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Bubble Column Hydrodynamic Study with Experimental Investigation and CFD Computations

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ABSTRACT

By achieving simulation of hydrodynamics in a bubble column reactor, have taken an important step towards designing an efficient slurry reactor for large-scale conversion of synthesis gas to liquid hydrocarbons. The simulation allows determining gas holdup, a key variable affecting the reaction rate of gas-to-liquid (GTL) conversion using Fischer-Tropsch (FT) chemistry. This work have two parts, the first part experimental work with bubble column with specific conditions and the second deals with computational fluid dynamics *CFD* for bubble column have the same geometry and operating conditions. This study is to clarify experimentally the effect of superficial gas velocity on the gas holdup, and the mass transfer coefficient (k_La) where each of them increases as the superficial gas velocity increase. *NaCl* addition will increase the transition velocity and the gas holdup for certain concentration and superficial gas velocity

2-D simulation was applied in this work. Gas holdup computational results using *ANSYS CFX* used on Eulerian-Eulerian multiphase model have been compared to experimental data. These results for air-water system were encouraging against the experiment results.

INTRODUCTION

Bubble columns or airlifts are widely used in the chemical industry where hetero-geneous gas-liquid or gas-solid reactions take place, particularly, in which the liquid film controls mass transfer processes due to the relative insolubility of gases *[V?zquez et al., 2000; Lye and Stuckey, 2001]*. Important applications of bubble columns include oxidation, hydrogenation, ozonolysis, alkyl-ation, column flotation, wastewater treat-ment, etc. *[Yang et al., 2001; Wu et al., 2002]*. The design parameters for bubble columns are: gas-liquid specific interfacial area *a*, individual mass transfer coefficient k_L, flow regime, bubble size distribution, and coalescence of bubbles. Most studies on bubble columns were devoted to the experimental determination of some of these parameters, and more specifically, of the volumetric mass transfer coefficient, k_{La}, which depends fundamentally on the superficial gas velocity and on the physical properties of the absorption phase. Numerous correlations have been proposed for the superficial velocity of the gas as well as for the viscosity of the liquid phase *[Joshi, 2001; Mitsuharu et al., 2001]*.

Experimental Work

The experimental apparatus used in this work is shown in figure (1), the bubble column made of transparent plexiglass of 0.081 m in diameter and 1.03 m height. Porous distributor was used as gas distri-butor. Tap water at room temperature was used (28-31 °C) as liquid phase in the experiments, but results were also obtained for many concentrations of *NaCl* which are (0.24, 0.30, 0.36, 0.42, 0.6, 0.8) M *NaCl*.

As shown in figure (1), the base that holds the column has a regulator screws to ensure exact verticality of the column with effective liquid height of 0.7 m. Runs were performed with different superficial gas velocities with the range from 0.009657 m/s to 0.131521 m/s. The systems that used in this work are air-water, air-*NaCl* solution of different concentrations, and CO_2-water.

In this work 3-D CFX was used demonstrates the Eulerian-Eulerian multi-phase model to evaluate the gas holdup. The experiments were performed in bubble column with 0.081 m diameter and with air-water at atmospheric pressure. The following parameters were used: air volume fraction of 0.25, air inlet velocity close to the terminal velocity, water inlet velocity zero, and symmetry planes for the cross sections.

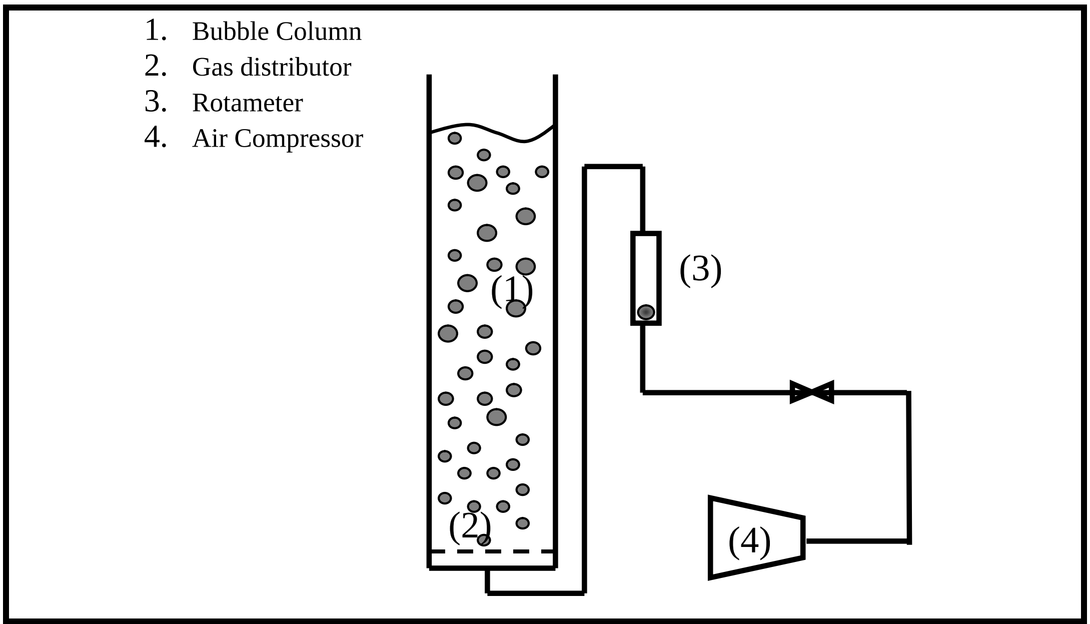

Figure (1) Schematic Diagram of Experimental Apparatus.

PROCEDURE

The column was filled with water; the liquid height was 0.7 m initially, gas was taken from compressor; the desired flow rate was measured by rotameter.

The overall gas liquid level measured to determine the gas holdup (foam, if present, was not included). The above procedure was repeated with a new gas velocity for the three systems: air-water, CO_2-water, air-*NaCl* solutions of six different concentrations. Gas holdup calculation based on measurements of the bubble column in the laboratory, using the following equation:

$$\varepsilon_G = \frac{h_i - h}{h_i} \qquad \ldots 1$$

where

h_i = total height of liquid and gas

h = height of standing water

Result and Discussion

Three variables were used in semi-batch bubble column, which included superficial gas velocities, two types of gases, and the concentration of *NaCl*.

The effect of superficial gas velocity on gas holdup can be shown in figure (2) to (5). These figures indicated that the gas holdup increases with increasing superficial gas velocity. This is due to the fact that higher superficial gas velocity gives bubbles with lower rising velocity. This will lead to form large residence time and hence higher gas holdup.

Tap water with aqueous solution with different commercial *NaCl* concentration was used. As shown in figures (2) and (3) the addition of *NaCl* with (0.24, 0.36) M will increase the gas holdup as compared with that of water for superficial gas velocity below 0.03 m/s.

This is because of *NaCl* acts that prevent coalescence by the repulsive forces that acts and the bubbles unable to coalescence.

As shown in figures (2) and (3) the gas holdup curve of *NaCl* solution fall below that of water for superficial gas velocity above 0.03 m/s. At this velocity the sudden formation of spherical cap bubbles that could be observed caused this falling.

As shown in figures (3) and (4), for concentration of 0.36 and 0.42 M *NaCl* and superficial velocity below 0.03 m/s, the gas holdup decrease until the gas holdup curve of 0.42 M take the same behavior of water curve.

As show in figures (5) for high *NaCl* concentration and for superficial gas velocity below 0.06 m/s, the gas holdup curve of *NaCl* solution fall below that of water, this is due to increasing *NaCl* ions which are (Na^+, Cl^{-1}) in the solution that will overcome the water ions so that the coalescence property will stop causing the formation of large bubbles and then decreasing the gas holdup.

When the gas velocity increases above 0.06 m/s these large bubbles will break-up into small bubbles this caused increasing the gas holdup.

As shown in figures (6) to (10) the intersection of the two lines represents transition velocity from bubbly to churn turbulent flow. These results show that the transition velocity from bubbly region to turbulent region increases as the *NaCl* concentration increase. This is because of the effect of salts that preventing coalescence between the bubbles. This will lead to increase the laminar region range and hence increase the transition velocity to the turbulent region.

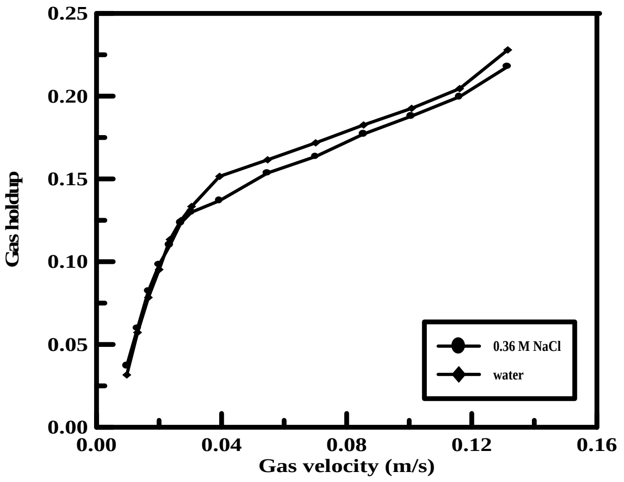

Fig. (2) Gas holdup vs. superficial gas velocity for water and 0.36 M *NaCl*

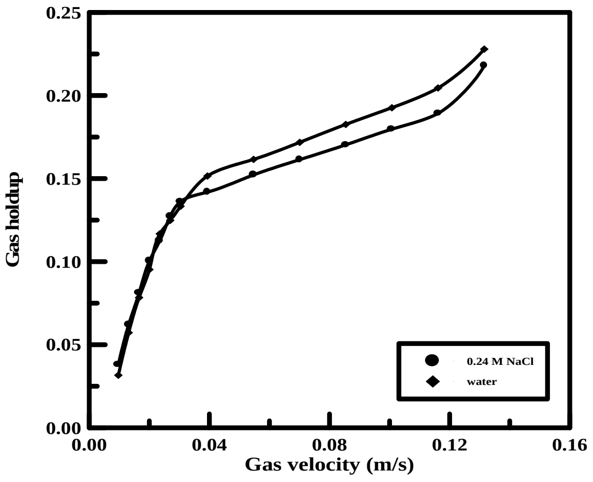

Fig.(3) Gas holdup vs. superficial gas velocity for water and 0.24 M *NaCl*.

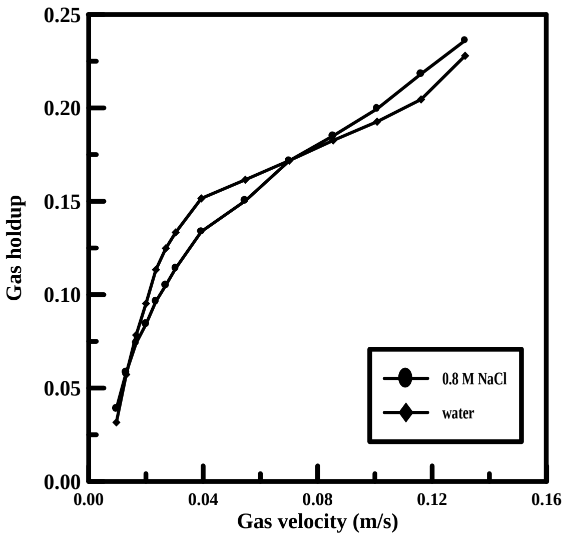

Fig. (4) Gas holdup vs. superficial gas velocity of water and 0.8 M *NaCl.*

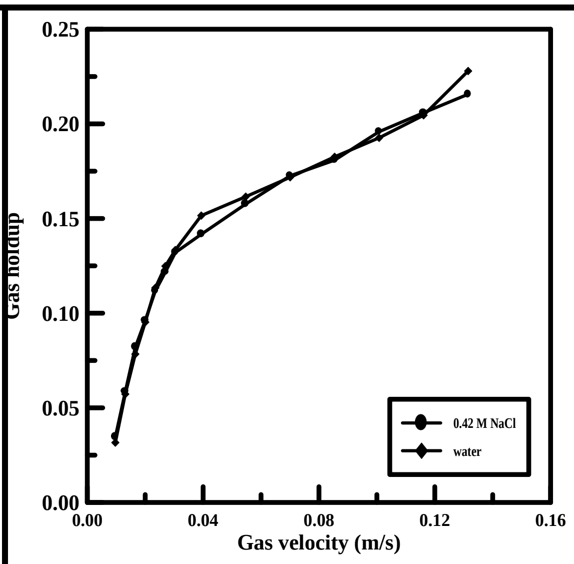

Fig. (5) Gas holdup vs. superficial gas velocity of water and 0.42 M *NaCl.*

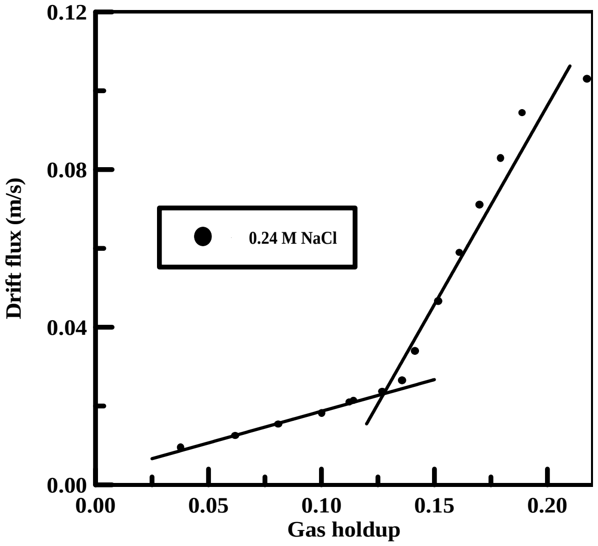

Fig. (6) Gas holdup vs. Drift flux for (air- 0.24 *NaCl*)

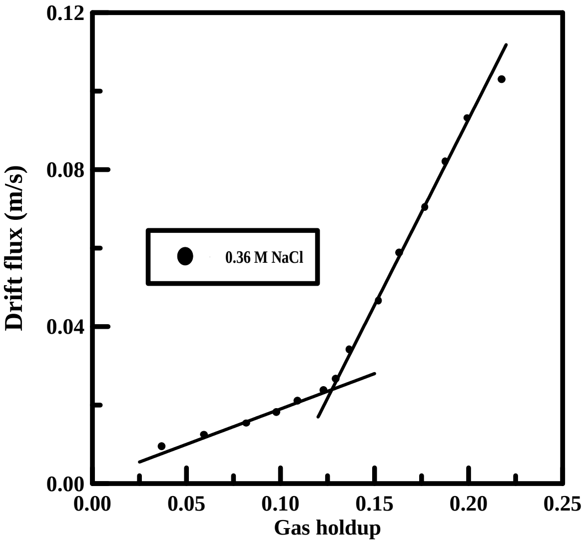

Fig. (7) Gas holdup vs. Drift flux for (air- 0.36 *NaCl*)

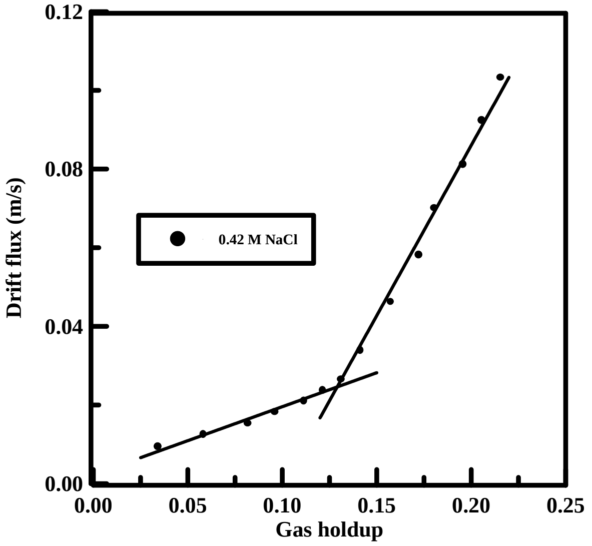

Fig. (8) Gas holdup vs. Drift flux for (air- 0.42 *NaCl*)

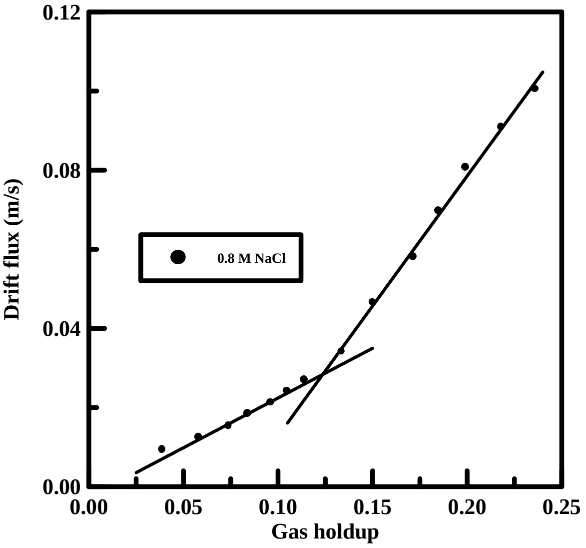

Fig. (9) Gas holdup vs. Drift flux for (air- 0.8 *NaCl*)

In this work 3-D CFX demonstrates the Eulerian-Eulerian multiphase model to evaluate the gas holdup. The following figures show contours of air volume fraction at different superficial gas velocity:

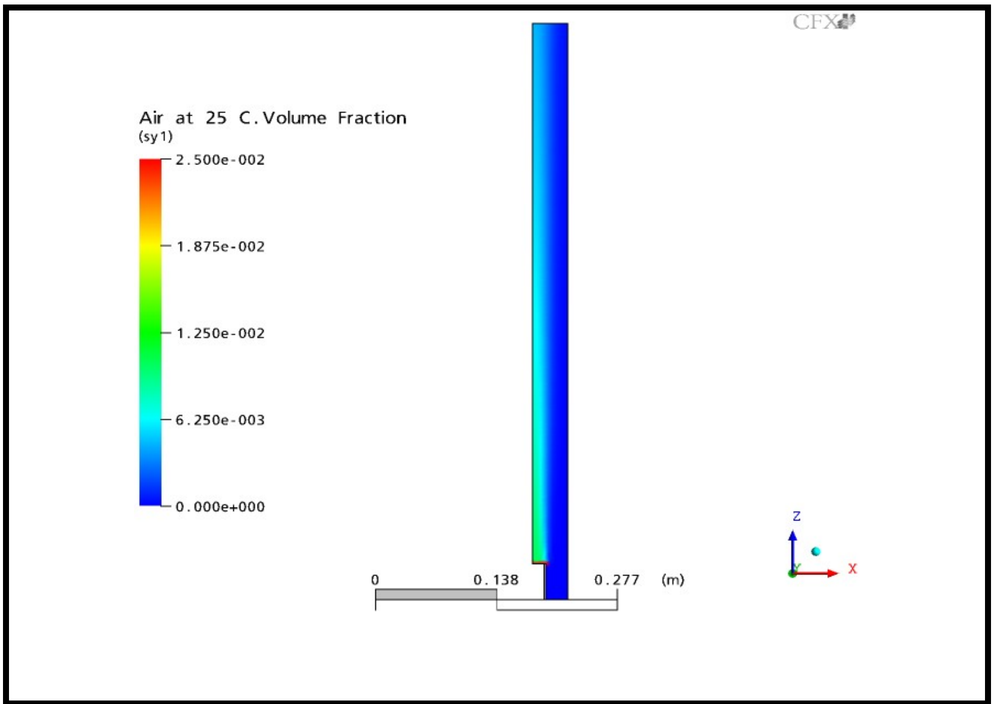

Fig. (6) Results showing contours of air volume fraction at 0.009657 m/s superficial gas velocity

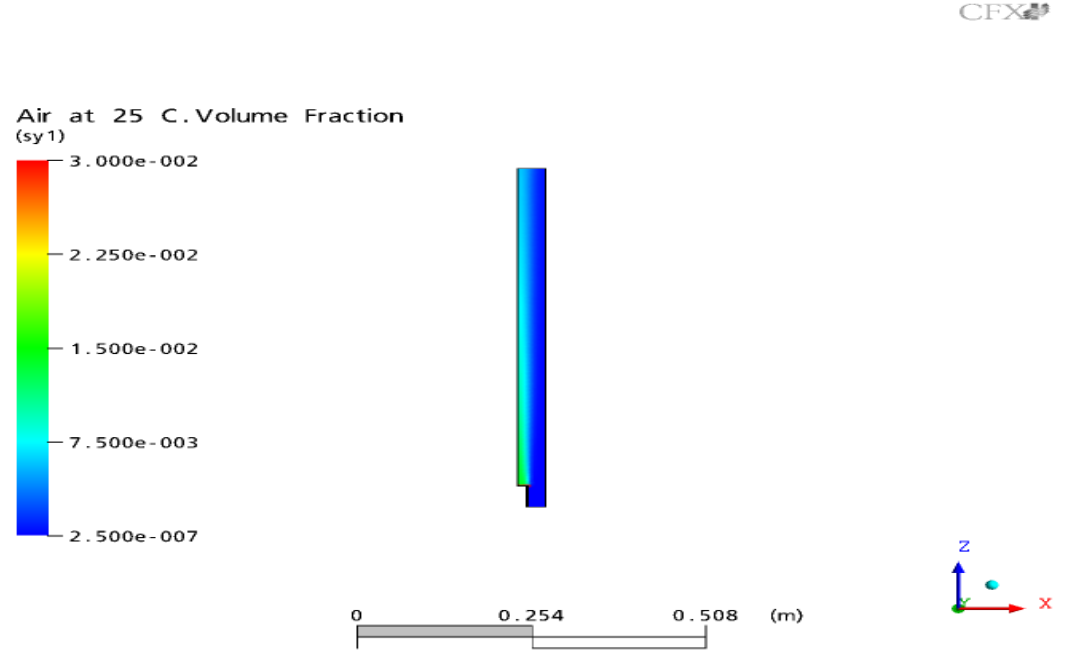

Fig. (7) Results showing contours of air volume fraction at 0.013114 m/s superficial gas velocity

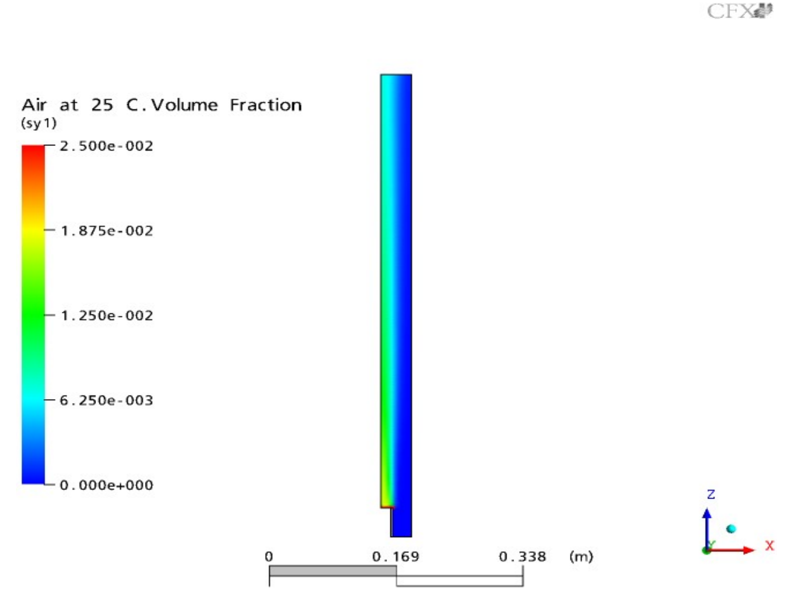

Fig. (8) Results showing contours of air volume fraction at 0.01657 m/s superficial gas velocity

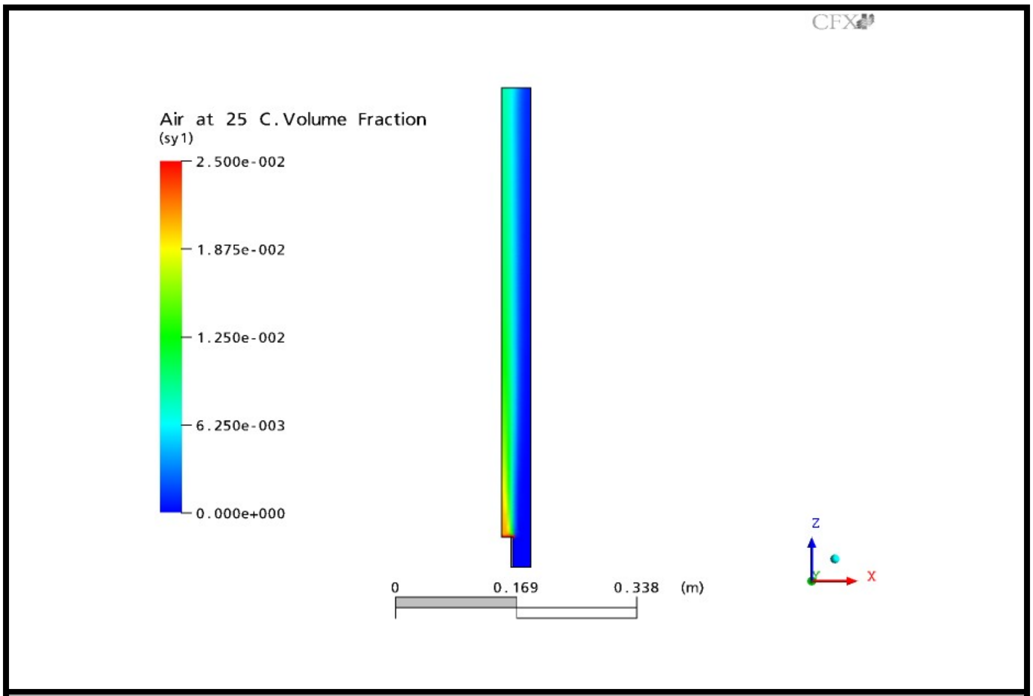

Fig. (9) Results showing contours of air volume fraction at 0.020026 m/s superficial gas velocity

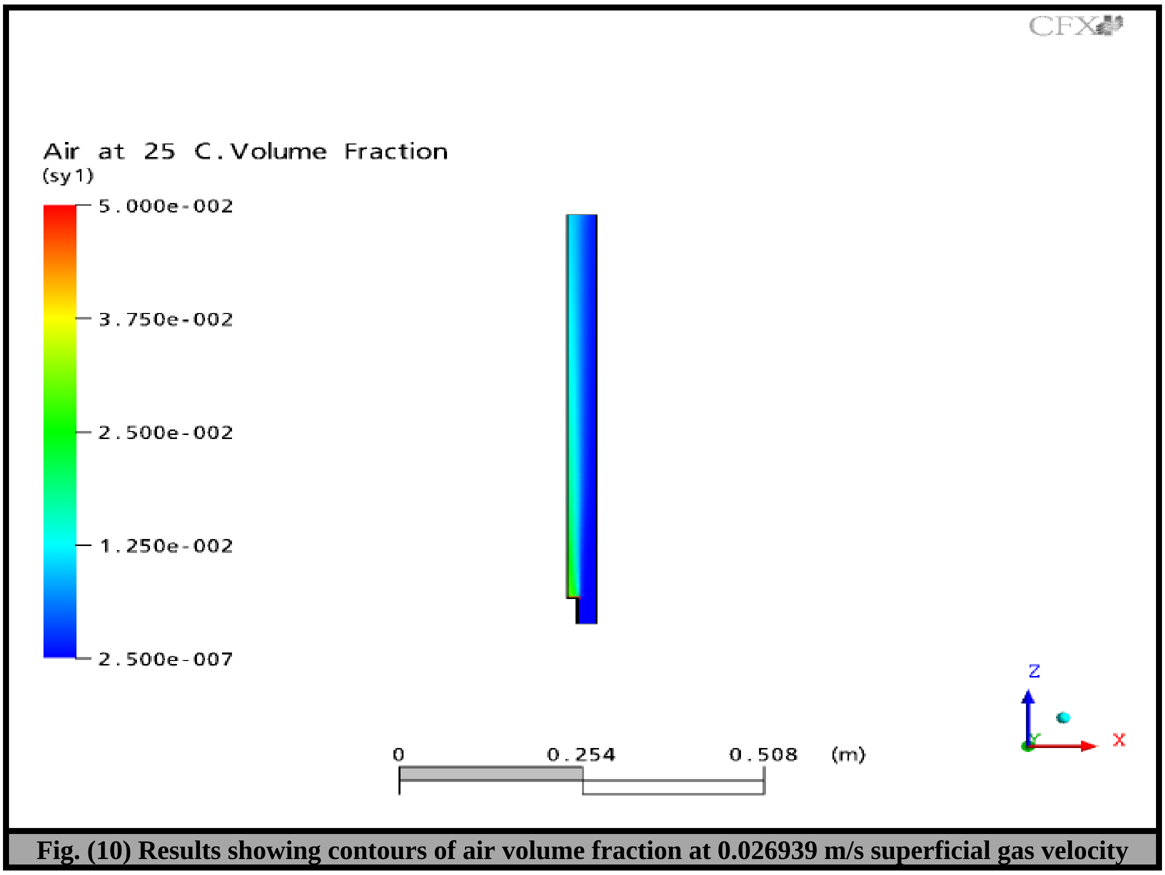

Fig. (10) Results showing contours of air volume fraction at 0.026939 m/s superficial gas velocity

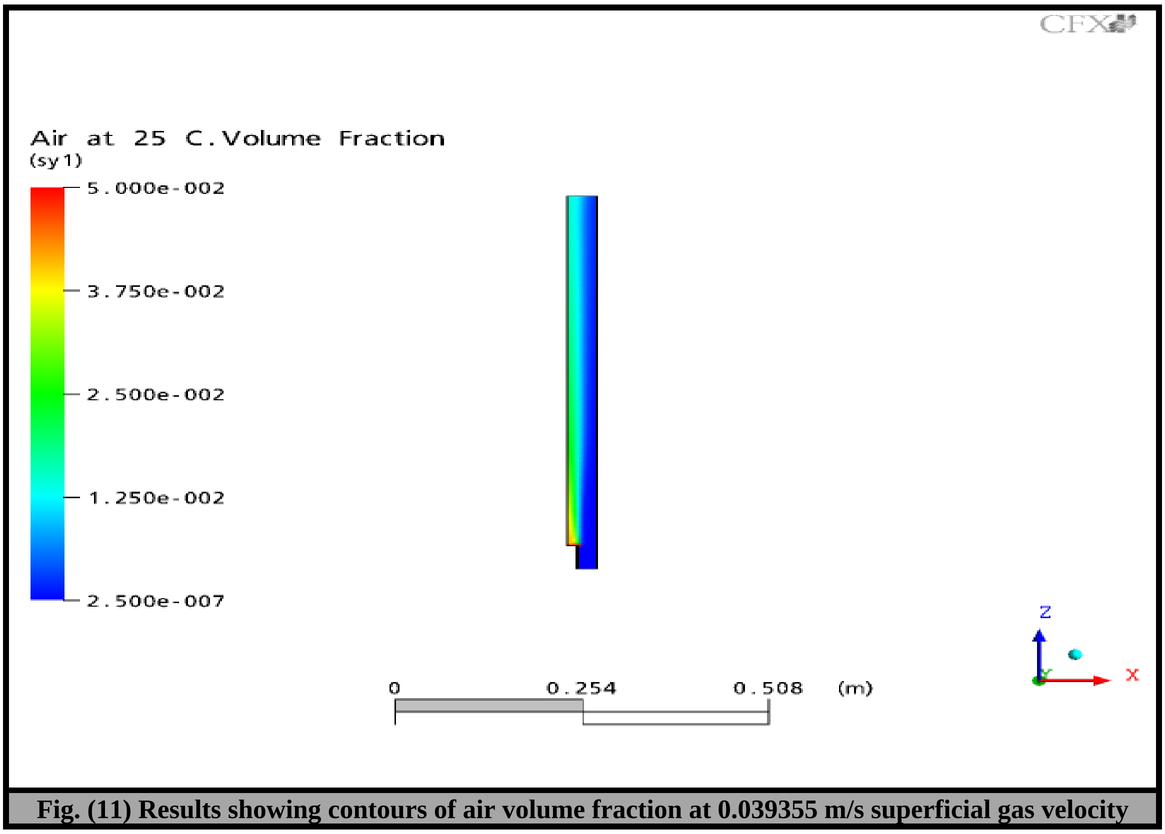

Fig. (11) Results showing contours of air volume fraction at 0.039355 m/s superficial gas velocity

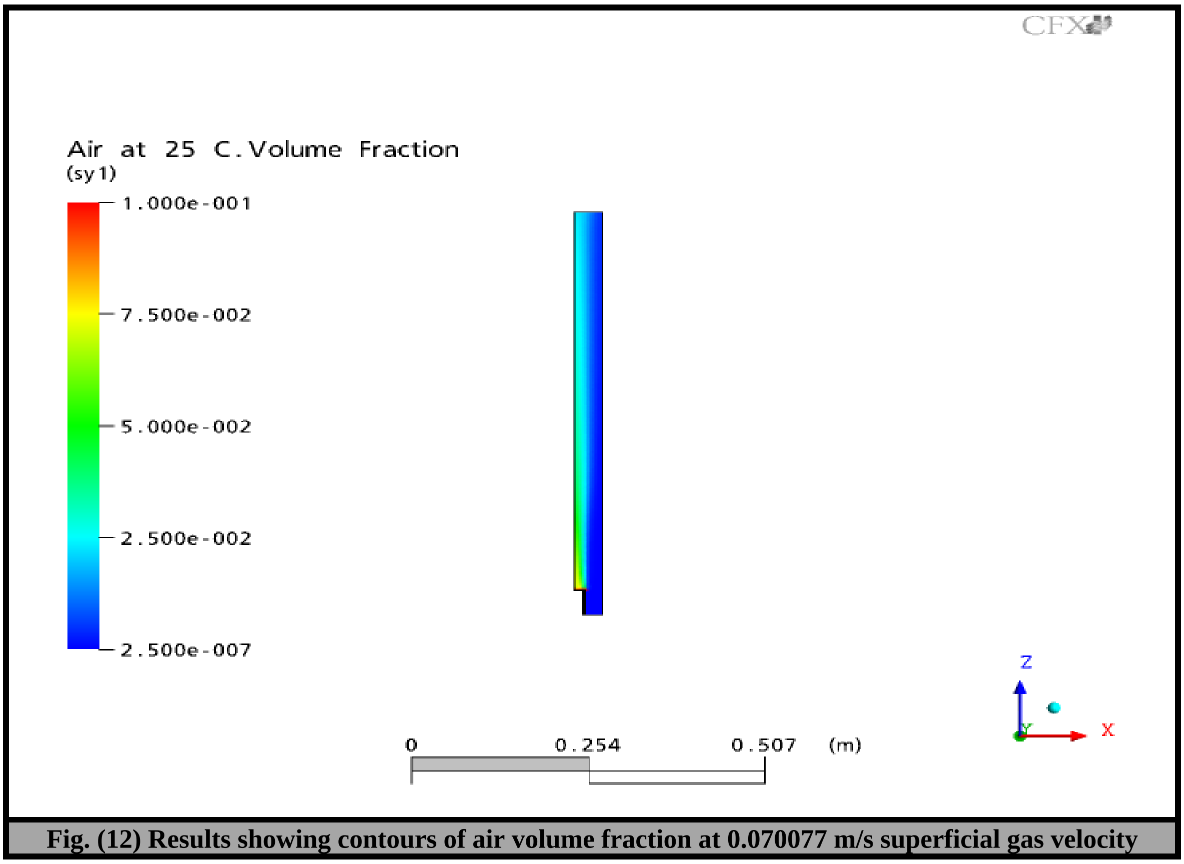

Fig. (12) Results showing contours of air volume fraction at 0.070077 m/s superficial gas velocity

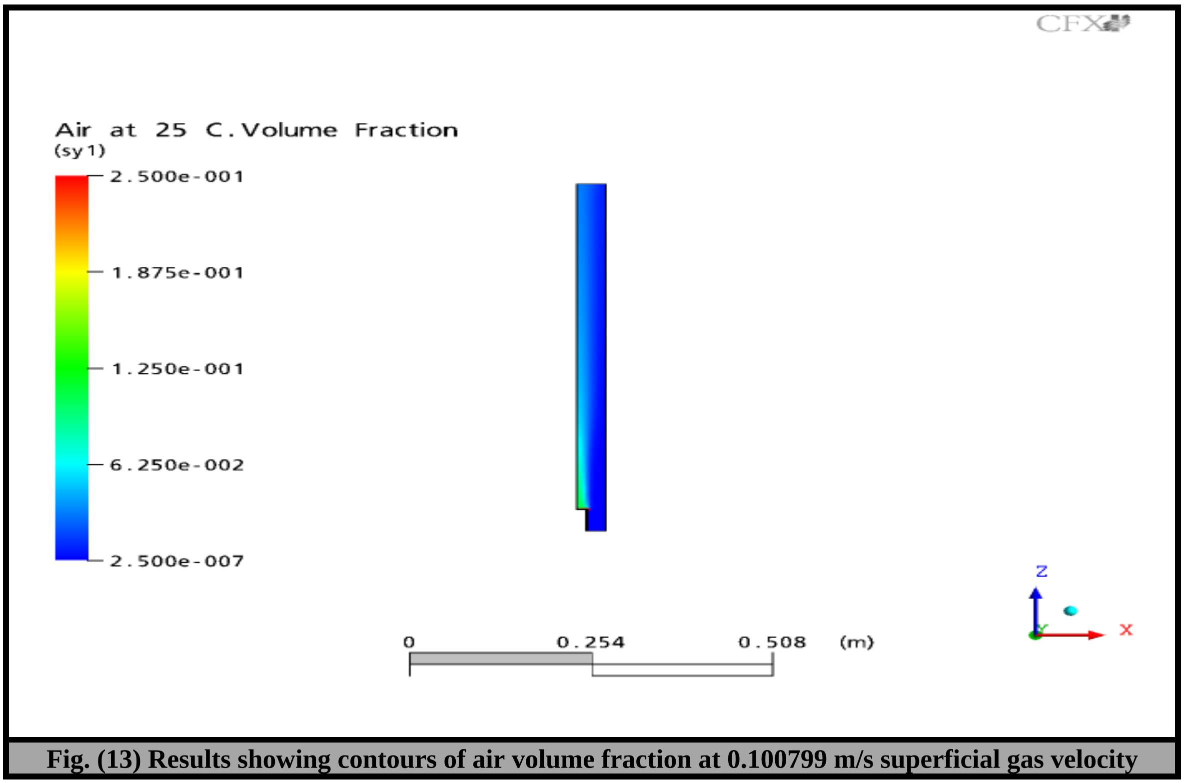

Fig. (13) Results showing contours of air volume fraction at 0.100799 m/s superficial gas velocity

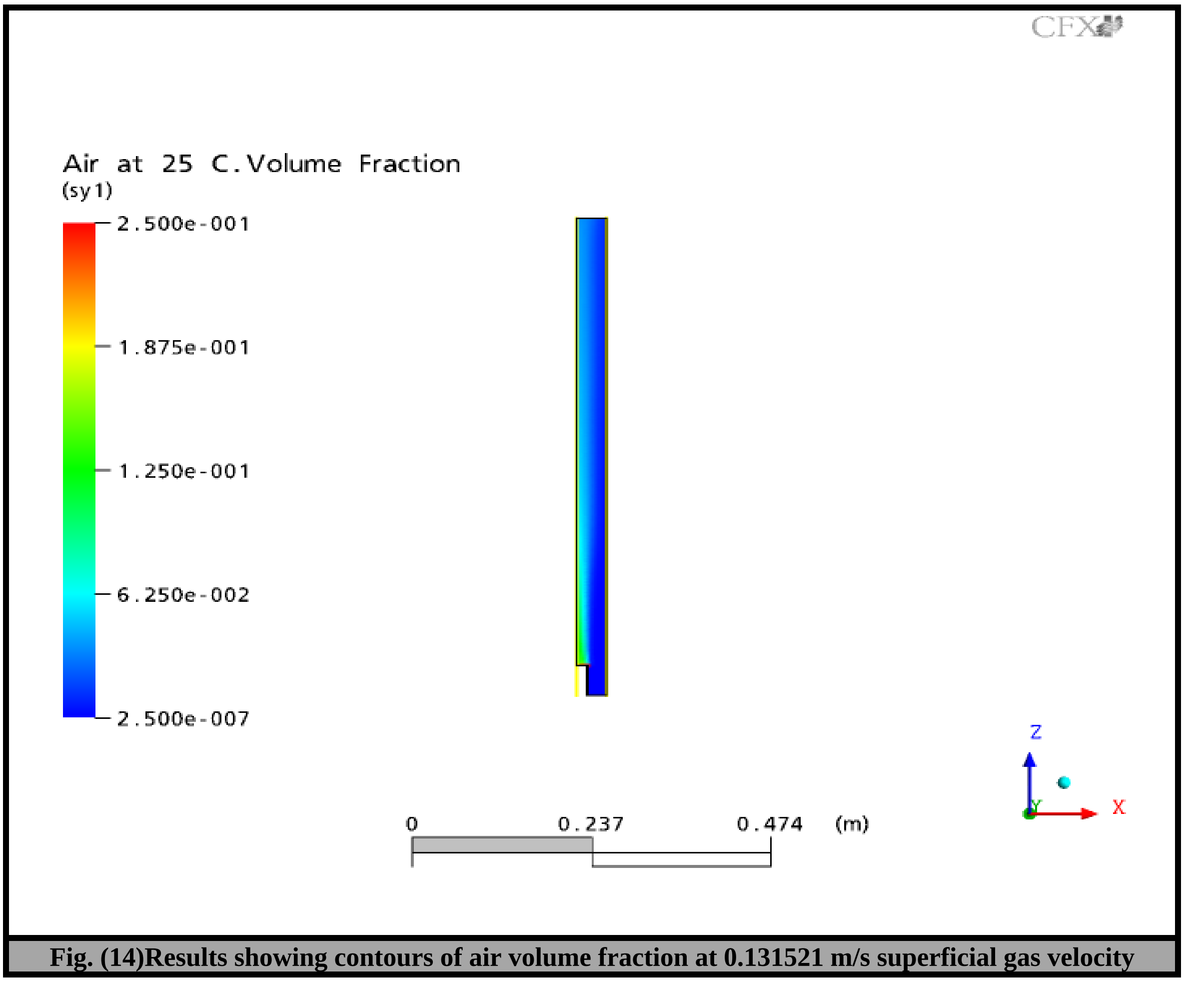

Fig. (14)Results showing contours of air volume fraction at 0.131521 m/s superficial gas velocity

Conclusions

Increasing the superficial gas velocity leads to increase in gas holdup for the three systems and the mass transfer coefficient. At the critical concentration of *NaCl* solution, which is *0.42 M*, the gas holdup curve takes the same behavior of water gas holdup curve.

The addition of *NaCl* concentration below the critical concentration will increase the gas holdup for superficial gas velocity below 0.03 m/s compared to that of water while for higher velocity the gas holdup curve falls below of water with slightly increasing in the gas holdup as the *NaCl* concentration increase. The addition of *NaCl* with concentration above the critical concentration and for superficial velocity below 0.06 m/s will decrease the gas holdup compared to that of water. When the superficial gas velocity increased above 0.06 m/s the gas holdup will increase.

The transition velocity from bubbly flow to churn turbulent flow increase with increasing the concentration of *NaCl.* This is because of the effect of salts that preventing coalescence between the bubbles that will lead to increase the laminar region range and hence increase the transition velocity to the turbulent region.

Computational results have been compared to experimental data. The theoretical results were multiplied by factor 10 because of the difference in the distributor porosity between the simulation and the experimental work.

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NOMENCLATURE

a	Specific gas-liquid interfacial area based on aerated volume	m^{-1}
h_i	Dispersion height	m
h	Initial height	m
k_L	Individual mass transfer coefficient	$m.s^{-1}$
k_La	Volumetric mass transfer coefficient	s^{-1}
ε	Phase holdup	-

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المستخلص

بالوصول الى الموائمة الهادرويناميكية للاعمده الفقاعيه التي تعتبر خطوة مهمة باتجاه التصميم لهذه الاعمدة في العمليات الصناعيه. تمكن الموائمة من حساب معامل احتجاز الغاز كعامل مهم في سرعة التفاعلات على سبيل المثال عملية فيشر تروبش.

العمل يتضمن جزئين اولهما اجراء التجارب العملية والاخر اجراء الموائمة بواسطة الديناميكية الحسابية للمائع للعمود الفقاعي لنفس الابعاد للعمود المستخدم في التجارب.

الغرض من هذه التجارب هو دراسة تاثير كل من سرعة الغاز، اضافة ملح كلوريد الصوديوم بتراكيز مختلفة على معامل احتجاز الغاز و السرعه الانتقاليه. تمت دراسة تاثير سرعة الغاز على معامل انتقال الكتله ايضا.

التجارب وضحت ان معامل احتجاز الغاز يزداد بزيادة سرعة الغاز وكذلك معامل انتقال الكتله وعند اضافة كلوريد الصوديوم يزيد السرعه الانتقاليه.

الموائمة الثنائية الابعاد استخدمت بواسطة برنامج تشغيلي *ANSYS CFX* الذي يعتمد على لطريقة الرياضية Eulerian-Eulerian ومقارنتها مع النتائج العملية وكانت الطريقة الحسابية مشجعة لتقاربها من النتائج العملية.