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STUDIES ON HYDRODYNAMICS, MIXING TIME AND RESIDENCE TIME DISTRIBUTION BEHAVIOUR OF EXTERNAL LOOP AIRLIFT REACTOR

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ABSTRACT: Mixing is one of the important unit operations in chemical and allied industries. Airlift reactors are known to be efficient contactors for processes involving gases, liquids and solids. Airlift reactors are mostly used in biological processes, aerobic waste water treatment, fermentation processes. In the present work focused on investigation of hydrodynamics and mixing index behavior (i.e., gas holdup, residence time distribution) in an external-loop airlift reactor and a stimulus-response tracer technique were used in the measurements. The geometry of External loop airlift reactor of column diameter 100mm and height 1000mm. Pressure drop, Gas hold-up, Mixing time, Residence time distribution have been measured for various electrolytes and solvents with various concentrations have been studied. In addition, the effects of superficial gas velocities on the gas holdup and RTD were also investigated. Comparisons made on both electrolytes and solvents by graphically.

Keywords: external loop airlift reactor, electrolytes, solvents, gas holdup, pressure drop, mixing time, residence time distribution

INTRODUCTION

The airlift reactor (ALR) is a multiphase reactor which is used in gas–liquid or gas–liquid–solid pneumatic contacting devices that are characterized by fluid circulation. It is also defined as a cyclic pattern through channels built specifically for this purpose.. Recent literature reveals that 80% of losses in process is due to improper mixing. Mixing can be achieved in two ways one with moving parts and another without moving parts. Batch and flow reactors come under the first category. The second category includes bubble column, fluidized bed and air lift reactor. The main difference between ALRs and bubble columns (which are also pneumatically agitated) lies in the type of fluid flow, which depends on the geometry of the system. This class of reactor is very attractive for use in the chemical process industry and biotechnology due to their design flexibility, low power requirement, and less pressure drop with further advantages of good mass and heat transfer. The rate of liquid circulation depends on gas flow rate. Two basic classes of the gas lift are distinguished: (i) the internal-loop gas lift reactor (IL-ALR) and (ii) the external-loop gas lift reactor (EL-ALR). The External loop airlift reactor has greater flexibility (Weiland and Onken, 1981) and its performance could be manipulated better by controlling parameters for the individual sections. EL-ALR is selected in this study. Gas holdup is an important hydrodynamic parameter in the reactor. It affects to mass and heat transfer in the system. Gas holdup measurements usually provide overall average information, i.e.

level measurement, pressure measurement. However, local gas holdup information is important for accuracy design and performance prediction. The residence time distribution (RTD) is one of the most informative characterizations that describe mixing behavior in a reactor. The knowledge of the liquid RTD is important for a number of reasons (Danckwerts, 1953) allowing an accurate kinetic modeling of the system, help reactor design to achieve or preserve a desired flow pattern, and to compare the behavior of real reactors to their ideal models. A stimulus-response tracer technique is a well-established method in investigation of a flow process dynamics and evaluation of residence time distribution (RTD). The principle of a tracer experiment consists of a common impulse-response method: injection of a tracer at the inlet of a system followed by the measurement of some relevant property of the outlet solution (e.g. the solution electrical conductivity) is the most commonly used RTD experiment in loop reactors. Therefore, this work focused on investigation of hydrodynamics and mixing index behavior (i.e., gas holdup, residence time distribution) in an external-loop gas lift reactor and a stimulus-response tracer technique were used in the measurements. In addition, the effects of superficial gas velocities on the gas holdup and RTD studies were also investigated. The main objective of the project is (i) To study the effect of hydrodynamics characteristics of gas and liquid phase in an external loop airlift reactor. (ii)To study mixing time and Residence Time Distribution (RTD) characteristics of external loop airlift reactor. (iii) Model was developed based on the experimental results

2. EXPERIMENTAL SECTION

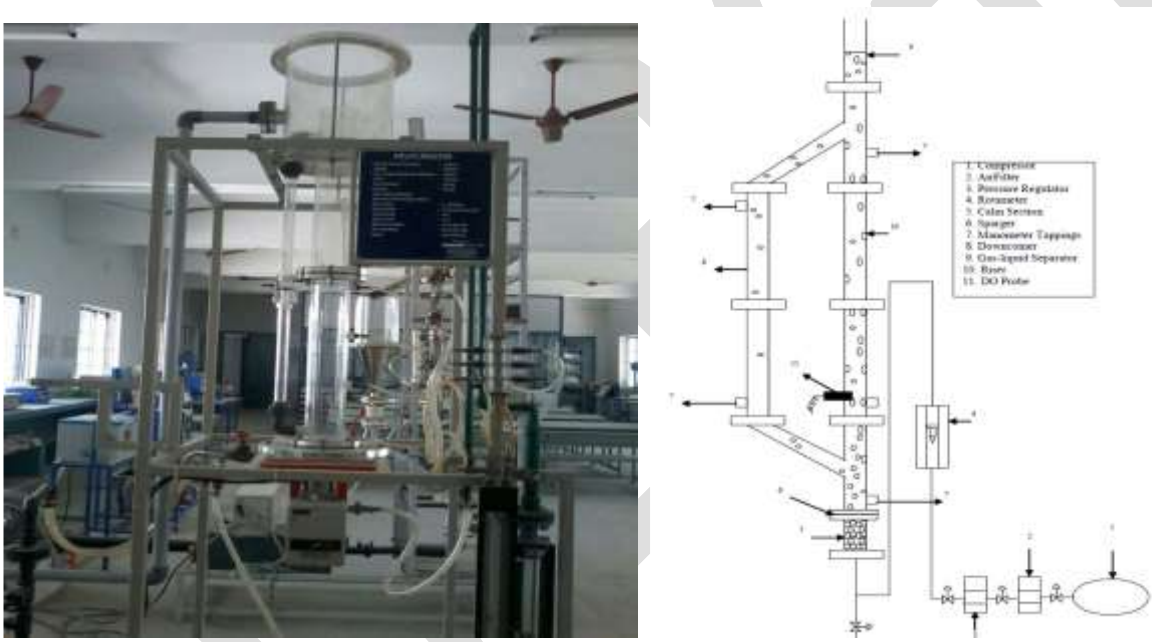

Fig 2.1 External loop airlift reactor

Table 2.1: Physical properties of the materials used

SYSTEM(vol %)	DENSITY(kg/m3)	SURFACE TENSION(x10^^{3},N/m)
Tap water	998.2	72.8
Nacl(5%)	1018.2	49.32
Nacl(10%)	1021.6	48.37

Acetic acid(5%)	1011.5	24.59
Acetic acid(10%)	1026	22.23
Sucrose(5%)	1014	21.54
Sucrose(10%)	1031	22.11
Methanol(0.25%)	997.7	72.1
Methanol(0.5%)	997.2	71.7
Methanol(0.75%)	996.7	71.6
Ethanol(0.25%)	997.7	71.4
Ethanol(0.5%)	997.2	70.3
Ethanol(0.75%)	996.8	69.3
Propanol(0.25%)	997.7	71.5
Propanol(0.5%)	997.2	69.9
Propanol(0.75%)	996.7	65.1
Benzene (0.25%)	996.5	70.5
Benzene (0.5%)	996.2	69.7
Benzene (0.75%)	995.7	69.3

A schematic of the external loop airlift reactor used in this study is as shown in figure 2.1. It consists of acrylic column and a column diameter of 100mm and height 1000mm with a supporting screen diameter of 0.8mm.The external loop airlift column has perforated plate gas sparger with 243holes of 1mm diameter on a triangular pitch placed at the base of the column. The down-comer and riser are connected via two horizontal acrylic tubes. The gas phase that is the compressed air is injected at the bottom of the column. Water, electrolytes and solvents are used as liquid phase. The experiment was conducted in room temperature. Gas hold-up is one of the important design parameter of airlift reactors. Gas hold-up was measured by level measurements (Expansion volume method).Pressure drop, Gas hold-up, Mixing time, Residence time distribution was measured for various electrolytes and solvents of various concentrations for different superficial gas velocities.

3. RESULTS AND DISCUSSION

3.1 GAS HOLD-UP AND PRESSURE DROP FOR AIR - WATER SYSTEM

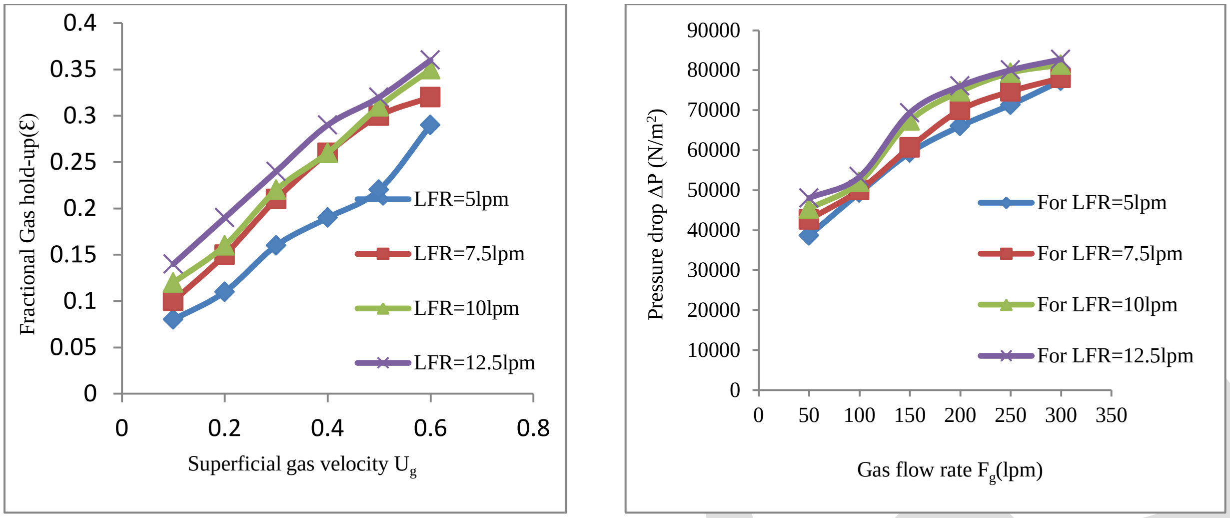

Figure 3.1.1 Effect of superficial gas velocity on Fractional gas hold-up and Gas flow rate on Pressure drop by varying liquid flow rates

From the figure 3.1.1 it can be observed that superficial gas velocity increases the fractional gas hold-up and pressure drop also increases with increasing liquid flow rates from 5 lpm to 12.5 lpm.

3.2GASHOLD-UP FOR ELECTROLYTES AND SOLVENTS BY VARYING LIQUID FLOW RATES:

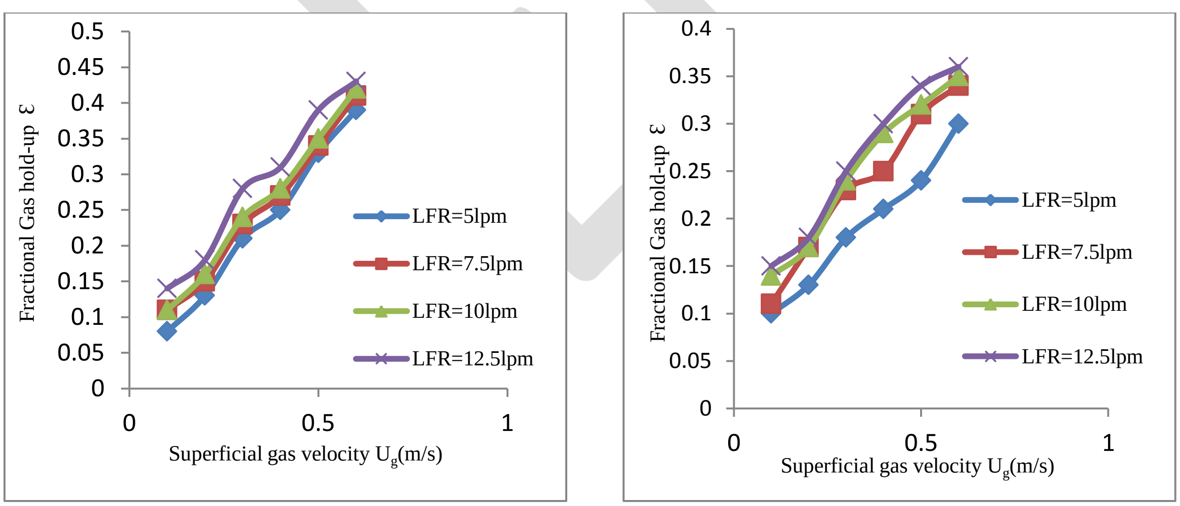

Fig 3.2.1: Effect of superficial gas velocity on Fractional gas hold-up by varying liquid flow rates for 5% Nacl and 0.25% Methanol

From the figure 3.2.1 it was found that the fractional gas hold-up increases with increasing superficial gas velocity and increasing liquid flow rates for both electrolytes and solvents. When we increasing the concentration of electrolytes (acetic acid, sucrose) and solvents (ethanol, propanol and benzene) the same observations are made.

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3.3 GASHOLD-UP FOR ELECTROLYTES AND SOLVENTS BY VARYING SOLUTIONS:

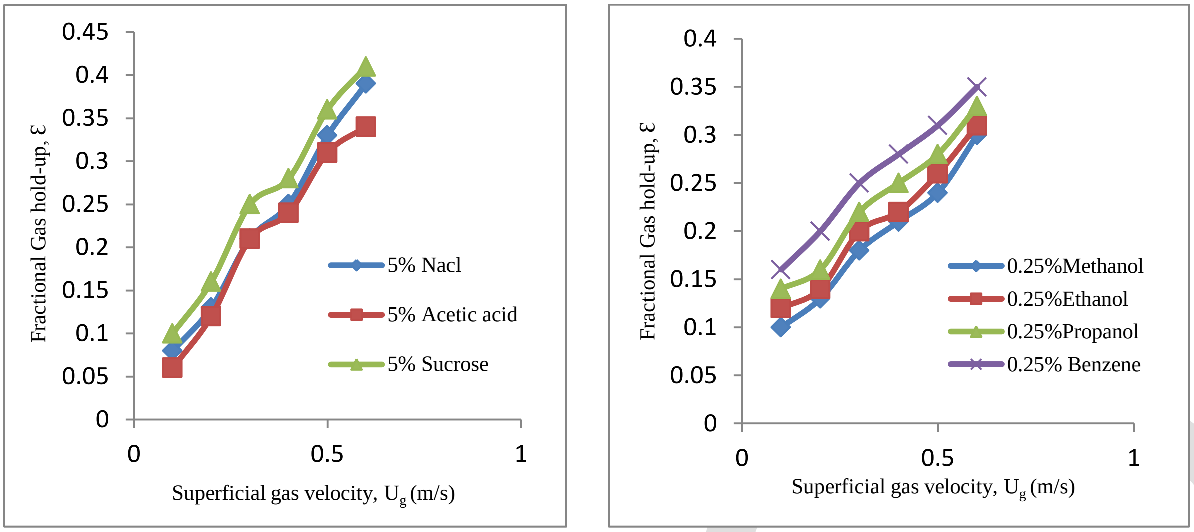


Figure 3.3.1 Effect of superficial gas velocity on fractional gas hold-up by varying electrolytes at constant concentration of 5% and varying solvents at constant concentration 0.25%

From the figure 3.3.1 it can be found that sucrose have higher gas hold-up compared to other electrolytes. Because sucrose has lower surface tension, so it yields higher gas hold-up. From the figure4.3.2it can be observed that the gas hold increases with increasing the concentration of the solvents(0.25%,0.5% and 0.75%) and also increases with increasing the carbon atoms in the alcohol molecules. As the number of carbon atom increases the surface tension reduces it causes to create smaller bubbles. So gas hold-up rises (Propanol with longest carbon chain has the maximum gas hold-up). The gas hold-up increased as: Water < methanol< ethanol< propanol< benzene

3.4 GASHOLD-UP FOR ELECTROLYTES AND SOLVENTS BY VARYING CONCENTRATIONS:

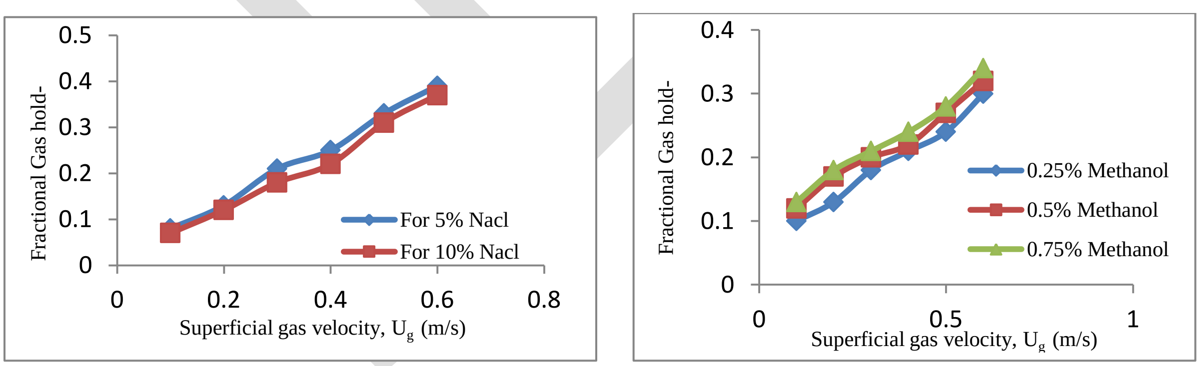
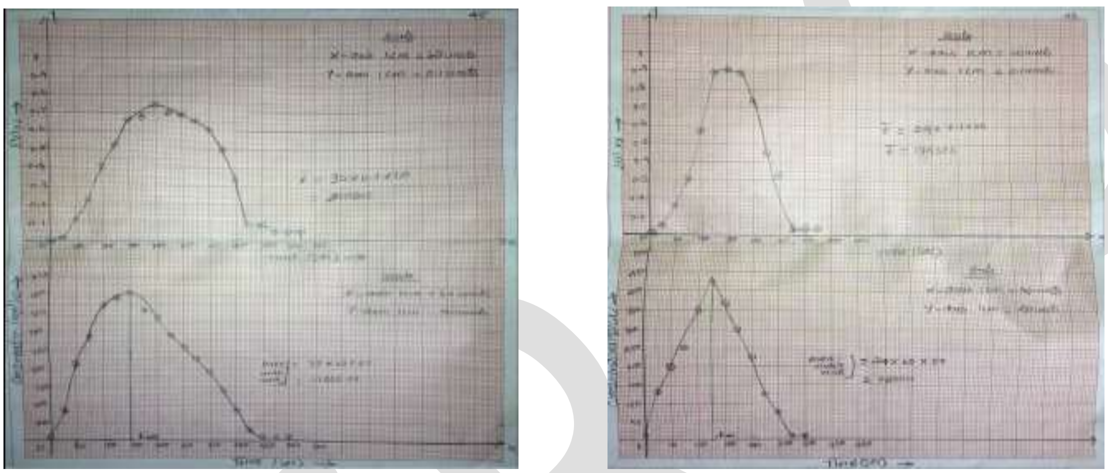


Figure 3.4.1 Effect of superficial gas velocity on fractional gas hold-up by varying concentration of electrolyte (Nacl) and solvent (CH_3OH)

From the figure 3.4.1 it can be seen that gas holdup increases with increasing the superficial gas velocity but decreases with increasing the electrolyte concentration for various liquid flow rates. Low electrolyte concentrations have no noticeable effect on the surface tension of the solution. However the ionic force in the liquid bulk reduces the bubble rise velocity and the bubble coalescence. As a result, the gas hold-up increase. For high electrolyte concentration, the interfacial tension increases, resulting in increased the bubble size and reduce gas hold-up. And also it can be observed that the gas hold increases with increasing the concentration of the solvents(0.25%,0.5% and 0.75%) When we increasing the concentration of the solvents the surface tension reduces it causes to create smaller bubbles. So gas hold-up rises. The alcohols with concentration of 0.75% have higher gas hold-up compared to those with concentration of 0.5% and 0.25%.

4.1. RTD STUDIES

4.1.1 Air –Water System



(a) (b)

Fig:4.1 Effect of time on concentration and E(t)*t for Air-Water system at constant (a) gas flow rate =25lpm (b) gas flow rate =50lpm

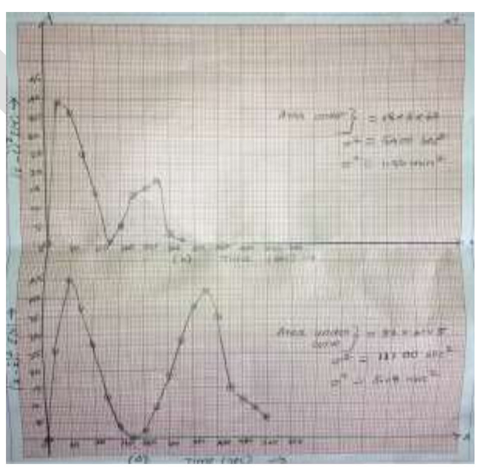


Fig 4.2: Effect of time on variance for air –water system

RTD characteristics of External loop airlift reactor using the stimulus response tracer technique was carried out. Works were carried out at two gas flow rates i.e. 25lpm and 50lpm. The water flow rate is maintained constant as 5lpm. From the results, it was found that the mean residence time were 210sec and 174sec for 25lpm and 50lpm respectively. It is shown in the figure 4.1(a) and (b). The mixing times were obtained from the c-curve and it is found as 180sec and 150sec for those flow rates. The reduction in the residence time value while increasing the gas flow rate was expected because when the gas flow rate increases, mixing takes place more vigorously and which leads to the early outcome of the fluid.

The RTD kinetic data obtained were applied to the compartment models. This particular mixed flow reactor can be only fit to the tank in series model since the dimensionless parameter (D/uL) obtained nearly to infinity. From the results it was found to be the number of tanks was 4 and 5 for the gas flow rates 25lpm and 50lpm respectively. The reason may be attributed to the decrease in the residence time would leads to the increase in number of tanks.

Table 4.1: Table shows mean residence time and mixing time for solvent and electrolyte

SYSTEM	GAS FLOW RATE lpm	MEAN RESIDENCE TIME(sec)	VARIANCE (min^2)	MIXING TIME (sec)	NO. OF TANKS
Air-water	25	210	3.08	180	4
Air-water	50	174	1.50	150	5
Air –Acetic acid (0.25%)	25	318	4.91	300	5
Air –Acetic acid (0.25%)	50	252	3.08	240	6
Air –Acetic acid (0.5%)	25	372	6.17	360	6
Air –Acetic acid (0.5%)	50	282	3.16	270	7
Air –Methanol (0.25%)	25	228	3.83	150	3
Air –Methanol (0.25%)	50	180	1.83	120	4
Air –Methanol (0.5%)	25	276	4.67	120	4
Air –Methanol (0.5%)	50	198	2.00	120	5

4.1.2 Air – Acetic acid System

In this study, the flow rates are maintained as similar to the air-water system. Experiments are done by varying the acetic acid concentration such as 0.25 vol% and 0.5vol% . From the results of 0.25vol% acetic acid- air system, it was found that the mean residence time were 318sec and 252sec for the case1 and 2 respectively. As similar to the air water system the mixing time were obtained from the C-curve and the values are 300sec and 240sec for those flow rates.

When the concentration of the acetic acid is increase to 0.5vol%, the mean residence time were changed to 372sec and 282 sec for the gas flow rates of 25lpm and 50lpm respectively. Similarly the mixing time were varied as 360sec and 270sec for case 1 and 2 respectively. The reason may be due to the higher viscosity of acetic acid compared to water. since the viscosity and specific gravity of the acetic acid is higher than that of water, the mixing requires more time.

Since the dimensionless parameter obtained for this kinetic data were very high, tank in series model is proposed for the system. For the 0.25vol% acetic acid, it was found to be the number of tanks was 5 and 6 for case1 and 2 respectively. Similarly for the 0.5vol% acetic acid, the number of tanks was found to be 6 and 7 for case1 and 2 respectively.

4.1.3 Air – Methanol System

In this study, the flow rates are maintained as similar to the air – water system. Experiments are done by varying the methanol concentration such as 0.25vol% and 0.5vol%. From the results, of 0.25vol% methanol- air system, it was found that the mean residence time were 228sec and 180sec for the case1 and 2 respectively. As similar to the air water system the mixing time were obtained from the C-curve and the values are 150sec and 120sec for those flow rates.

When the concentration of the methanol is increases to 0.5vol%, the mean residence time were changed to 276sec and 198 sec for the gas flow rates of 25lpm and 50lpm respectively. Similarly the mixing time were varied as 120sec and 120sec for case 1 and 2 respectively. The reason may be due to the lower viscosity of methanol compared to water. since the viscosity and specific gravity of the methanol is lower than that of water, the mixing requires less time.

Since the dimensionless parameter obtained for this kinetic data were very high, tank in series model is proposed for the system. For the 0.25vol% methanol, it was found to be the number of tanks was 3 and 4 for case1 and 2 respectively. Similarly for the 0.5vol% methanol, the number of tanks was found to be 4 and 5 for case1 and 2 respectively.

5. CONCLUSION

- Fractional Gas hold-up increases with increasing the gas flow rates
- Fractional Gas hold-up increases with increasing the concentration of solvents
- Fractional Gas hold-up decreases with increasing the concentration of electrolytes
- Among the solvents and electrolytes studies shows Benzene and Sucrose more fractional gas hold-up
- Pressure drop increases for both electrolytes and solvents when we increasing the concentration as well as gas flow rates
- RTD and mixing time characteristics of External loop airlift reactor was studied and found that experimental data fits well with tank in series model and number of tanks was varies from 4 to 6

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