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Effect of Solid Properties on Axial Liquid Dispersion in Bubble Column

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Abstract

Experiments were conducted to study axial liquid dispersion coefficient in slurry bubble column of 0.15 m inside diameter and 1.6 m height using perforated plate gas distributor of 54 holes of a size equal to 1 mm diameter and with a 0.24 free area of holes to the cross sectional area of the column. The three phase system consists of air, water and PVC used as the solid phase. The effect of solid loading (0, 30 and 60 kg/m^3) and solid diameter (0.7, 1.5 and 3 mm) on the axial liquid dispersion coefficient at different axial location (25, 50 and 75 cm) and superficial gas velocity covered homogeneous-heterogeneous flow regime (1-10 cm/s) were studied in the present work. The results show that the axial liquid dispersion coefficient increases with increasing superficial gas velocity, axial distance, solid concentration and an inverse relationship with particles diameter.

Keywords: *Axial liquid dispersion coefficient; Axial dispersion; Mixing; Liquid circulation; Backmixing; Slurry bubble column; Bubble column.*

1. Introduction

Slurry Bubble column are multiphase contactors widely used as absorbers, strippers and reactors in chemical, biochemical and petro chemical industrial processes, because of their advantages as simple construction and excellent heat and mass transfer, as mixing is induced only by gas aeration [1,2].

Holdup and axial dispersion of liquid are two important parameters affecting the performance of the gas – liquid contacting devices. Wrong estimations of liquid holdup and axial dispersion lead to an unexpected low performance [1]. Flow distribution in different axial locations is an important aspect of study in gas-liquid-solid three phase fluidized beds [3].

The main drawback is a severe degree back mixing in the liquid phase, which is due to the low liquid flow rate. Back mixing is known to increase drastically when local liquid circulation develops [4]. The dispersion coefficient is expressed in dimensionless form as Peclet number (P_e); its value denoting the degree of back mixing in the column. If Pe=0 back mixing is complete and if Pe=∞ plug flow prevails [1].

Axial and radial mixing of the liquid phase in bubble columns is characterized by using dispersion coefficients that are analogous to the diffusion coefficient of Fick's law diffusion [1]. The estimation of the axial dispersion coefficient of the liquid phase is important for the design and scale up of bubble column reactors [2]. Dispersion coefficients are generally calculated using the measured concentration – time response to input of a nonreactive, nonabsorptive inter tracer in the reactor. The methodology is well established for calculating the axial dispersion coefficient only, as the one dimensional dispersion model that is typically used for the fitting contains axial dispersion coefficient as the only fitting parameter [5]. It is usually assumed that the dispersion coefficient does not depend on the column height [6].

Unlike diffusion, dispersion arises from convective motion of fluid caused by the following main factors : relative movement of the gas and liquid phase; bubble coalescence and break up; the carry forward of liquid in wakes behind the rising gas bubbles and the consequent return flow generated for maintaining mass balance; and turbulence generated by any superimposed flow of liquid [1,2].

As far as is known, in all previous dispersion studies in semi batch packed bubble columns performed, the tracer has been added directly to the top of the bed. In Co – or counter – current flow reactors, the tracer is generally injected to the liquid inlet stream whereas the response is measured at the outlet [7]. The mixing process involves a shuffling or redistribution of material either by slippage or eddies; this repeated a considerable number of times during the circulation in the reactor [5]. Ichikawa and Chen found a significant effect of superficial liquid velocity on axial liquid dispersion coefficient [8].

The effect of solid concentration and particle size on gas holdup has been investigated by a number of researchers. Several researches concluded that an increase in solids concentration generally reduces the gas holdup [9]. The influence of particle size on hydrodynamics of bubble column has been found to depend on a number of factors including flow regime, gas velocity, liquid properties and slurry concentration [10].

Shawaqfeh [11] reported that the liquid superficial velocity had negligible effect on gas holdup, but had significant effect on the axial dispersion coefficient. The axial liquid dispersion coefficient was found to depend on both gas and liquid velocities.

Shah et al., [1] stated that the increase in gas velocity generally increases the liquid dispersion coefficient.

Therning and Rasmuson [12] using packed bubble column, reported that in both homogeneous and heterogeneous flow regime the one dimensional axial liquid dispersion coefficient increases with increasing gas velocity.

Krishna et al., [13] measured the axial liquid dispersion coefficient at three Metrophm immersing-type conductivity cells which were placed near the wall.

Rubia et al., [5] reported that the value of the radial dispersion coefficient was typically about 1% axial liquid dispersion coefficient value under any given condition. The larger bubbles in tap water underwent more frequent breakup and coalescence and this increased the axial liquid dispersion coefficient.

The aim of the present work is to study the effect of solid concentration and particle size at different axial location and superficial gas velocity (covered homogeneous-heterogeneous flow regime) on the axial liquid dispersion coefficient.

2. Experimental

Experiments were carried out in a QVF cylindrical bubble column of (15 cm inside diameter and 1.6 m height) with static liquid height (100 cm). The system is operated in a semi-batch mode with stagnant liquid and continues gas flow. A schematic diagram is shown in Fig. (1).

In all experiments, the liquid phase was tap water and the gas phase was air. The air flow rate was measured with a pre-calibrated rotameter. A compressed air was dispersed from the bottom of the column through perforated plate consisted of 54 hole, 1 mm diameter and free surface area to cross sectional diameter of 0.24.

PVC particles (1025 kg/m^3 density) were used as the solid phase. Different particles size were used (0.7, 1.5 and 3 mm) and different loading solid particles (0, 30 and 60 kg/m^3) were used in the experiments.

For the tracer experiments, residence time distribution (RTD) of the liquid phase was measured using different amounts of saturated solution of NaCl as a tracer. Different volumes of tracer were used to obtain the optimal amount of tracer that corresponds to optimal signal within the operating range of conductivity cell. This optimal amount of a saturated solution of NaCl was found equal to 5 wt % .The probes were placed on three points (25, 50 and 75 cm) from the distributer axially. The signals from the electrodes were transmitted to conductance meter (Philips type). The meters were connected via an interface to a PC computer.

Tracer was injected as a pulse input; local changes in tracer concentration were displayed and saved continuously on PC.

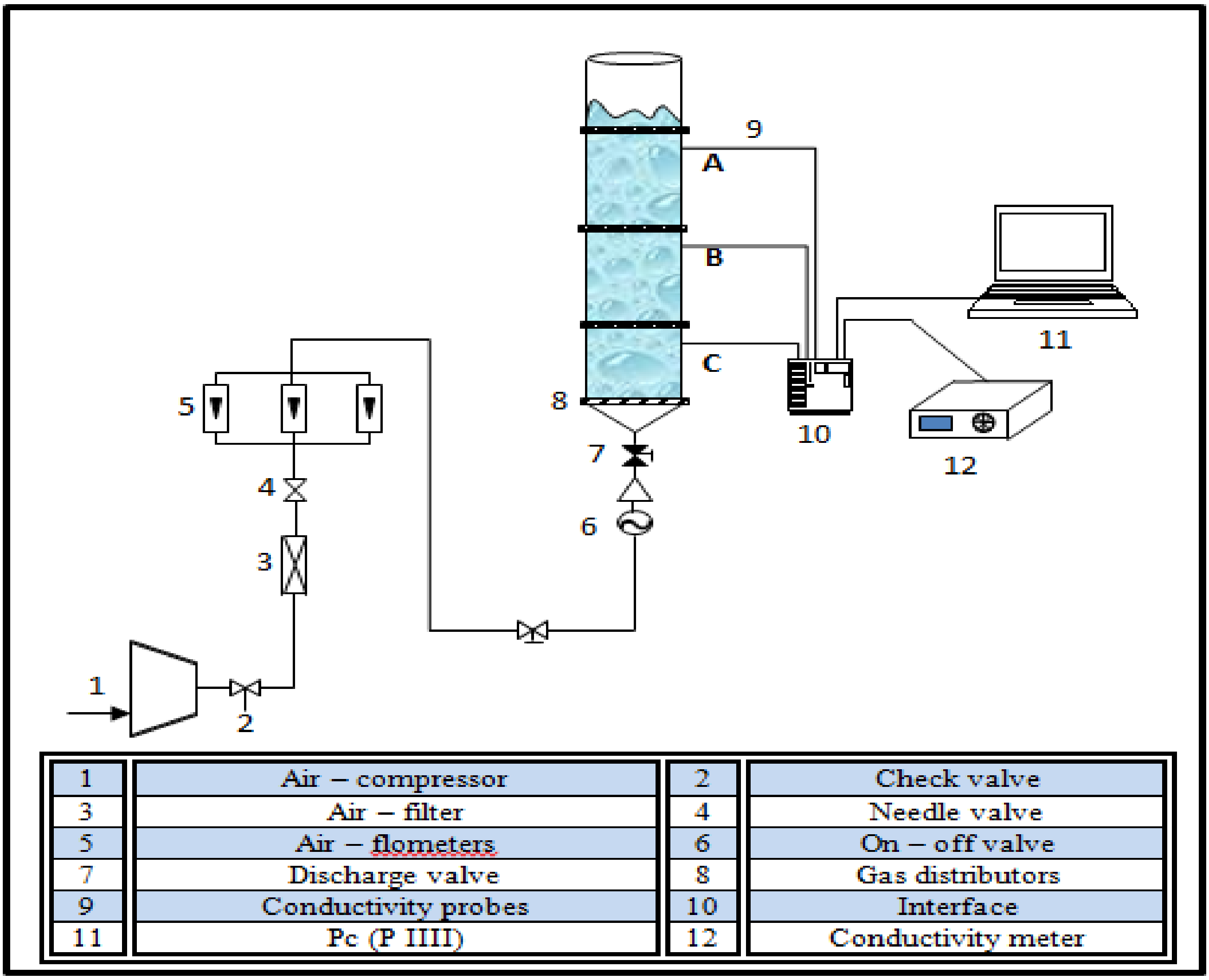

Fig.1. Schematic Diagram of the Experimental Apparatus.

3. Theoretical Analysis

In order to characterize mixing in bubble column, a two dimensional dispersion model has been used. The dimensionless tracer concentration can be written as [14, 5]:

$$C_T = \sum_{n=1}^{\infty} \frac{J_0(\upsilon_n x)}{J_0^2(\upsilon_n \beta)} e^{(-\upsilon_n^2\theta)} \times \left(1+2\sum_{m=1}^{\infty}\cos(m\pi y)\, e^{(-m^2\pi^2\theta)}\right) \qquad \ldots(1)$$

Where:

$$\theta = \frac{D_{ax.L}\, t}{L^2} \qquad \ldots(2)$$

$$y = \frac{z}{L} \qquad \ldots(3)$$

$$C_T = \frac{C - C_0}{C_\infty - C_0} \qquad \ldots(4)$$

Accordingly when C_T in Eq. (1) is radially invariant (i.e. $Dr=\infty$), υ_n, $\beta$and x become zero and $J_{0t}(\upsilon_n\beta)=J_0(\upsilon_n x)=1$. In this case Eq. (1) reduces to:

$$C_T = 1 + 2\sum_{m=1}^{\infty}\cos(m\pi y)\, e^{(-m^2\pi^2\theta)} \qquad \ldots(5)$$

The average axial liquid dispersion coefficient ($D_{ax.L\ av}$) was calculated:

$$D_{ax.L\ av} = \sum_{i=1}^{n} \frac{D_{ax.L}}{n} \qquad \ldots(6)$$

4. Results and Discussion

4.1. Liquid Phase Dispersion in Bubble Column

The conductivity data used for the calculation of dispersion coefficients are smoothed in order to remove the noise that already present due to occasional gas bubbles being in contact with the conductivity probes. A typical set of the pulse-response data and the best fit model curve generated using Eq. (1) is shown in Fig. (2). the value of the radial dispersion coefficient influenced the height of the model generated peak, whereas the value of the axial dispersion coefficient influenced the width of the peak. The solution of Eq. (1) was found by using MATLAB R 2010b program.

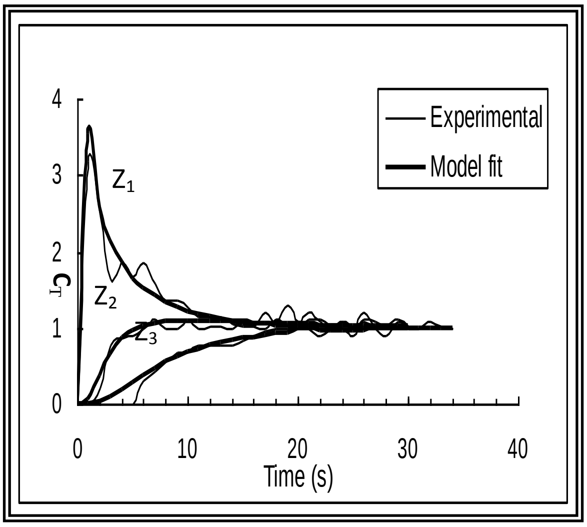

Fig. 2. Typical Conductivity Responses of Different Probes.

4.2. Radial Liquid Dispersion Coefficient (Dr,L)

This work takes into account only the axial (neglecting radial) liquid dispersion. Fig. (3-9) showed that its value does not exceed 1%. This is in agreement with the results obtained by Rubia et al., [5].

The few measurements of radial dispersion coefficients cited by Deckwer [2], suggest that the radial dispersion coefficient is always less than one-tenth of the value of the axial coefficient.

Moreover, Joshi and Sharma [15] showed that the radial component of the velocity, i.e. the component that is relevant to radial mixing, is only about 36% of the axial component. This explains, that the relatively poor radial mixing in bubble columns compared to the axial mixing.

4.3. Axial Liquid Dispersion Coefficient (Dax,L)

The method of calculation of ($D_{ax,L}$) carried out using equations (1) and (5) [i.e., using mathematical models with and without radial dispersion].

4.3.1. Effect of Superficial Gas Velocity (Ug) and Axial Distance of Probe's Location (Z) on Axial Liquid Dispersion Coefficient (Dax,L)

Fig. (3-9) show the effect of superficial gas velocity (U_g) on the axial dispersion coefficient for different axial distance (Z) from the distributor. It can be seen that, the axial dispersion coefficient increases with increase superficial gas velocity (U_g). This can be attributed to the decrease in mixing time which results from the increases of the average liquid circulation velocity (V_C) which increases with the increase of (U_g). This result is in agreement with Therning and Rasmuson [12] and Shah et al., [1].

The axial dispersion coefficient increases slightly with increasing superficial gas velocity in the homogeneous regime (0-4 cm/sec) and then the increasing rate becomes faster in the heterogeneous regime (5-10 cm/sec).

Moreover the axial liquid dispersion coefficient ($D_{ax,L}$) increases with increase of the axial distance (Z). This increases in ($D_{ax,L}$) due to a decrease in bubble rise velocity results from a decrease in bubble diameter and consequently increasing the liquid circulation velocity (V_C), then increase ($D_{ax,L}$). These results are in agreement with Krishna et al., [13].

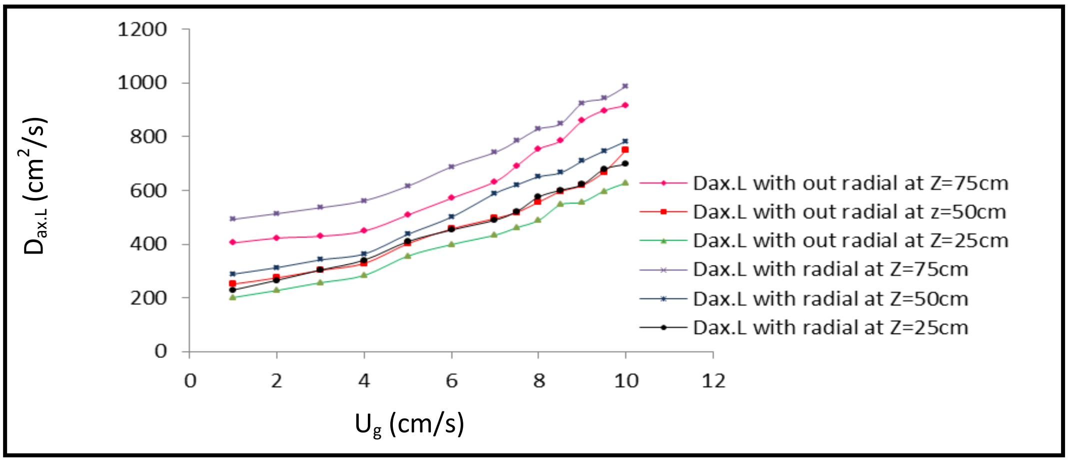

Fig. 3. Effect of Superficial Gas Velocity on Axial Liquid Dispersion Coefficient at Different Z and C_S=0.

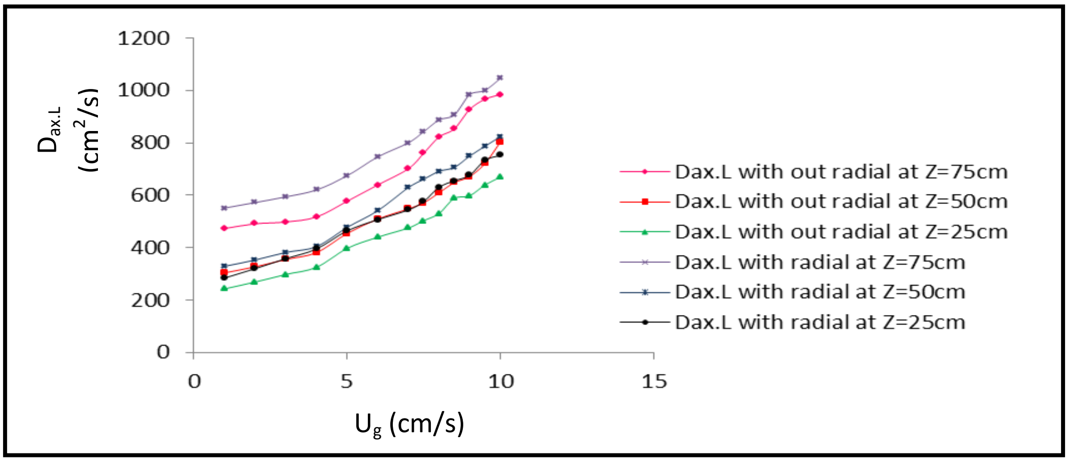

Fig. 4. Effect of Superficial Gas Velocity on Axial Liquid Dispersion Coefficient at Different Z, CS=30 and dp=3mm.

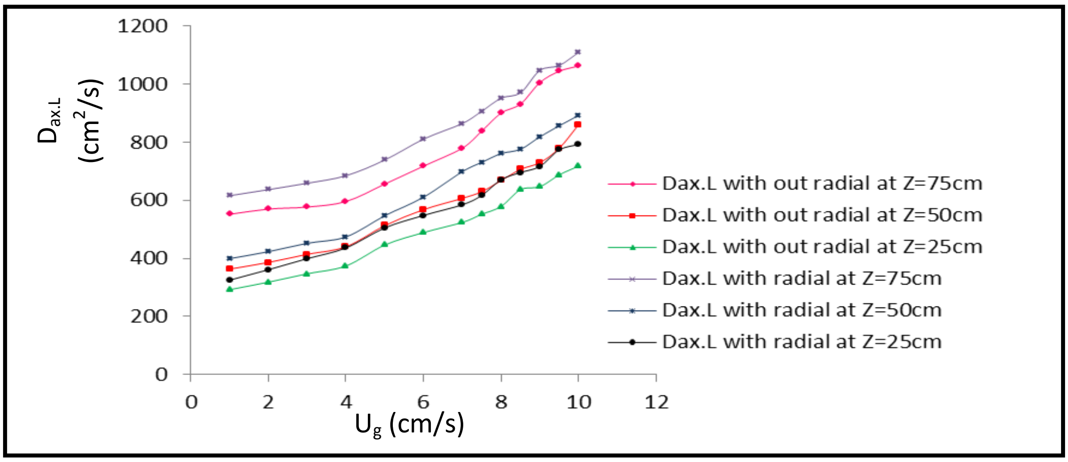

Fig. 5. Effect of Superficial Gas Velocity on Axial Liquid Dispersion Coefficient at Different Z, CS=60 and dp= 3mm.

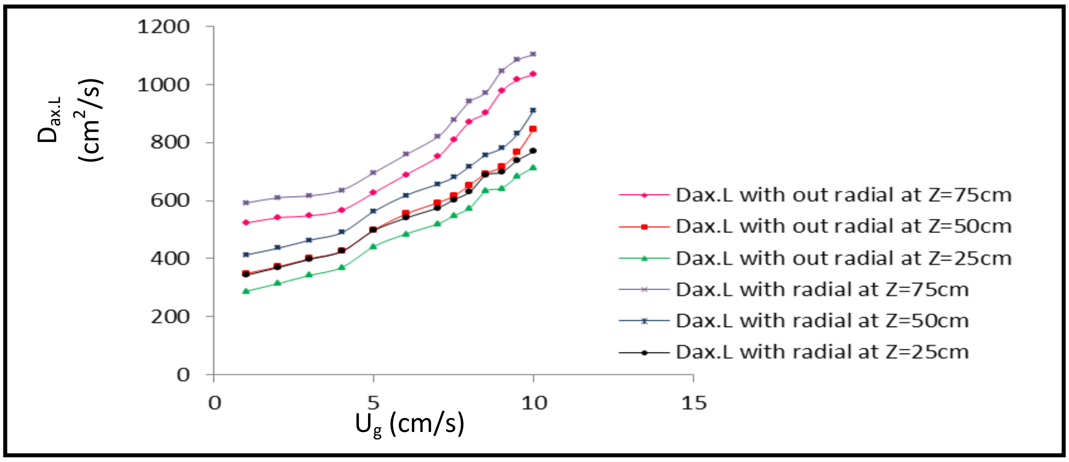

Fig. 6. Effect of Superficial Gas Velocity on Axial Liquid Dispersion Coefficient at Different Z, CS=30 and dp= 1.5mm.

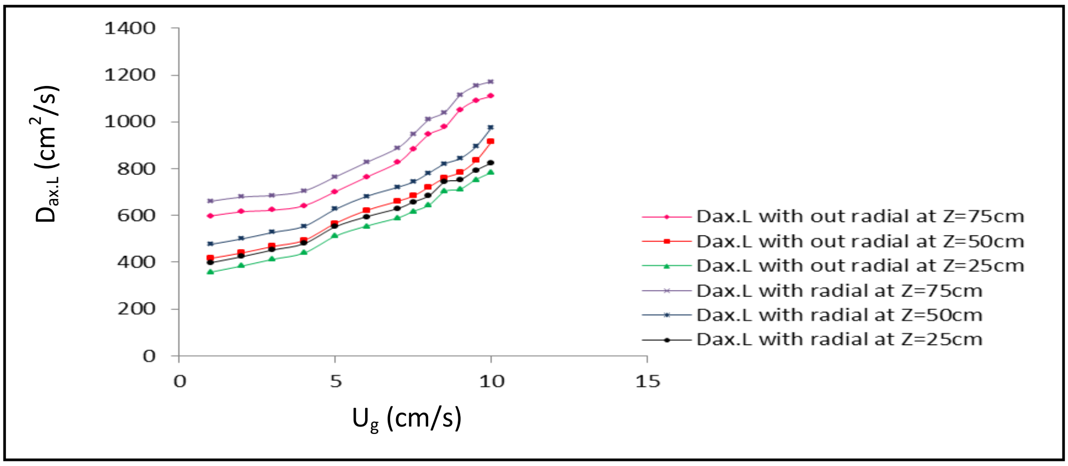

Fig. 7. Effect of Superficial Gas Velocity no Axial Liquid Dispersion Coefficient at Different Z, C_S=60 and dp= 1.5mm.

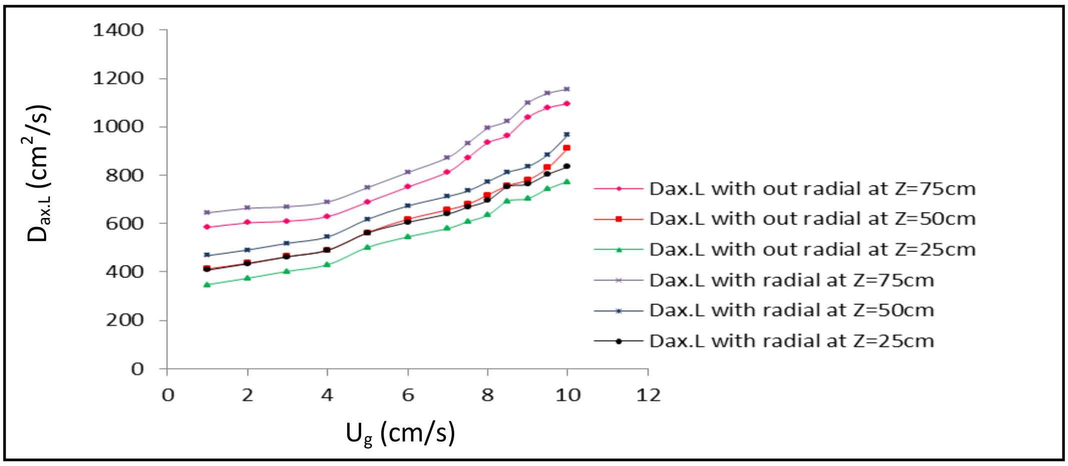

Fig. 8. Effect of Superficial Gas Velocity no Axial Liquid Dispersion Coefficient at Different Z, CS=30 and dp= 0.7mm.

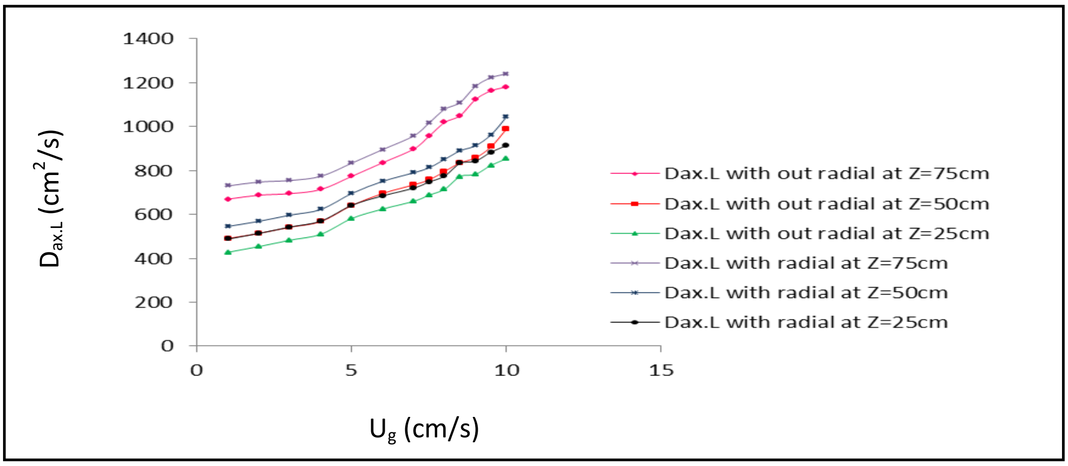

Fig. 9. Effect of Superficial Gas Velocity no Axial Liquid Dispersion Coefficient at Different Z, CS=60 and dp= 0.7mm

4.3.2. Effect of Solid Concentration (Cs) on Axial Liquid Dispersion Coefficient (Dax,L)

Fig. (10-12) show the effect of solid concentration on average axial dispersion coefficient. It can be seen that, the axial dispersion coefficient increases with the increase of solid concentration. This may be due to the fact that when the solid concentration increases lead to higher gas bubble concentration produced. Since the liquid envelopes the gas bubbles, therefore it will be entrained and dragged upwards and also part of gas – liquid dispersion will flow downwards again and consequently causing an increase in the liquid phase dispersion coefficient. These results are in agreement with Deckwer [2].

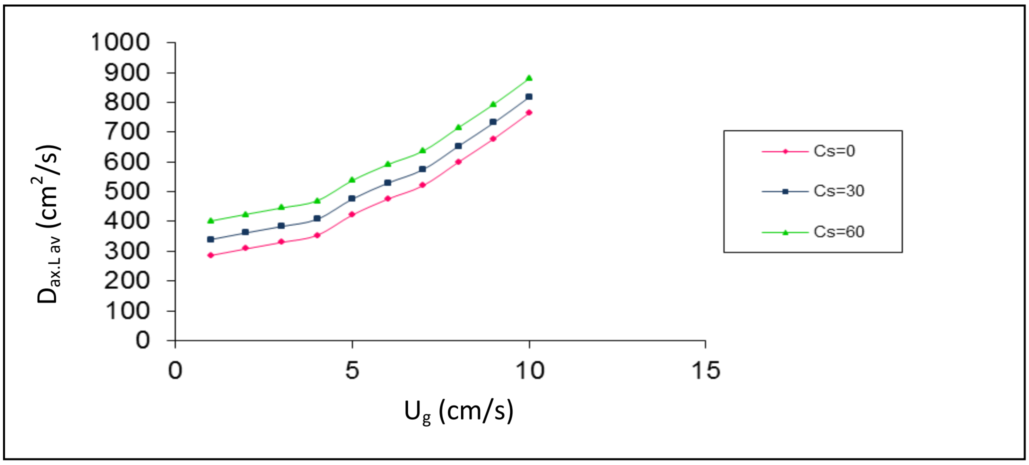

Fig.10. Effect of Superficial Gas Velocity and Solid Concentration on Average Axial Liquid Dispersion Coefficient at dp= 3mm.

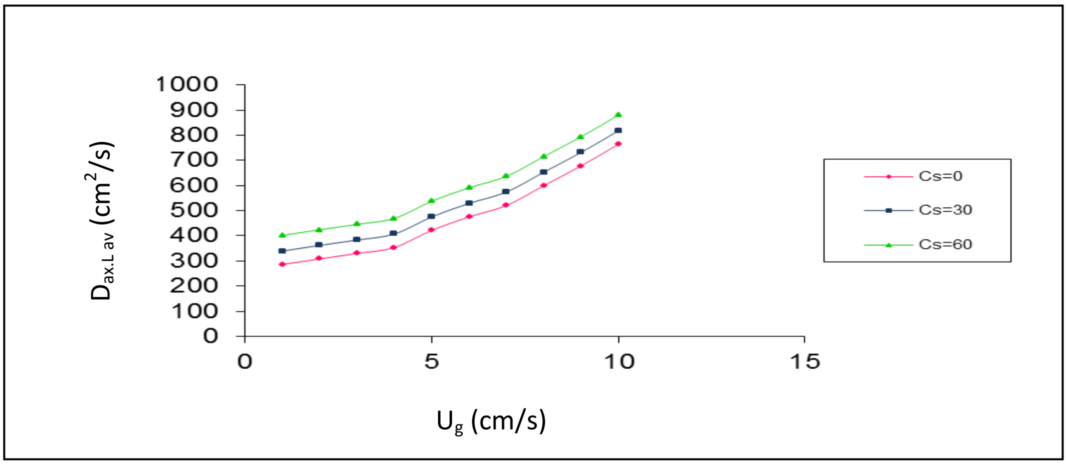

Fig. 11. Effect of Superficial Gas Velocity and Solid Concentration on Average Axial Liquid Dispersion Coefficient at dp= 1.5mm.

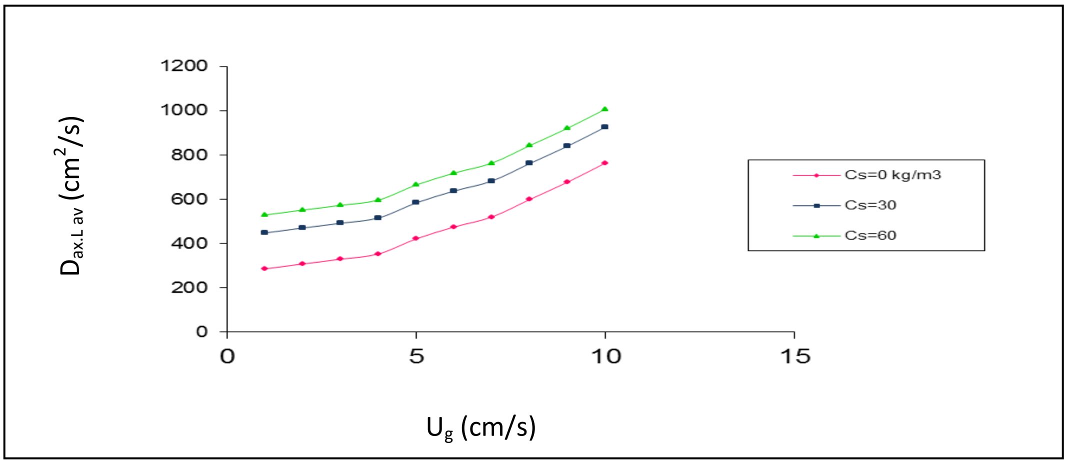

Fig. 12. Effect of Superficial Gas Velocity and Solid Concentration on Average Axial Liquid Dispersion Coefficient at dp= 0.7mm.

4.3.3. Effect of particle diameter (dp) on axial liquid dispersion coefficient (Dax,L)

Fig. (13 and 14) show the effect of superficial gas velocity for various particle diameters. From these figures it can be noticed an inverse relationship between particles diameter and axial liquid dispersion coefficient. This can be attributed to the fact that the bubble rise velocity decreases lead to the rate of bubble coalescence increases as the particles diameter decreases.

The larger bubbles which results from coalescence lead to an increase the axial liquid dispersion coefficient. This result is in agreement with Rubia et al., [5].

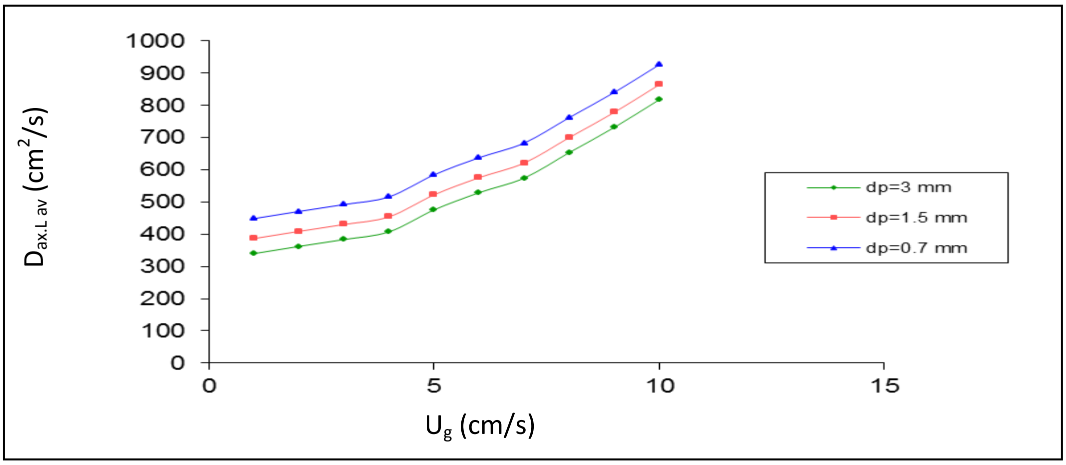

Fig. 13. Effect of Superficial Gas Velocity and Solid Concentration on Average Axial Liquid Dispersion Coefficient at CS= 30kg/m3.

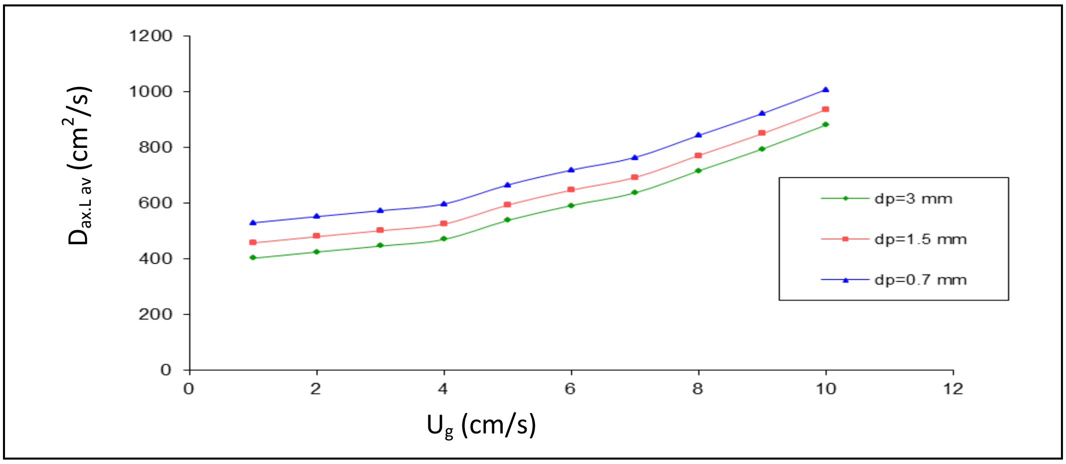

Fig. 14. Effect of Superficial Gas Velocity and Solid Diameter on Average Axial Liquid Dispersion Coefficient at CS= 60kg/m3

5. Conclusions

The following major conclusions can be drawn from the present work.

1. In homogeneous regime (0-4), axial liquid dispersion coefficient increases slightly with increasing superficial gas velocity while it increases rapidly in heterogeneous regime.
2. Increases the axial distance of the probe's location led to increase the axial liquid dispersion coefficient.
3. Increasing solid concentration the gas – liquid flow exhibit higher gas bubble concentration led to increase the axial liquid dispersion coefficient.
4. Axial liquid dispersion coefficient decreases with increasing particle diameter.

Nomenclature

C	tracer concentration, kmol m^{-3}
C_T	Dimensionless tracer concentration defined by Eq. (4)
C_0	initial concentration of the tracer, kmol m^{-3}
C_∞	final or equilibrium concentration of the tracer, kmol m^{-3}
$D_{ax.L}$	axial liquid dispersion coefficient., m^{2}s^{-1}
D_r	radial liquid dispersion coefficient, m^{2}s^{-1}
J_0	zero-order Bessel function
J_1	first-order Bessel function
L	height of dispersion, m
T	time or instantaneous time, s

U_G	superficial gas velocity, ms^{-1}
y	dimensionless axial position
z	axial distance, m
Vc	liquid circulation velocity
C_s	solid concentration, Kg/m^3
dp	particle diameter
n	flow index

Greek symbols

v_n	the *n*th root of the first-order Bessel function
Π	the number pi
θ	dimensionless time
β	parameter in Eq. (1)
m	integer.

6. Reference

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تأثير خواص الصلب على التشتت الطولي للسوائل في ابراج التفقيع

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الخلاصة

اجريت التجارب العملية لدراسة معامل التشتت الطولي في ابراج التفقيع (للسوائل العالقة) ذو قطر داخلي 0.15م وارتفاع 1.6م بأستخدام صفيحة مثقبة لتوزيع الهواء تحوي على 54 فتحة بقطر 1ملم مع 0.24 نسبة مساحة حرة للفتحات الى المساحة المقطعية. بأستخدام نظام ثلاثي متكون من الهواء – الماء – الصلب (بولي فينيل كلورايد). أستخدمت تراكيز مختلفة من المادة الصلبة (0 ، 30، 60 كغم / م^3) واقطار للصلب (0.7 ، 1.5 ، 3 ملم) لدراسة تأثيرها على معامل التشتت الطولي وابعاد طولية مختلفة (25 ، 50 ، 75 سم) وسرعة غاز (1 – 10 سم/ثا) لتغطي المنطقة المتجانسة والغير متجانسة. اظهرت النتائج زيادة معامل التشتت الطولي للسائل مع ازدياد سرعة الغاز والبعد الطولي وتركيز الصلب ونقصان المعامل مع قطر الصلب