Re_g; \]  \hspace{1cm} (5)

\[ \ln Sh_{cal}'/Sc = \ln n + a \ln Re'_g. \]  \hspace{1cm} (6)
In addition a deviation has been defined for each calculated value of the parameters of the various dimensionless groups [7].

\[
\text{Prob}(r_0 - \Delta r < r < r_0 + \Delta r) = 0.95
\]

where \( r_0 \) is the estimated value of \( r \) exponent and constant \((n, a)\) and \( \Delta r \) the deviation on \( r \). The corresponding equations are with the following values of deviations in Table 5 for the whole range of volume of Arachitol nano

\[
\text{Sh}^{\text{cal}} / \text{Sc} = 0.783 \text{Re}_g^{0.0018}
\]  

(7)

\[
\text{Sh}^{\text{cal}} / \text{Sc} = 0.7695 \text{Re}_g^{0.0847}
\]  

(8)

\[
\text{Sh}^{\text{cal}} / \text{Sc} = 0.7316 \text{Re}_g^{0.0022}
\]  

(9)

\[
\text{Sh}^{\text{cal}} / \text{Sc} = 0.7421 \text{Re}_g^{0.0969}
\]  

(10)

\[
\text{Sh}^{\text{cal}} / \text{Sc} = 0.7444 \text{Re}_g^{0.0023}
\]  

(11)

Table 3

| \( V_n \) | PS | H | \( n \) | a | b | \( R^2 \) |
|---|---|---|---|---|---|---|
| 0 | 0.4 | 3 | 0.7505 | 0.2706 | 1 | 0.96 |
| 3 | 0.4 | 3 | 0.803 | 0.2198 | 1 | 0.96 |
| 5 | 0.4 | 3 | 0.8123 | 0.2152 | 1 | 0.96 |
| 7 | 0.4 | 3 | 0.8522 | 0.1743 | 1 | 0.96 |
| 0 | 0.4 | 5 | 0.7305 | 0.3178 | 1 | 0.94 |
| 3 | 0.4 | 5 | 0.8038 | 0.2286 | 1 | 0.94 |
| 5 | 0.4 | 5 | 0.8454 | 0.1809 | 1 | 0.94 |
| 7 | 0.4 | 5 | 0.861 | 0.162 | 1 | 0.94 |
| 0 | 0.4 | 7 | 0.7641 | 0.2877 | 1 | 0.93 |
| 3 | 0.4 | 7 | 0.8394 | 0.2056 | 1 | 0.93 |
| 5 | 0.4 | 7 | 0.8613 | 0.2029 | 1 | 0.93 |
| 7 | 0.4 | 7 | 0.9056 | 0.1509 | 1 | 0.93 |

Table 4

| \( V_n \) | PS | H | \( n \) | a | b | \( R^2 \) |
|---|---|---|---|---|---|---|
| 0 | 0.4 | 3 | 0.22 | 0.304 | 1 | 0.95 |
| 3 | 0.4 | 3 | 0.3251 | 0.2336 | 1 | 0.95 |
| 5 | 0.4 | 3 | 0.3335 | 0.229 | 1 | 0.95 |
| 7 | 0.4 | 3 | 0.413 | 0.1868 | 1 | 0.95 |
| 0 | 0.4 | 5 | 0.3184 | 0.3368 | 1 | 0.95 |
| 3 | 0.4 | 5 | 0.3122 | 0.244 | 1 | 0.95 |
| 5 | 0.4 | 5 | 0.3982 | 0.1941 | 1 | 0.95 |
| 7 | 0.4 | 5 | 0.4367 | 0.1748 | 1 | 0.95 |
| 0 | 0.4 | 7 | 0.2347 | 0.305 | 1 | 0.95 |
| 3 | 0.4 | 7 | 0.3589 | 0.2193 | 1 | 0.95 |
| 5 | 0.4 | 7 | 0.3712 | 0.2171 | 1 | 0.95 |
| 7 | 0.4 | 7 | 0.4821 | 0.1624 | 1 | 0.95 |
It can be seen that the differences between the values of $n$ and $a$ are in equations are less important than the deviations so unique equation can conveniently represent all the mass transfer data on the whole range of nano fractions and bed heights

$$\text{Sh}_{\text{cal}}/\text{Sc} = 0.7789\text{Re}_g^{0.0925}$$

(12)

For the following range of dimensionless variables

$$57.8 < \text{Re}_g \leq 150.31$$

$$1.2 < \text{Re}_g^\prime \leq 3.34$$

$$532 < \text{Sc} < 981$$

Figs. 1 and 2 represent the proposed correlations for overall range of bed heights and volume percent of Arachitol nano based on Reynolds number and particle Reynolds number respectively. The regression constant obtained were 95.6% and 95.8% show satisfactory fit between $\text{Sh}_{\text{cal}}/\text{Sc}$ vs $\text{Re}_g$ and $\text{Sh}_{\text{cal}}/\text{Sc}$ vs $\text{Re}_g^\prime$ respectively for overall range of parameters.

\[ \Delta n = 0.2621 \quad \Delta a = 0.174 \]

\[ \text{Sh}_{\text{cal}}^\prime/\text{Sc} = 0.7635\text{Re}_g^{0.0914} \]

(14)

\[ \Delta n = 0.1751 \quad \Delta a = 0.1669 \]
A comparison among correlations has been achieved by calculating a quadratic criterion of deviation ($\sigma^2$) derived by the following formula [7] and Table 6 shows deviation for individual experimental value with model value for all bed height range.

$$\sigma^2 = \frac{1}{N} \sum_{i=1}^{n} \left( \frac{Sh_{\text{cal}} - Sh_{\text{exp}}}{Sh_{\text{exp}}} \right)^2$$

(15)

**Appendix A. Supplementary data**

Supplementary data to this article can be found online at https://doi.org/10.1016/j.dib.2019.104990.

**Conflict of Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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