CHAPTER 2

Backgrounds and Literature Review

2.1 Backgrounds: Airlift Contactors

2.1.1 Classification of airlift contactors

Airlift contactors (ALCs) can be classified into two major types, the external and internal loop as shown diagramatically in Figure 2.1.

The internal loop ALC is simply a conventional bubble column which is separated into two sections by a cylindrical tube (concentric ALC, Figure 2.1a) or a baffle plate (split ALC Figure 2.1b).

The external loop type is the ALC where the riser and downcomer are physically separated as two columns interconnected at the top and bottom parts for liquid flow as depicted in Figure 2.1c.

2.1.2 Transport mechanism in ALCs

The ALCs comprise three connecting zones: riser, downcomer and gas separator. The concentric ALC is chosen to illustrate the major components of ALCs (depicted in Figure 2.2), each of which is described as follows:

1. Riser is the section through which gas is sparged, creating a net upward flow of fluid. This upflow of fluid is replaced by the recirculating fluid from downcomer.

2. Fluid from riser enters the gas separator from which a large portion of gas disengages at the top surface. The flow pattern in this section is similar to that found in CSTRs where the highly turbulent condition exists.
3. After the disengagement of gas bubbles, liquid and the remaining gas bubbles enter the downcomer. As the fluid in this section contains less proportion of gas, the density of the fluid becomes greater than that in other sections of the ALC. This creates a downward movement of the fluid which leaves the downcomer at the bottom and enters the riser together with the supplied gas.

The liquid circulation in the ALC is caused primarily by the energy transfer from gas to liquid in a similar way to a bubble column. As the gas is only supplied at the riser, this creates a low density portion of fluid in this part of the contactor (a mixture between liquid and gas bubbles) which moves upward from bottom to top. On the other hand, heavier fluid in the downcomer (less proportion of gas bubbles) moves downwards and enters the riser section at the bottom junction. This portion of fluid is mixed with the gas supplied at the bottom of the riser and continues to move up the column again. Therefore a certain circulating pattern of fluid can be observed in the ALC. It is noted that this kind of circulation is not found in bubble columns as there is no net difference between the density of the fluid in the system.

2.2 Backgrounds: Hydrodynamic Behavior of ALCs

To understand the fundamentals behind the ALC performances, one needs to be able to describe its hydrodynamic behavior. This knowledge is crucial for the design and control of the contactors. The early investigations of hydrodynamic behavior of ALC focused on the effect of the design parameters such as sparger and the ratio between the cross-sectional areas between downcomer and riser (A_d/A_r). One of the very first researches was carried out by Merchuk and Stein (1981) who investigated the effect of single orifice sparger together with multiple orifice sparger on gas holdup and liquid velocity in an external loop airlift contactor. They found that multiple orifice sparger produced higher mean gas holdup than that in the single orifice sparger. However, this result was not consistent with the finding of Koide *et al.* (1983 a) who investigated the effect of sparger on hydrodynamics behavior in a concentric ALC. They found that the number of holes on spargers had no effect on gas holdup when gas was sparged into the annulus, and smaller nozzle diameter gave a higher gas holdup. On the other hand, when gas was sparged into the draft tube, no effect of sparger on gas holdup was observed but the mass transfer for single nozzle, perforated plate and porous sparger decreased in that order.

A number of investigations were carried out to study the effects of the ratio between the downcomer and riser cross sectional areas, A_d/A_r (Koide *et al.*, 1984; Weiland, 1984; Bello *et al.*, 1985; Popovic and Robinson, 1989; Choi and Lee, 1993; Gavrilescu and Tudose, 1998; and Korpijarvi *et al.*, 1999). A common conclusion can be drawn as all of the experiment showed that gas holdup decreased with increasing A_d/A_r. This was attributed to a reduction of residence time in riser which caused the gas to leave the contactor more quickly and resulted in a decrease in gas holdup. Moreover, Koide *et al.* (1983 b) found that column diameter did not affect gas holdup provided when A_d/A_r was kept constant.

Lately, several groups of researchers paid attention on the new geometrical design of conventional ALC in order to improve the contactor performances. Investigations were carried out on the modified ALCs with the main objective to improve the rate of gas-liquid mass transfer. Orazem and Erickson (1979) introduced the one and two-stage airlift contactors. The observed gas holdup in one-stage tower was found to be lower than that in the two-stage due to bubble coalescence appeared in the system. Tung *et al.* (1997) studied the effect of double perforated draft tube on gas holdup and found that gas holdup in such system was much greater than that in bubble columns. This agreed well with the results obtained by Bando *et al.* (1992) who investigated the flow characteristics in concentric ALC with perforated draft tube. He found that a higher perforated draft tube could retain more gas bubbles in the system as a result of higher subdivision, so more bubbles could transfer into the downcomer, and this led to a higher gas holdup.

The investigation on converged-diverged riser ALC (ALC with varying sizes of diameter) was carried out by Ghosh *et al.* in 1993. They found that gas holdup in converged-diverged tube ALC was much higher than other fermenters having uniform tube. They concluded that large bubbles are broken to smaller size in converged-diverged sections which contributed to higher gas holdup.

The result of static mixer was published in 1997 by Gavrilescu *et al.* Their results showed that static mixer provided a higher riser gas holdup than in conventional ALC. The shear effect of static mixer got rid of bubble coalescence, this decreased average size of bubble diameter. Consequently, residence time of gas bubbles increased, hence, riser gas holdup increased.

In 1998, Tung *et al.* presented the multiple net draft tubes ALC which significantly increased number of bubbles and decreased bubble diameter. As a consequence, the gas holdup in such system was greater than that in the bubble column.

Schlötelburgh *et al.* (1999) studied the characterization of the airlift reactors with helical flow promoter together with effect of solid particles on reactor performances. He found that solid particles acted as a means to break up gas bubbles. Although the performance of the reactor with helical flow was not significantly different from the conventional one in terms of the mass transfer rate, the velocity of the liquid in the helical flow reactor was much higher.

One common option that several researchers employed as a means to increase the gas holdup in the ALC was to use a baffle plate or a sieve plate. The introduction of baffles or sieve plates was reported to slow down the flow of fluid, causing bubbles to break up, and therefore increasing the contacting area between gas and liquid. Miyahara *et al.* (1986) investigated the size of bubbles in a bubble column with a draft tube and a sieve plate. They found that the introduction of the draft tube into the bubble column could decrease bubble size by approximately 15%. This led to a higher gas holdup. However, no thorough investigation on the mass transfer performance was yet provided. Chen *et al.* (1997) introduced a novel rectangular ALR with mesh baffle-plates. The results revealed that mesh baffle-plates facilitated the attainment of gas bubbles in the system resulting in a higher level of gas holdup compared to a conventional ALC. However, the overall gas holdup was still less than that in the bubble column with the same condition.

2.3 Backgrounds: Gas-Liquid Mass Transfer in ALCs

The early works on gas-liquid mass transfer in ALCs were usually involved with the investigation of the interrelationship between the mass transfer rate and geometrical parameters such as A_d/A_r, column height, column diameter, etc. For instance, Koide *et al.* (1983 a) studied the volumetric mass transfer coefficient for liquid phase in a bubble column with draft tube where gas was dispersed into annulus. They found that k_La inversely varied directly with the ratio of A_d/A_r. This was because a higher A_d/A_r induced a higher liquid circulation velocity which resulted in the reduction of the riser gas holdup and k_La correspondingly. Their results were in good agreement with the works of Choi and Lee (1993), Bello *et al.* (1985) and Al-Masry and Abasaeed (1998).

A number of works have been contributed to the design of new configuration of ALCs with an improvement in the mass transfer rate. Lin *et al.* (1976) investigated the oxygen transfer and mixing in a tower cycling fermentor (external loop) with baffles installed in the riser. They found that the baffles broke large air bubbles into smaller ones and hence increased the interfacial area (a). Hence, the fluid flow in this section was also made turbulent and a high level of gas-liquid mass transfer rate could be observed. In addition, k_La value was found to increase with the increase in distance from the bottom of the vessel due to the increasing level of turbulent intensity with column height. Later in 1979, Orazem and Erickson studied the efficiencies and oxygen mass transfer rates in one-and two-stage airlift towers. He found that k_La in the two-stage was a linear function of superficial gas velocity and also higher than that in a one-stage tower for high superficial gas velocity (U_{sg}>1300 cm/min). This was due to the increasing of coalescence in single stage which caused bubbles to increase in size and to escape more quickly from the dispersion.

Voigt and Schügerl (1981) cultivated *Hansenula polymorpha* (CBS 4732) in a three-stage tower loop comparing to a single stage reactor. They found that the k_La value in multi-stage was greater than those found in single stage. And together with higher k_La, a slightly higher cell productivity could also be achieved. However, the cell concentration became very low at the lowest stage of the column, and foams occurred at the upper stage (surface) which limited the substrate concentration.

A perforated draft tube was introduced in 1992 by Bando *et al.* who studied the flow characteristics of a bubble column with a perforated draft tube. The results revealed that unperforated draft tube was not effective as a means to improve mass transfer, while perforated draft tube presented a higher gas holdup with a correspondingly greater k_La. They also found that gas holdup and k_La increased with increasing draft tube height as a result of higher bubble subdivision frequency.

Goto and Gaspillo (1992) investigated the effect of static mixer on mass transfer in a draft tube bubble column and in an external loop column. They found large bubbles dispersed and broke into smaller sized bubbles by static mixer in the riser and therefore resulted in an increase in the k_La.

Ghosh *et al.* (1993a, 1993b) studied the effect of converged-diverged tube riser on gas holdup and mass transfer coefficient of the modified airlift fermentor. They found that k_La decreased with increasing superficial gas velocity. This was the result of lower liquid velocity (more resistance to the liquid flow) which reduced molecular diffusion and led to the decreasing of k_La. Also the gas-liquid interfacial area decreased while liquid velocity increased due to large bubbles produced by bubble coalescence.

Siegel and Merchuk (1991) and Merchuk (1994) introduced an idea to investigate the effect of geometrical design on performances of a concentric tube airlift reactor. They concluded that the design of gas separator was an important factor affecting mass transfer. They also presented new configurations of gas separator and mathematical models to predict mass transfer in the developed ALC. The experimental results revealed that higher top section clearance gave a higher gas-liquid mass transfer rate.

An airlift reactor with double net draft tube was investigated by Tung *et al.* (1997). Experimental results revealed that the improvement in the liquid mixing and gas-liquid mass transfer could be obtained. They also showed that the mass transfer rate in the double net draft tube was higher than that in the bubble column.

Chen *et al.* (1997) introduced a novel rectangular airlift reactor with mesh baffle-plates. They found that the k_La values of the airlift reactor were lower than those of the bubble column and the proposed reactor. At low superficial gas velocity ($U_{sg} \leq 1.5$ cm/s) the performance of the proposed reactor was similar to that found in bubble column, but at high superficial velocity, the baffle broke up large bubbles into smaller ones resulting in a higher mass transfer rate (than the bubble column).

Tung *et al.* (1998) investigated the bubble characteristics and mass transfer performances in an airlift reactor with multiple net draft tubes and found that k_La in the airlift reactor was higher than in the bubble column at the same gas flowrate. It was found that bubble diameters in the proposed reactor were smaller than those in conventional contactors such as bubble columns. This was because the net draft tubes broke up large bubbles into smaller sized which increased contacting surface area between gas and liquid. Also the number of bubbles found in such system was higher due to the interchange of bubbles between riser and downcomer.

Zhao *et al.* (1994) investigated the influence of baffles on the mass transfer of oxygen from gas bubbles into viscous liquids in bubble columns and airlift reactors. They found that viscosity was the main parameter that influenced the hydrodynamic and mass transfer in the systems. However, baffles were found to be beneficial to the rate of mass transfer as it helped break up the large bubbles into smaller ones and this increased gas-liquid interfacial area.

2.4 Remarks

It can be seen that inserting baffles or sieve plates into the ALC can be a potential modification of the system, which can be easily implemented to improve the gas-liquid mass transfer performance. Literature shows that there existed experimental evidences on this topic, however, very little information is available on detail evaluation of the configuration of baffles on the performances of the ALC, e.g. the optimal number of baffle plates or the optimal number of holes on the baffle plate. There is therefore a clear need to perform a deeper investigation on this area, and it is the aim on this work to examine the performances of the ALC with baffle(s) inserted perpendicularly to flow direction.

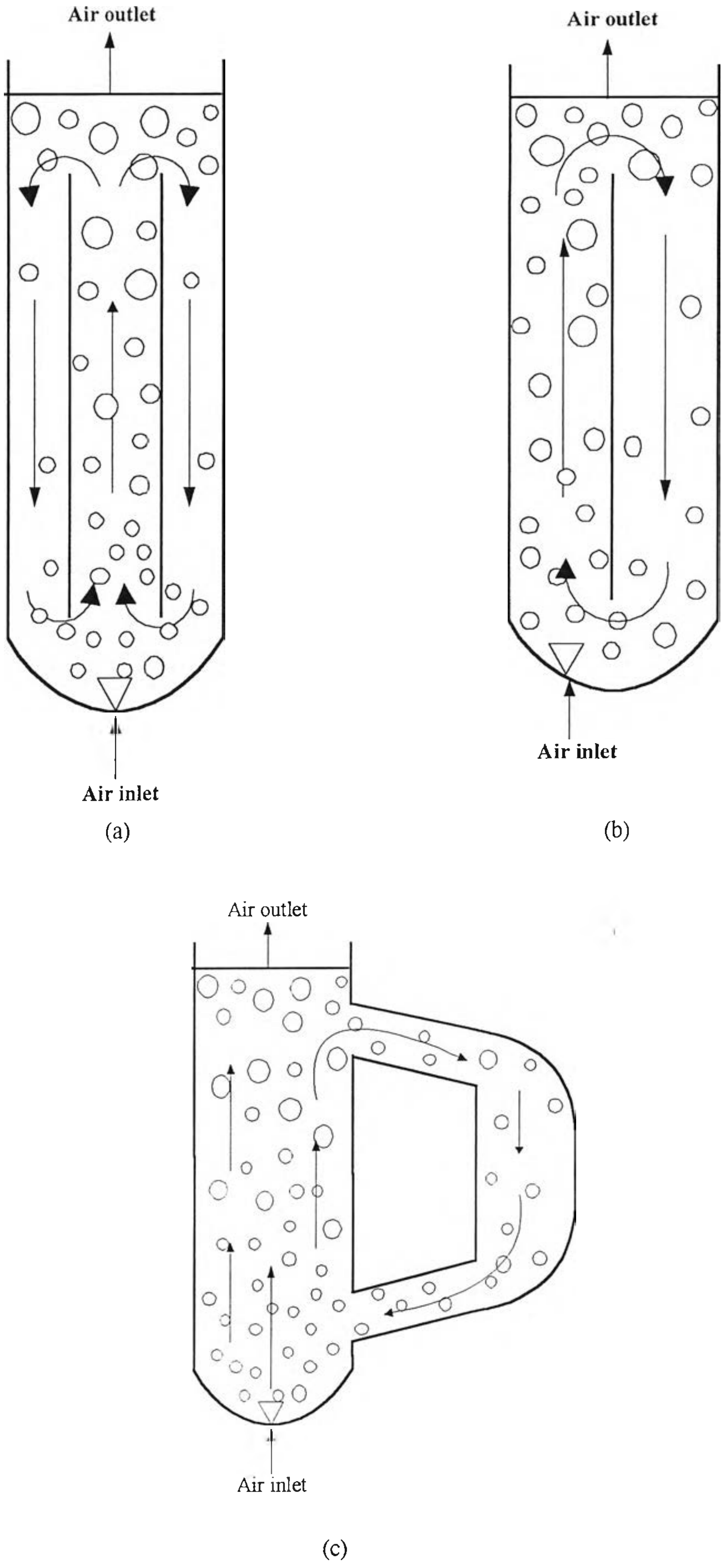

Figure 2.1 Airlift contactor (a) concentric ALC. (b) split ALC.
(c) external loop ALC.

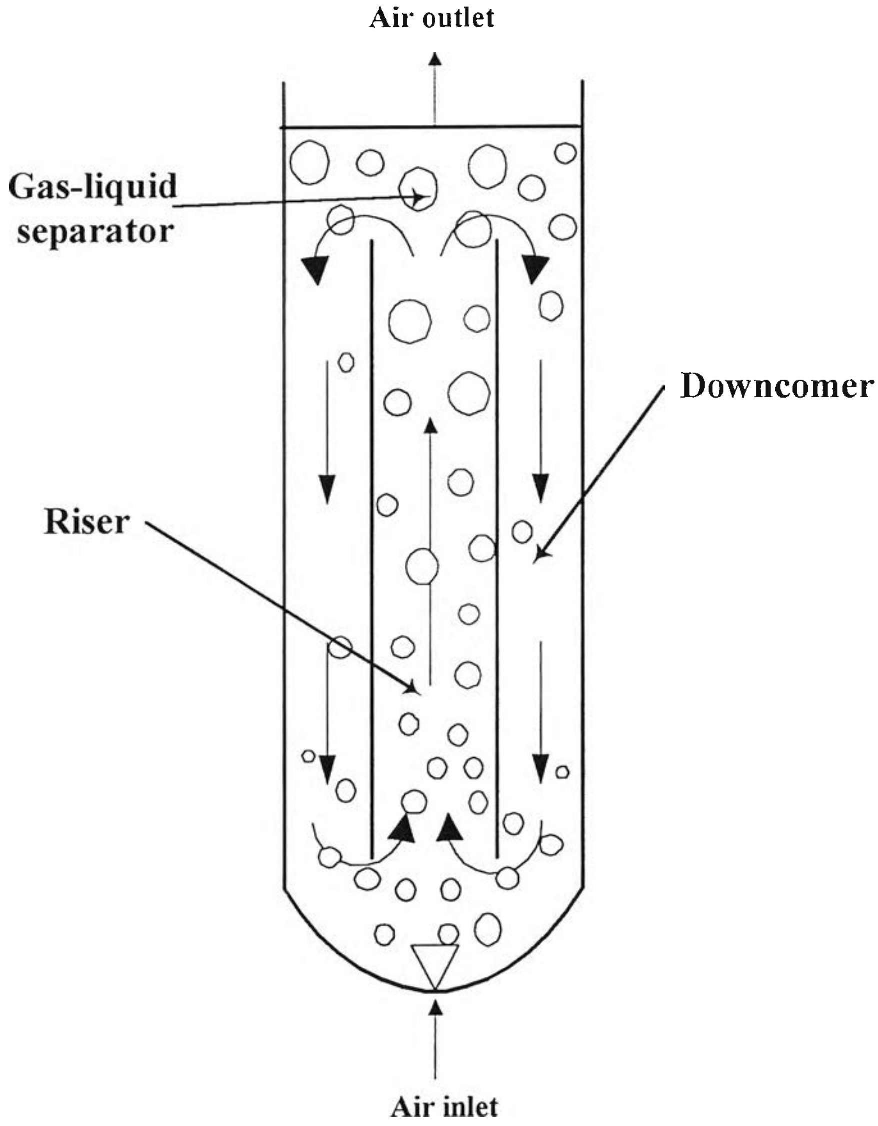

Figure 2.2 Basic structures of airlift contactor