อิทธิพลของลักษณะของท่อภายในต่อสมบัติทางอุทกพลศาสตร์และการถ่ายเทมวลสาร
ในถังสัมผัสแบบอากาศยกขนาดใหญ่

นายเจนวิทย์ ลิ้นทอง

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INFLUENCE OF DRAFT TUBE CONFIGURATION ON HYDRODYNAMIC PROPERTIES AND MASS TRANSFER IN LARGE SCALE AIRLIFT CONTACTORS

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A Thesis Submitted in Partial Fulfillment of the Requirements
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เจนวิทย์ ลิ้นทอง : อิทธิพลของลักษณะของท่อภายในต่อสมบัติทางอุทกพลศาสตร์และการถ่ายเทมวลสารในถังสัมผัสแบบอากาศยกขนาดใหญ่ (INFLUENCE OF DRAFT TUBE CONFIGURATION ON HYDRODYNAMIC PROPERTIES AND MASS TRANSFER IN LARGE SCALE AIRLIFT CONTACTORS.) อ. ที่ปรึกษา : รศ. ดร. ประเสริฐ ภวสันต์, 63 หน้า.

วัตถุประสงค์ของงานวิจัยนี้คือการปรับปรุงประสิทธิภาพของถังสัมผัสแบบอากาศยกขนาดใหญ่ โดยการเปลี่ยนจำนวนของท่อภายใน ซึ่งกำหนดอัตราส่วนระหว่างพื้นที่ในการไหลลงและพื้นที่ในการไหลขึ้นของของไหลไว้คงที่ที่ 2.1 ผลที่ได้แสดงให้เห็นว่าจำนวนของท่อภายในมีผลต่อปริมาณก๊าซในระบบ ความเร็วของของเหลว และการถ่ายเทมวลสาร โดยการเพิ่มจำนวนท่อภายในมีผลให้การเคลื่อนที่ของของเหลวเร็วขึ้นจาก 24 เป็น 28 เซนติเมตรต่อวินาที และให้ปริมาณก๊าซในระบบเพิ่มมากขึ้นจาก 0.008 เป็น 0.010 เมื่อทำการเพิ่มจำนวนท่อภายในจากหนึ่งท่อเป็นหกท่อ ถังที่มีจำนวนท่อภายในห้าท่อจะให้การถ่ายเทมวลสารดีที่สุด โดยค่าสัมประสิทธิ์การถ่ายเทมวลสารเชิงปริมาตรเพิ่มขึ้นจาก 0.0024 เป็น 0.0031 ต่อวินาที เมื่อเพิ่มจำนวนท่อภายในจากหนึ่งเป็นห้าท่อ สำหรับถังสัมผัสแบบอากาศยกที่มีท่อภายในห้าท่อและหกท่อทำการทดสอบโดยมีการจัดเรียงของท่อภายในสองรูปแบบ คือ 1. จัดเรียงท่อภายในตามเส้นรอบวงภายในถัง 2. จัดเรียงให้มีท่อภายในหนึ่งท่อวางอยู่ตรงกลางถังและมีท่อที่เหลือวางอยู่ล้อมรอบท่อภายในที่อยู่ตรงกลางถัง ซึ่งพบว่ารูปแบบการจัดวางท่อภายในไม่ส่งผลต่อปริมาณก๊าซที่อยู่ในระบบ ความเร็วของของไหลที่ไหลขึ้น และการถ่ายเทมวลสารอย่างมีนัยสำคัญ

ความเค็มทำให้แรงตึงผิวของของเหลวมีค่าเพิ่มขึ้นซึ่งส่งผลให้ฟองมีขนาดเล็กลง ปริมาณก๊าซที่อยู่ในระบบน้ำประปามีค่าน้อยกว่าในระบบน้ำเค็มเสมอแต่เมื่อมีการเปลี่ยนแปลงความเค็มของน้ำจาก 15 30 และ 45 พันส่วนในล้านส่วนจะไม่มีผลต่อปริมาณก๊าซที่อยู่ในระบบและความเร็วของของเหลวที่ไหลขึ้น อย่างไรก็ตาม ขนาดของฟองที่เล็กลงส่งผลต่อการถ่ายเทมวลสารและทำให้พื้นที่ผิวในการถ่ายเทมวลสารในระบบเพิ่มขึ้น

ภาควิชา.......วิศวกรรมเคมี.......ลายมือชื่อนิสิต.......เจนวิทย์ ลิ้นทอง

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Large scale internal loop airlift contactors were examined for their hydrodynamic and mass transfer behavior using tap water and saline solution. These behavior was manipulated by changing the number of draft tubes while keeping the ratio between downcomer and riser cross sectional area constant at 2.1. The results showed that the number of draft tube could have effects on: gas holdup, liquid velocity, and gas-liquid mass transfer. Increasing the number of draft tubes seemed to promote a better liquid movement with higher gas holdup where the overall gas holdup of 0.008 was obtained in the airlift with a conventional one draft tube airlift, whereas this was increased to 0.010 when there were five draft tubes. Liquid velocity seemed to also increase with an increase in the draft tube number and this velocity was 24 cm/s with one draft tube, and 28 cm/s with five draft tubes. Five draft tubes seemed to provide the best level of mass transfer where k_La increased from 0.0024 to 0.0031 1/s with an increase in the number of draft tubes from 1 to 5, respectively. In the airlift with five and six draft tubes, two configurations were examined, one with draft tube installed around the peripheral of the outer column, and the other with one draft tube in the center and the rest surrounding the central draft tube. However, the pattern of draft tube configurations did not seem to have great effect on overall gas holdup, and riser liquid velocity and mass transfer

The salinity raised the liquid phase surface tension which resulted that smaller bubble formation. Overall gas holdup in tap water was always less than in saline water, but changes in salinity of the water medium from 15, 30 and 45 ppt did not show impacts on overall gas holdup and riser liquid velocity. However, smaller bubble enhanced the surface area, and hence, increased the rate of mass transfer within the system.

Department....Chemical Engineering...Student's signature.....เจนวิทย์ ลินทอง.....

Field of study..Chemical Engineering...Adviser's signature.................................

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CHAPTER I

INTRODUCTION

1.1 Motivations

In current days, gas-liquid contactors are significant in chemical industry; examples include units such as neutralization of wastewater, pharmaceuticals, foods and fermentation processes. Airlift contactors are one type of gas-liquid contactors with several advantages over other reactor types, *e.g.* simple design, low power requirement, low shear stress, high mass transfer, high circulation rate and short mixing time, *etc.* Thus, in comparison with bubble columns, the airlift can provide a better circulation of liquid inside the system, and when compared with mechanically stirred tanks, the airlift supports the mixing with less shear rate. This outstanding features make the airlift system attractive for chemical and biochemical industries.

Fundamentally, airlift contactor is a modification of bubble columns which is generally done by adding the draft tube to create an aeration zone separated from the anaerated zone. Such configuration supports a liquid circulation in the system. Inevitably, the design of airlift contactor necessitates accurate estimate of several parameters. In general, the three most important parameters that describe the performance of airlift systems are gas hold-up, liquid circulation velocity and mass transfer coefficient. These parameters can be variable by variations of operating parameters such as gas flow rate, and physical properties of the fluid, and also are subject to geometrical modifications, particularly downcomer to riser cross-sectional area ratio (A_d/A_r).

Most previous research only limited their investigation to laboratory scale airlift systems. The knowledge on airlift contactors is therefore only limited to laboratory scale airlift systems. In the large scale airlift contactors, the inherit large riser often destroys the flow pattern in the riser itself as it allows local backflow of the liquid. This often results in an uneven distribution of bubbles, reduces the liquid circulation rate and also the gas-liquid mass transfer rate [Wongsuchto, 2002]. A multiple draft tube airlift system has therefore been introduced as a potential configuration that might facilitate the design and operation of such large scale reactor [Tanthikul, 2004]. In multiple draft tube airlift, each draft tube is connected with individual gas sparger that helps distribute gas within the contactor, and hence, the gas-liquid mass transfer is improved. Our previous work at the

Department of chemical Engineering, Faculty of Engineering, Chulalongkorn University, [Tanthikul, 2004] demonstrated that an increase in the number of the draft tubes in the large scale airlift contactor led to an improved liquid circulation and gas-liquid mass transfer. However, Tanthikul (2004) only limited the work to the system with four draft tubes where it was concluded that this four draft tube system provided a better performance than the one and two draft tubes airlift. Therefore, it still cannot be made a general conclusion on the optimal number of draft tube for the large scale airlift contactors.

This work, therefore, aimed at the extension of that previovs work, where the airlift system with a larger number of draft tubes than four was brought under consideration. The airlift system employed in this work was in principle the same as that used in Tanthikul's work, but with the number of draft tubes varied from 4, 5 and 6. The performance of the various airlifts was compared in terms of hydrodynamics and mass transfer properties.

1.2 Objective

This work was set out to study the influence of draft tubes configuration on hydrodynamics and gas-liquid mass transfer properties in large-scale airlift reactors.

1.3 Scope of this work

1. The airlift employed in this work was a 170L airlift column with dimensions as stated in Table 3.1.
2. The range of superficial gas velocity employed in this work was between 0.4-2 cm/s.
3. The downcomer to riser cross-sectional area ratio (A_d/A_r) in this work was 2.1.
4. Water with 0-45 ppt salinity levels was used as liquid phase and ambient air as gas phase.
5. All experiments were performed at ambient temperature.

CHAPTER II

BACKGROUNDS AND LITERATURE REVIEWS

2.1 Airlift contactors

Airlift contactors (ALCs), in general, consist of two main parts, i.e. riser and downcomer. Riser is a part where liquid flows up and downcomer is where liquid flows down as shown in Figures 2.1 (a) and (b). Liquid flow in airlift contactors is primarily caused by the difference in fluid density between bottom of reactor and top of reactor, and also the energy transfer from the aeration. Based on the geometrical dimension of the setup, airlift contactors can be classified into two types as described below.

2.1.1 Type of airlift contactors

In general, airlift contactors can be separated into two types:

1. Internal loop airlift contactors

Internal loop airlift contactor is a design which allows liquid circulation within one main column. The main column is separated into riser and downcomer using a draft tube or a plain plate is illustrated in Figure 2.2. The flow direction of liquid in this internal loop airlift contactor is shown in Figure 2.1 (a). The upflow in riser is obtained from the hydrostatic pressure difference in the riser and downcomer and also from the energy transfer from the gas bubbles. The downflow in the downcomer is a result of the liquid being degassed and becomes heavier and therefore moves down in the unaerated section of the system.

2. External loop airlift contactors

External loop airlift contactor is the system where a downcomer part is split from the main column as shown in Figure 2.1 (b). The downflow of the liquid flow in external loop airlift contactors therefore takes place in the separate column.

2.2 Gas-liquid hydrodynamics and mass transfer in airlift contactors

Liquid circulation, gas holdup and mass transfer are the major parameters and the understandings of such mechanisms are essential for a reliable description of the airlift systems. The hydrodynamic behavior and the gas-liquid mass transfer are described in this section.

2.2.1 Gas-liquid hydrodynamics

2.2.1.1 Gas holdup

The volume fraction of the gas-phase in the gas-liquid dispersion is known as the gas void fraction or the gas holdup. The overall gas holdup (ε) is ratio between volume of gas phase and the total volume of reactor can be expressed as:

$$\varepsilon = \frac{V_G}{V_G + V_L} \tag{2.1}$$

where: V_G is gas volume

V_L is liquid volume.

In airlift contactors gas holdups are different in the various parts of the system. In general, gas holdups are described using the three quantities, i.e. overall gas holdup, riser gas holdup and downcomer gas holdup. The three holdups can be correlated as follows:

$$\varepsilon = \frac{A_r \varepsilon_r + A_d \varepsilon_d}{A_r + A_d} \tag{2.2}$$

where: ε_r is riser gas holdup

ε_d is downcomer gas holdup

A_r is riser area

A_d is downcomer area.

The overall gas holdup from experimental can be determined by this equation:

$$\varepsilon_o = 1 - \frac{h_L}{h_D} \tag{2.3}$$

where: ε_o is overall gas holdup

h_L is unaerated liquid height

h_D is dispersed liquid height.

Wongsuchoto (2002) and Tunthikul (2004) used this empirical correlation to determine gas holdup in internal loop airlift contactor. Downcomer gas holdup is determined from pressure drop between the two ports of the column and calculates by used this equation:

$$\varepsilon_d = 1 - \frac{\Delta Z_{manometer}}{\Delta H} \tag{2.4}$$

where: ΔZ is pressure difference of defined liquid level

ΔH is distance of liquid level in the airlift column

Riser gas holdup can then be calculated from the overall and downcomer gas holdup according to:

$$\varepsilon_r = \varepsilon_o + (A_d / A_r)(\varepsilon_o - \varepsilon_d) \tag{2.5}$$

2.2.1.2 Liquid velocity

Liquid velocity in the airlift system is described using the velocities in riser and downcomer. The liquid velocity in riser is induced from the input gas sparger at the bottom of airlift contactors whereas the liquid velocity in downcomer is influenced by the different fluid densities between bottom and top of airlift contactors. As the air is supplied into the riser section, the apparent density of the fluid in this section is lower than that of the liquid. The fluid therefore moves upwards. Having reached the gas separating section, the bubbles in the fluid separate from the liquid at the top surface. The heavy liquid moves down in the downcomer section where no aeration is supplied. In this manner, the liquid circulation takes place in the airlift systems.

Generally, liquid velocity is measured in terms of linear liquid velocity defined as:

$$u_L = \frac{x_L}{t} \tag{2.6}$$

where: u_L is liquid velocity

x_L is the liquid path length

t is times for liquid complete movement.

u_L is often called superficial velocity as it is calculated from the assumption of non-obstructed flow in the column. However, the actual liquid velocity, v_L, must be calculated taken into account the obstruction. The obstruction in this case is caused by the existence of gas bubbles. The superficial liquid velocity and the linear liquid velocity can be related as:

$$v_{Lr} = \frac{u_{Lr}}{1-\varepsilon_r} \tag{2.7}$$

and

$$v_{Ld} = \frac{u_{Ld}}{1-\varepsilon_d} \tag{2.8}$$

where: v_{Lr} and v_{Ld} is actual linear liquid velocity in riser and downcomer, respectively

u_{Lr} and u_{Ld} is superficial liquid velocity in riser and downcomer, respectively.

The relationship of superficial liquid velocity in riser and in downcomer can be expressed as:

$$u_{Lr} A_r = u_{Ld} A_d \tag{2.9}$$

2.2.2 Gas-liquid mass transfer

Gas-liquid mass transfer is probably one of the most important characters for gas-liquid contacting systems. The mechanisms of gas-liquid mass transfer can be generalized into four steps as follows:

1. the transport in a gas film inside the bubble
2. the transfer at the gas-liquid interface
3. the transfer in a liquid film at the gas-liquid interface
4. the transport in the bulk liquid

The liquid side film often has a much higher mass transfer resistance than that in the gas side. Therefore the overall mass transfer resistance is controlled by the resistance of the liquid film.

The overall volumetric mass transfer coefficient *(k_La)* is a combination of 2 quantities, i.e. k_L and a where k_L is a gas-liquid mass transfer coefficient and a is specific surface area that the transfer takes place. Such two parameters are difficult to determine separately. Conventionally these two parameters are combined and called "overall volumetric mass transfer coefficient" which can be determined from:

$$\frac{dC_L}{dt} = k_L a(C_L^* - C_L) - r_{o_2} \tag{2.10}$$

where: C_L is the dissolved oxygen concentration

C_L^* is the dissolved oxygen concentration in equilibrium with partial pressure of oxygen in the air

r_{O_2} is the rate of oxygen used per unit mass of organisms

For systems without reaction, r_{O_2} disappears and Equation (2.10) becomes

$$\frac{dC_L}{dt} = k_L a(C_L^* - C_L) \tag{2.11}$$

Previous research showed that an increase in the superficial gas velocity could decrease the liquid film and increased overall mass transfer coefficient. In contrast, when A_d/A_r increased, the overall mass transfer coefficient often decreased [Al-Masry and Abasaeed, 1998].

Wongsuchoto (2002) demonstrated that k_La increased with u_{sg} but decreased with an increase in A_d/A_r, whilst the influence of number of hold in sparger on k_La was negligible.

Our previous work at the Department of Chemical Engineering, Faculty of Engineering, Chulalongkorn University, [Tanthikul, 2004] demonstrated that an increase in the number of the draft tubes in the large scale airlift contactor led to an improved liquid circulation and gas-liquid mass transfer.

2.3 Large scale airlift contactors

In the last decade, gas-liquid contactors are significant in chemical industry; examples include units such as neutralization of wastewater, pharmaceuticals, foods and fermentation processes. A number of research works in this area particularly the work on airlift systems have also increased significantly.

In 1997, Heijnen *et al*. designs a simple model to predict hydrodynamics behavior of a three phase internal loop airlift contactors. Three different scales of the airlift were used in this work, i.e. laboratory-scale with the volume of 19L, pilot-scale with the volume of 400L, and a large scale with 284,000L, the ratio between downcomer and riser cross sectional areas or A_d/A_r was set same ratio (about 1.04-1.47). The result showed that, at the same superficial gas flow rate, the larger scale airlift contactors had a higher liquid velocity than smaller scale because the smaller scale was subject to a higher wall friction.

In 1998, Al-Masry and Abasaeed studied scale-up of external loop airlift contactors. Three external loop airlift contactors with different volumes were used in experiment, i.e. 60, 350 and 700 liters, respectively. The result showed that at constant gas throughputs, the liquid circulation velocity increased with the reactor size, but the gas holdup and volumetric mass transfer coefficient decreased. However, this investigation was subject to the system with different ratio of the cross-sectional area of the downcomer to riser (A_d/A_r), i.e. A_d/A_r was 0.25, 0.44 and 1.0 for the small, medium and large reactors respectively.

In 2004, Blazej *et al.* (2004) studied the effect of reactor scale on hydrodynamic properties in three internal loop airlift reactors of different scales with a working volume of 10.5, 32 and 200, respectively. The three reactors were of similar geometry, i.e. with the same ratio between riser and downcomer cross-sectional areas, and similar aspect ratio of the column and the shape of the column bottom (the same A_d/A_r and H/D ratio). The average of the liquid circulation velocities increased with increasing reactor scale for the same superficial gas velocity. The value of the driving force ($\varepsilon_R - \varepsilon_D$) was found to be important only for lower values of gas flow rate, because at higher values, the circulation velocity seemed to be governed only by friction in the reactor wall.

Table 2.1 shows that scale-up airlift contactors often resulted in an increasing liquid circulation but the trend of mass transfer coefficient was opposite. It becomes a research problem in trying to scale up the airlift systems without causing a reduction in the gas-liquid mass transfer rate.

2.4 Non-ideality in large scale airlift systems

In reality, liquid circulation of large scale airlift contactors is often. It has been shown that, particularly the airlift with large riser, there exists internal liquid circulation within the riser itself. Wongsuchoto (2003) examined the internal liquid circulation in annulus sparged in airlift contactors with a volume of 13 L at different A_d/A_r (i.e. 0.067, 0.431, 0.540 and 1.540) and demonstrated that, for the case of large riser, the measured liquid velocity in riser was always observed to have a greater value than the calculated value. This meant that there must exist a down-flow of liquid in the riser to counterbalance the excess liquid up-flow. This existence of internal liquid circulation caused the airlift contactors to possess bubble column behavior. Therefore in the scale-up of airlift contactors, it is necessary to avoid internal liquid circulation and to maintain the liquid circulation at the level obtained for the small case form.

2.5 Multiple draft tube airlift contactors

To date, there were no investigations on the configuration of large scale airlift systems. Our experience showed that, in the systems with large riser, it was difficult to obtain good distribution of bubbles. Tung *et al.* (1998) studied the bubble characteristics and mass transfer in an airlift with multiple net draft tubes. They employed an internal loop airlift with 29 cm in diameter and 300 cm height with four modules of net draft tubes. Their primary concern was on the distribution of gas through the surface of the four net draft tubes which was not involved with the comparative investigation on hydrodynamic and gas transfer performance along with conventional single draft tube configuration.

Tanthikul (2004) employed the internal loop airlift contactors with 69 cm diameter and 56.5 cm height and varied number of draft tube from one to four while keeping the ratio between downcomer and riser cross sectional areas constant. The result showed that increasing the number of draft tube helped maintain liquid circulation and gas-liquid mass transfer. However, this experimental was limited to a four draft tube system which provided still the best performance, and therefore the optimal configuration of such multiple draft tube airlift system still cannot be concluded.

Table 2.1 Literature review

Author (year)	**Details**	**k_La (1/s)**	**Liquid velocity (m/s)**	**System**	**Sparger**
Heijnen et al. (1997)	Internal loop airlift A_d/A_r = 1.04 (19L)	-	0.3	air-water	-
	Internal loop airlift A_d/A_r = 1.47 (400L)	-	0.7		
	Internal loop airlift A_d/A_r = 1.04 (284,000L)	-	0.9		
Tung et al. (1998)	Internal loop airlift (4 net draft tubes) (132L)	0.08	-	air-water	perforated ring sparger
Al-Masry et al. (1998)	External loop airlift A_d/A_r = 0.25 (60L)	0.045	0.35	air-water	plate sparger with 1 mm diameter
	External loop airlift A_d/A_r = 0.44 (350L)	0.033	0.6		
	External loop airlift A_d/A_r = 1.00 (700L)	0.015	0.8		
Baten et al. (2002)	Internal loop airlift A_d/A_r = 1.25 (35L)	-	0.9	air-water	perforated plate with
	Internal loop airlift A_d/A_r = 2.03 (48L)	-	1.2		625 holes of 0.5 mm diameter
	Internal loop airlift A_d/A_r = 1.25 (882L)	-	1.2		

Table 2.1 (cont.)

Author (year)	**Details**	**k_La (1/s)**	**Liquid velocity (m/s)**	**System**	**Sparger**
Wongsuchoto et al. (2002)	Internal loop airlift A_d/A_r = 0.07 (15L)	0.045	0.2	air-water	perforated ring sparger with 14 holes of 1 mm diameter
	Internal loop airlift A_d/A_r = 0.43 (15L)	0.035	0.35		
	Internal loop airlift A_d/A_r = 1.0 (15L)	0.035	0.27		
Wongsuchoto et al. (2003)	Internal loop airlift A_d/A_r = 0.07 (130L)	-	0.3	air-water	perforated ring sparger with 14 holes of 1 mm diameter
	Internal loop airlift A_d/A_r = 0.43 (130L)	-	0.3		
	Internal loop airlift A_d/A_r = 1.0 (130L)	-	0.5		
	Internal loop airlift A_d/A_r = 1.54 (130L)	-	0.5		
Wang et al. (2003)	External loop airlift A_d/A_r = 0.36 (20 ml)	-	0.15	air-gluconate buffer	glass plate with pore size of 40-100 micron

Table 2.1 (cont.)

Author (year)	Details	k_La (1/s)	Liquid velocity (m/s)	System	Sparger
Blazej et. al. (2004)	Internal loop airlift A_d/A_r = 1.23 (10.5L)	-	0.35	air-water	plate sparger (teflon) with 25 holes of 0.5 mm diameter
	Internal loop airlift A_d/A_r = 0.95 (32L)	-	0.4		plate sparger (teflon) with 25 holes of 0.5 mm diameter
	Internal loop airlift A_d/A_r = 1.01 (200L)	-	0.45		plate sparger (stainless steel) with 90 holes of 1.0 mm diameter

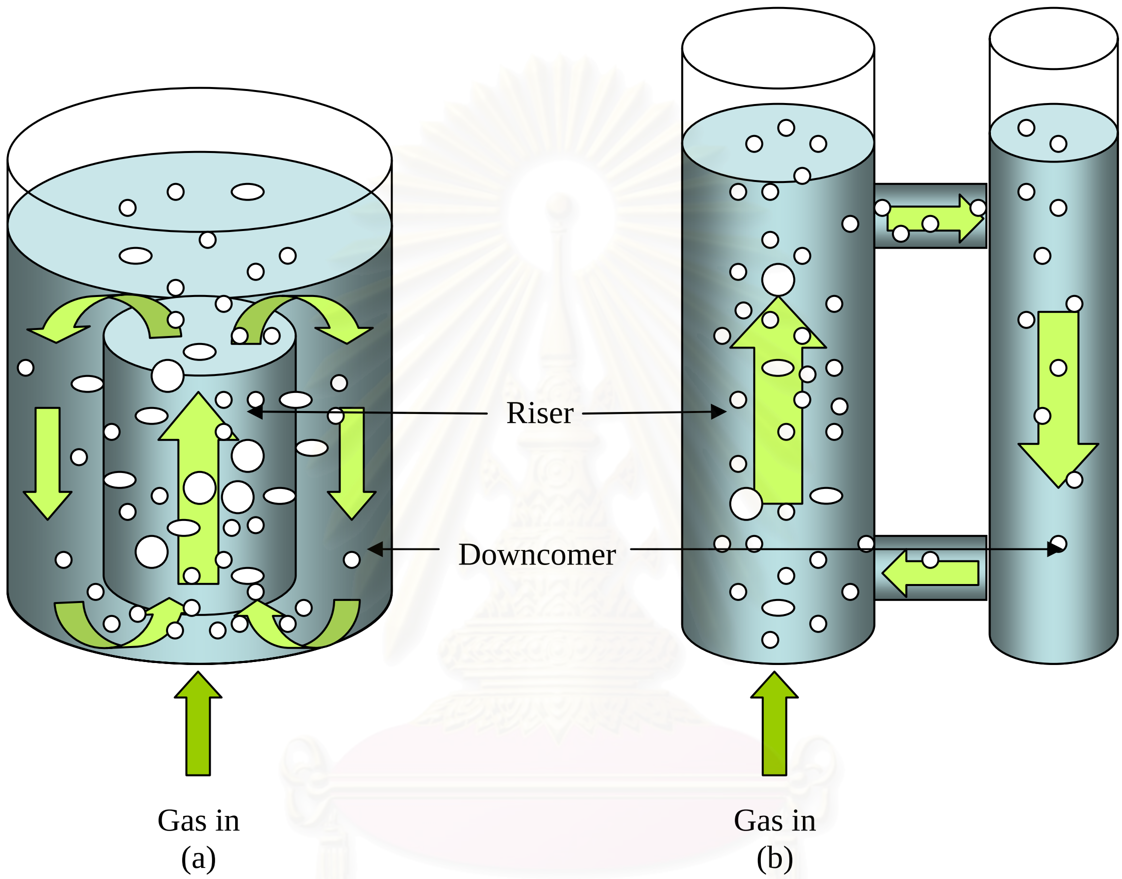

Figure 2.1 (a) Liquid flow in internal loop airlift contactors (b) Liquid flow in external loop airlift contactors (The arrows are liquid circulation direction)

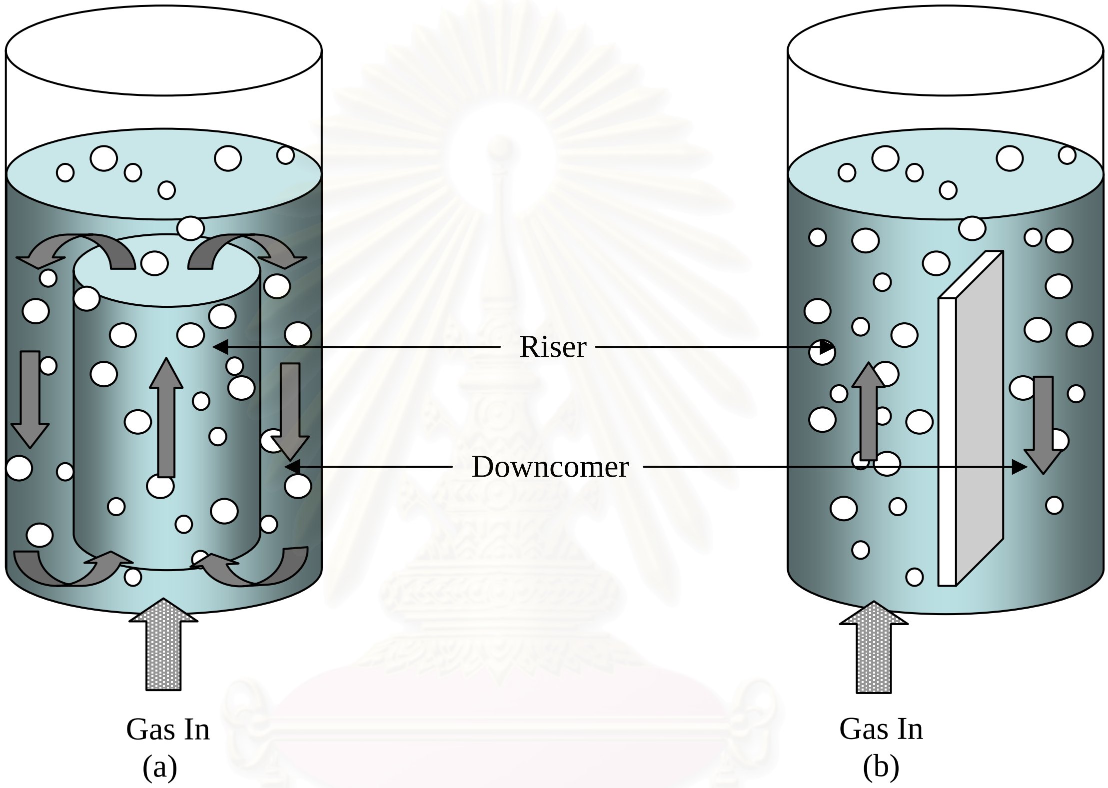

Figure 2.2 Internal-loop airlift contactors (a) airlift contactor using draft tube in main column (b) airlift contactor using plain plate in main column

CHAPTER III

MATERIALS AND METHODS

3.1 Experimental setup

The airlift system in this work was made of clear acrylic plastic with working volume of 170 L and dimension as defined in Table 3.1. The main column was cylindrical with a diameter of 69 cm and height of 56.5 cm. Water or seawater at various salinity levels was employed as liquid phase whereas air is used as gas phase. The operation was semi-batch where the liquid was filled in the column and the gas was continuously supplied by air pump. The installation of the systems was shown in Figure 3.1. For all experiments, air was dispersed by ring spargers installed in the middle of each draft tube and gas flow rate was regulated by calibrated rotameters in the range of 0.4 – 0.9 cm/s. Liquid phase was filled up to the level of 7 cm above the draft tubes before dispersing compressed air into the column.

The experimental setup can be divided into 2 parts as follows:

3.1.1 Airlift with various numbers of draft tubes

Previous work at the Department of chemical Engineering, Faculty of Engineering, Chulalongkorn University, [Tanthikul, 2004] demonstrated that increasing the number of draft tube resulted in a better liquid circulation and a better gas-liquid mass transfer rate. However due to a time limitation, the results were limited to a system with four draft tubes which provided still the best performance. This work was therefore set out to further examine this effect by increasing the number of draft tubes further to five or six. Figure 3.2 illustrates the setup of this system. The ratio between downcomer and riser cross sectional areas or A_d/A_r was set at 2.1 for all.

3.1.2 Salinity experiment

The influence of salinity of liquid phase was examined in the airlift system described in Section 3.1.1. The variation of seawater (15, 30 and 45 ppt.) was compared with tap water (or 0 ppt).

3.2 Experiments

3.2.1 Gas holdup measurement

The overall gas holdup was determined by using a volume expansion technique. The U-tube manometer was used to measure the pressure difference between the two defined levels, which enabled the determined of downcomer gas holdup. The experimental steps follow:

1. Add water into the reactor until liquid level is 7 cm above the draft tubes
2. Measure the liquid level (h_L)
3. Open air valve
4. Adjust superficial velocity
5. Measure the liquid level again (h_D)
6. Measure pressure drop
7. Calculate overall gas holdup used Equation 3.5
8. Repeat Steps 2 to 7 by varying gas superficial velocity from 0.4 to 0.9 cm/s.

3.2.2 Liquid velocity measurement

The measurement of liquid velocity in the airlift system was achieved by employing the tracer injection method as described below:

1. Add water into the reactor until liquid level is 7 cm above the draft tubes
2. Define two vertical distances for the dye tracer to travel
3. Open air valve
4. Adjust superficial velocity
5. Inject the color tracer and measure the time for the tracer to travel between the two defined points
6. Calculate riser used Equation 3.16
7. Repeat Steps 2 to 6 by varying gas superficial velocity from 0.4 to 0.9 cm/s.

3.2.3 Mass transfer coefficient measurement

The over volumetric mass transfer coefficient could be determined by the dynamic method [Cristi, 1989]. The dissolved oxygen (DO) meter was used measure oxygen concentration in the system. The steps are:

1. Add water into the reactor until liquid level was 7 cm above the draft tubes
2. Open nitrogen valve until DO reached zero % air saturation

3. Close nitrogen valve and Open air valve
4. Adjust superficial velocity
5. Record the dissolved oxygen concentration with respect to time during air is distributed until the water saturate with oxygen
6. Calculate k_La (Equation 3.8)
7. Repeat Steps 2 to 6 by varying gas flow rate from 0.4 to 0.9 cm/s.

3.3 Calculations of data

3.3.1 Calculation of gas holdup

1. Overall gas holdup

The overall gas holdup was determined using the volume expansion technique. The definition of gas holdup is

$$\varepsilon = \frac{V_G}{V_G + V_L} \tag{3.1}$$

where ε : Gas holdup [-]

V_G : Gas volume [cm^3]

V_L : Liquid volume [cm^3]

Because the volume of gas cannot be measured directly, we define V_D (dispersed volume) as the total volume of gas phase plus volume of liquid phase. Then

$$\varepsilon_o = \frac{V_D - V_L}{V_D} \tag{3.2}$$

$$\varepsilon_o = 1 - \frac{V_L}{V_D} \tag{3.3}$$

$$\varepsilon_o = 1 - \frac{h_L A}{h_D A} \tag{3.4}$$

finally,

$$\varepsilon_o = 1 - \frac{h_L}{h_D} \tag{3.5}$$

where ε_o : overall gas holdup [-]

h_D : dispersed liquid height [cm]

h_L : unaerated liquid height [cm]

3.3.2 Calculation of liquid circulation velocity

The tracer injection method was used to measure the liquid velocity in riser only. In downcomer the tracer injection method could not be used because color had a high distribution. We could determine the time that tracer travels between two fixed positions and calculate liquid velocity in riser from:

$$v_{Lr} = \frac{x}{t} \tag{3.6}$$

where v_{Lr} : riser liquid velocity [cm/s]

x : distance of tracer travel [cm]

t : tracer travel time [s]

3.3.3 Calculation of mass transfer coefficient

The volumetric mass transfer coefficient was determined by the dynamic method. Dissolve oxygen concentration was measured by DO meter. The oxygen balance in bioreactor gives:

$$\frac{dC_L}{dt} = k_L a(C_L^* - C_L) \tag{3.7}$$

Integrating both sides of Equation 3.21 from $C_L = 0$ to $C_L = C_L$ leads to

$$\ln\frac{(C_L^* - C_o)}{(C_L^* - C_L)} = k_L at \tag{3.8}$$

where C_L^* : saturation dissolved oxygen concentration. [%air saturation]

C_o : initial oxygen concentration in liquid phase [%air saturation]

C_L : dissolved oxygen concentration in liquid phases [%air saturation]

k_La : overall volumetric mass transfer coefficient [1/s]

t : time [s]

Table 3.1 Experimental details for airlift systems employed in this work

Key	No. of draft tubes	Draft tube diameter [cm]	A_d/A_r
ALC-1	**1**	**39.5**	**2.1**
ALC-3	**3**	**23.0**	**2.1**
ALC-4	**4**	**20.0**	**2.1**
ALC-5-A	**5**	**17.3**	**2.1**
ALC-5-B	**5**	**17.3**	**2.1**
ALC-6-A	**6**	**15.9**	**2.1**
ALC-6-B	**6**	**15.9**	**2.1**

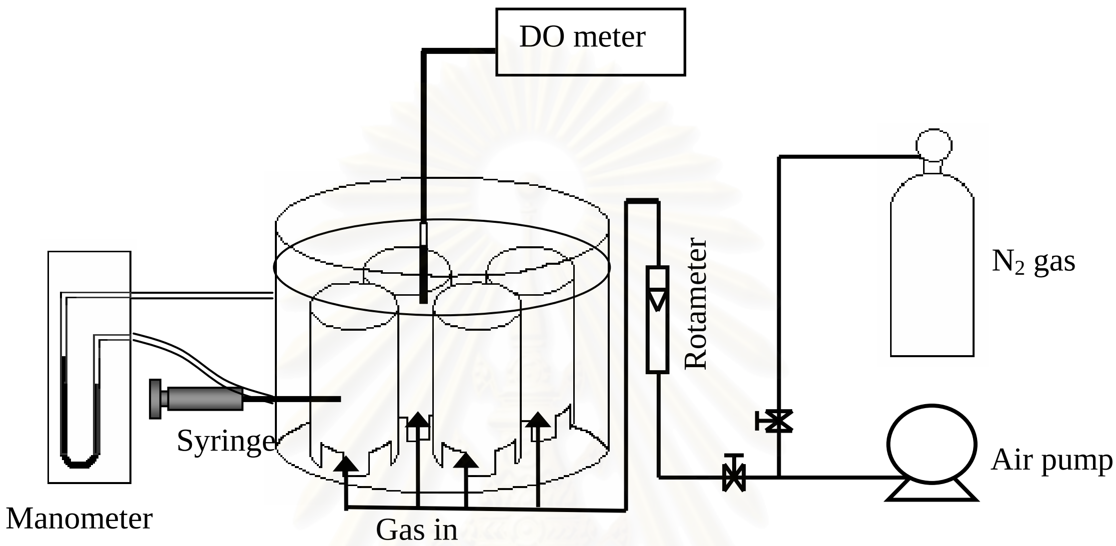

Figure 3.1 Experimental system

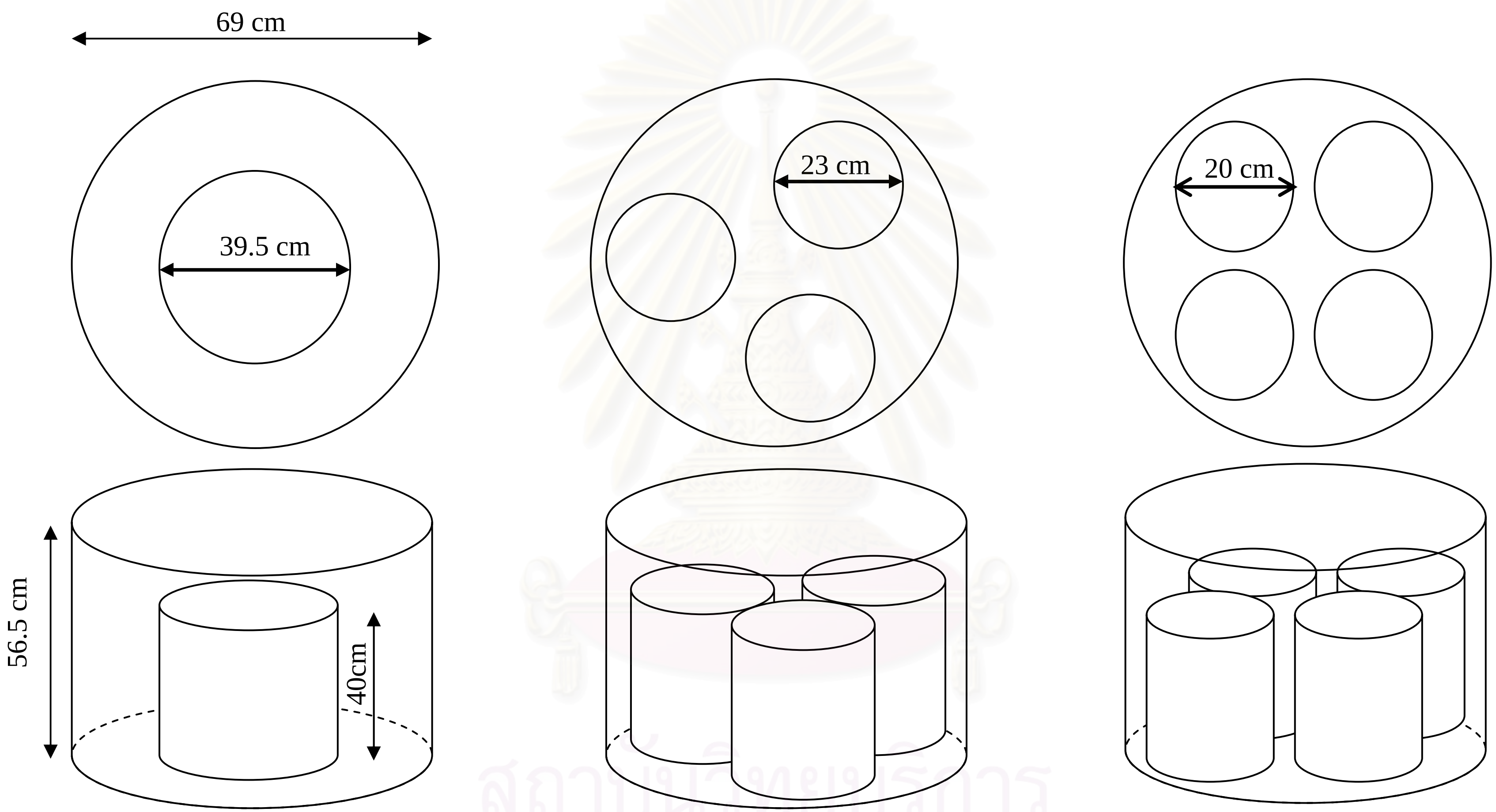

Figure 3.2 Schematic diagrams for the setup of draft tubes with the airlift system.

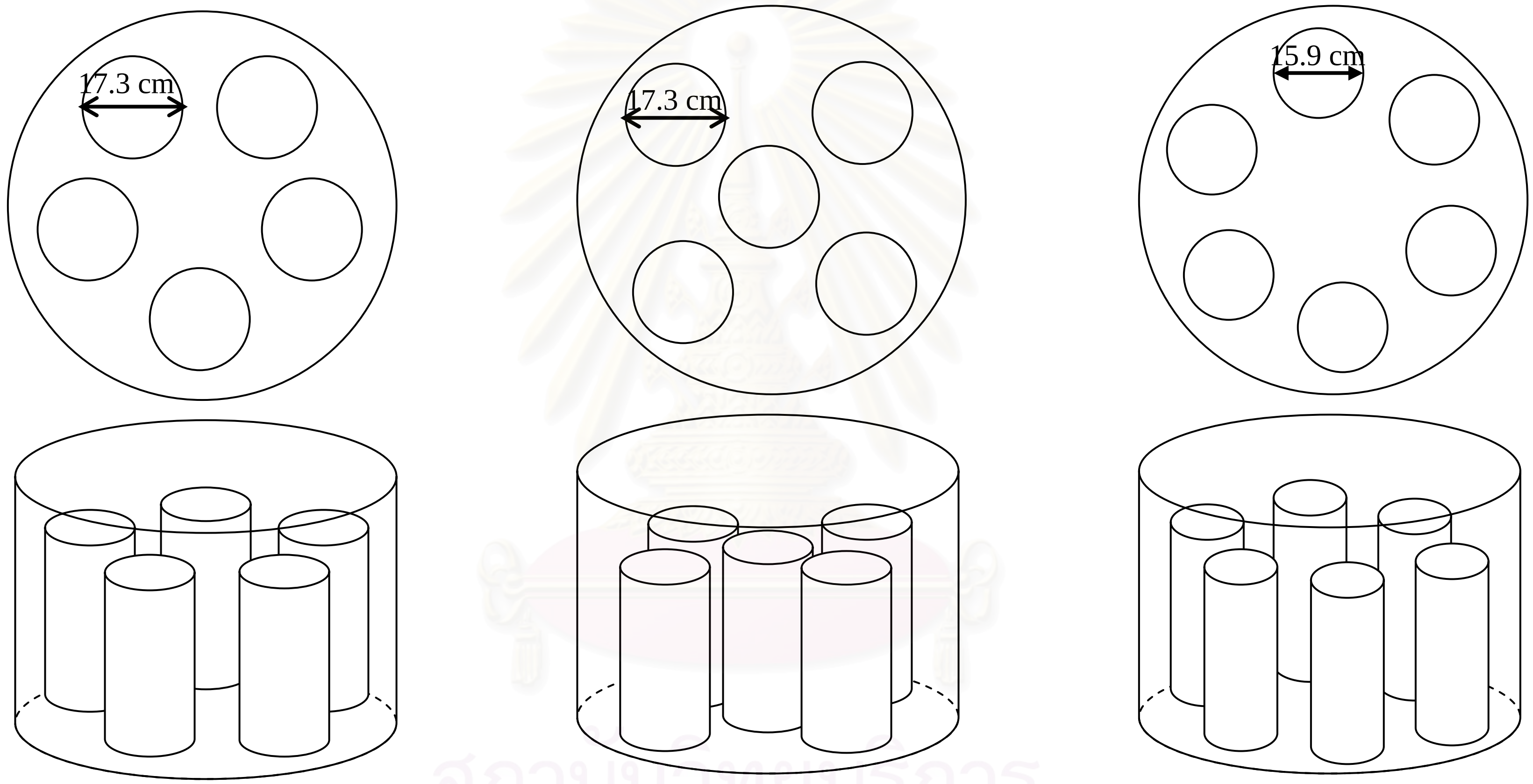

Figure 3.2 Schematic diagrams for the setup of draft tubes with the airlift system (Continue).

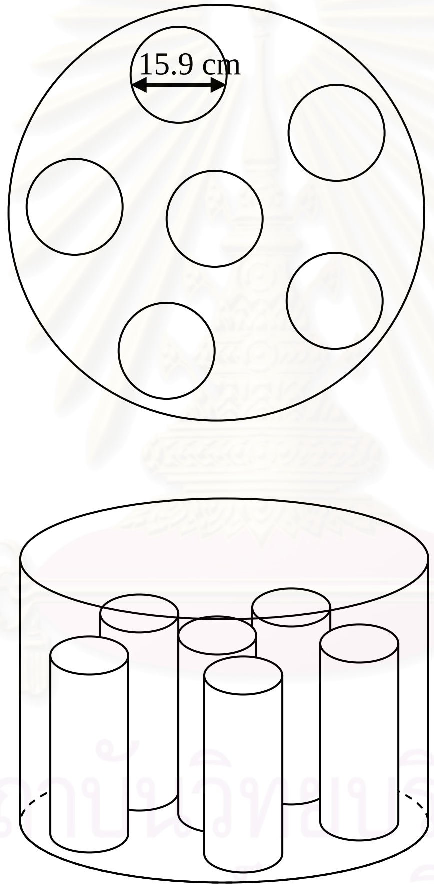

Figure 3.2 Schematic diagrams for the setup of draft tubes with the airlift system (Continue).

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Comparison between airlift contactors with different scales

A number of research works on the examination of the performance of airlift systems had mostly been investigated in laboratory scale. This limited the applicability of the scale up of such reactors to industrial or even pilot size. This work aimed to inspect the performance of the larger scale airlift system compared to the performance of the small scale airlift contactors. As the diameter of the airlift was enlarged, the performance of the airlift in terms of circulating velocity and gas-liquid mass transfer deteriorated. To illustrate this effect, the comparison between the airlifts with different scales was proposed in this section. Figures 4.1, 4.2 and 4.4 summarize data from literature which reported the performance of airlift with similar design and operating conditions but with different scales.

Figure 4.1 shows that the overall gas holdups decreased when the airlift contactor was enlarged. Wongsuchoto et al. (2002) showed that, in the range of very low superficial gas velocity, the relationship between the overall gas holdup and u_{sg} was linear. However, if u_{sg} was increased upto certain level, the gas holdup reached a constant value. This finding was also reported by Baten et al. (2002) who investigated the effects of reactor scale on hydrodynamic properties using CFD simulation and experiments. They reported that, riser liquid velocities increased when the airlift system was scaled up as demonstrated in Figure 4.2. In this case however, internal liquid circulation was highly likely to occur in the riser. Large riser often destroys the flow pattern in the riser itself, as it allows local backflow of the liquid. When this occurred, the normal technique for the measurement of liquid flow would give faulty results as it only measured the upflow velocity without taking into account the downflow portion. Figure 4.3 shows the model for liquid flow in riser with internal liquid circulation.

Figure 4.4 demonstrates that mass transfer declined when the airlift was enlarged. Al-Masry et al. (1998) studied the effect of the scale up on mass transfer and found that, at low u_{sg}, the behavior of the airlift contactors with different sizes in terms of mass transfer was different. Increasing u_{sg} in large scale airlift contactors caused a slight increase in the mass transfer rate (in terms of volumetric overall mass transfer coefficient, k_La) where k_La

reached its constant level at some certain superficial velocity. In contrast, mass transfer in small scale airlift drastically increased with superficial aeration velocity with almost a linear relationship between these parameters. This result was consistent with the results of gas holdup and riser liquid velocity.

In brief, literature illustrates that large scaled airlift systems could be operated with lower gas holdup and higher liquid velocity, and this ended up with the system with lower overall volumetric gas-liquid mass transfer coefficient, k_La.

Tanthikul et al. (2006) attempted to solve this problem by introducing the novel configuration of draft tubes within the airlift which could help reduce the level of non-ideality and slightly enhanced the mass transfer. The number of draft tubes in that study was, however, limited at four where the airlift with four draft tube provided the best performance. This created a doubt whether the configuration with a higher number of draft tubes would give a better performance. This work, hence, proposed to extend this work by increasing the number of draft tubes (one to six draft tubes) and investigated the effect of such configuration change. This examination was performed by fixing all other environmental parameters and the system was constructed with a constant riser and downcomer cross section area ratio at 2.1 whereas the superficial aeration velocity was controlled in the range from 0-0.8 cm/s. Exact configurations of airlift contactors in this research were given in Chapter III.

4.2 Effect of number of draft tubes

This section describes the influence of the number of draft tubes on the overall gas holdup, riser liquid velocity, and the overall volumetric mass transfer coefficient (k_La).

4.2.1 Effect of number of draft tubes on overall gas holdup

The overall gas holdup is one important parameter controlling the level of mass transfer and liquid velocity in the airlift system. Figures 4.5 and 4.6 show that the overall gas holdup increased with u_{sg} in all airlift configuration systems which demonstrates that the number of draft tubes in airlift contactors significantly affected the overall gas holdup. Figure 4.5 illustrates that the overall gas holdup in tap water changed when the configuration of airlift system changed. By and large, the overall gas holdup increased when the number of draft tubes in the airlift system increased. Relationship between the overall gas holdup and u_{sg} in airlift system operated with tap water was linear. However, the behavior in the saline water systems was slightly different. Figure 4.6 illustrates that the relationship between the overall gas holdup and u_{sg} in airlift system with saline water at 30 ppt was non-linear. In other words, at low u_{sg} (0.4 cm/s), the difference in overall gas holdup in the airlift systems with different draft tube configurations were around 0.003-0.008, whereas this difference was only 0.01-0.012 at superficial velocity of 0.9 cm/s. In the airlift systems with large riser cross section area, Wongsuchoto et al. (2003) indicated that there was local internal liquid circulation in the riser itself. This enhanced the coalescence of bubbles leading to a formation of large bubbles, which subsequently, moved faster and escaped from the system more rapidly than small ones. This reduced the overall quantities of gas in the system. In 2004, Tanthikul (2004) studied large scale multiple airlift systems and found that the system with one large riser cross section area had a larger bubble size than the airlift system with several smaller riser draft tubes. This was also evidenced in this work where the airlift configuration ALC-1 had smaller overall gas holdup than any other configurations investigated here.

With the same number of draft tubes, the installing pattern of the draft tube did not show strong impact on the overall gas holdup. For instance, in the system with five draft tubes, two configurations were proposed, one with all draft tubes lined up around the circumference of the outer column (ALC-5-A) whereas the other was with one draft tube at the center and the rest on the outer column circumference (ALC-5-B). The results indicated that the gas holdup were basically the same. Similar results were observed with the airlift with six draft tubes. It should be noted, however, that these findings are only valid for the operation of airlift at low superficial velocity.

4.2.2 Effect of number of draft tube on riser liquid velocity

Riser liquid velocity was measured by the tracer injection method. One of the problems concerned with this technique was that the tracer could be easily distributed all around the draft tube. This error was compensated by repeating the measurement many times. In this work, each experiment was repeated for 30 times. The measurement was then verified with the measurement of the velocity of the plastic tracer in the airlift where the results were reasonably satisfactory with approximately 7% accuracy.

Figures 4.7 and 4.8 reveal that riser liquid velocity increased linearly with u_{sg}. This was often the case with low range of u_{sg} as was employed in other works, e.g. Baten et al., (2002) and Wongsuchoto et al. (2003). Although in airlift systems with large riser cross section area, large bubbles could move faster than small ones, the overall riser liquid velocity could be suppressed due to the existence of local internal liquid circulation. In this phenomenon, the fluid moves backward within the riser itself reducing the overall velocity of the fluid in this section. In this work, the experiment was set up with a constant ratio between downcomer and riser cross section areas of 2.1 and the performance of airlift systems in terms of liquid velocity was quite different with a change in draft tube configurations. When increasing the number of draft tubes, the area of riser for each draft tube decreased leading to fluid (gas and liquid) moving up faster. This could potentially be due to the reduction in the local internal liquid circulation.

In addition, it was illustrated that, with the same number of draft tubes, (ALC-5-A and ALC-5-B) the installing pattern of the draft tubes in the contactor did not seem to have significant effects on the liquid velocity. This demonstrates that the geometry of the downcomer did not significantly affect the hydrodynamics of the airlift, rather the flow depended more notably on the area of each single draft tube.

4.2.3 Effect of number of draft tubes on overall volumetric mass transfer coefficient

The overall volumetric mass transfer coefficient (k_La) could be estimated from the tracking of the dissolved oxygen concentration in the system with the dissolved oxygen (DO) meter. Figures 4.9 and 4.10 demonstrate that the number of draft tube in the airlift system significantly influenced k_La where k_La decreased with an increasing number of draft tubes. The overall volumetric mass transfer coefficient *(k_La)* was a combination of two quantities, i.e. k_L and a where k_L is gas-liquid mass transfer coefficient and a is specific surface area that the transfer takes place, and in this case, a was specific surface of the bubbles and can be calculated from Sauter mean diameter (d_b) and gas holdup (ε) as follows:

$$a = \frac{6\varepsilon}{d_b(1-\varepsilon)} \qquad (4.1)$$

Sections 4.2.1 and 4.2.2 demonstrate that increasing the number of draft tubes enhanced the overall gas holdup and riser liquid velocity in the airlift system, and this led to a larger k_La.

To evaluate for the effect of draft tube configuration on the mass transfer, each component of k_La was scrutinized starting with "a" and "k_L". To evaluate for "a", the information on bubble size was required. As the bubble size in such airlift was difficult to measure, the bubble size was estimated from just visual observation which was about 0.8

mm. This was consistent with the results from Ruen-ngam (2007) who investigated the bubble size in the 17L airlift contactor under various salinity levels, and reported that, within a low range of superficial velocity (u_{sg} < 2 cm/s), bubble size remained constant at around 0.8 mm. This value was employed to calculate the specific area as shown in Table 4.1 which summarizes the results from the experiment with tap water (salinity = 0). The results at u_{sg} = 0.5 cm/s were arbitrarily selected to construct a bar graph between the draft tube configuration and both k_L and a as shown in Figure 4.11. This illustration shows that, with the same level of superficial velocity, k_La was the highest in ALC-5 (both –A and –B). However, k_L decreased almost monotonically with an increase in the number of draft tubes, and this was virtually true for all cases. This was because as the number of draft tubes increased, the liquid moved faster where the velocity approached that of the bubbles. This, typically, resulted in a decrease in the relative velocity or slip velocity between bubbles and liquid which then adversely affected the rate at which gas molecules transferred though the gas-liquid interface.

On the other hand, as an increase in the number of draft tubes destroyed the local internal circulation of liquid within the system, bubbles seemed to move slower resulting in more gas bubbles residing in the system. This was reflected by the higher gas holdup. This increased the specific area (a) of the gas bubbles quite significantly. It was interesting to note that, although k_L decreased continually with an increase in the number of draft tubes whilst a took the opposite direction, the maximum k_La occurred when the number of draft tubes was five. This was because k_La depended greatly on the compensation between these two quantities. Note that the two configurations at five and six draft tubes (ALC-5-A and ALC-5-B, and ALC-6-A and ALC-6-B) did not seem to have distinguishable effects on the mass transfer.

Table 4.2 also illustrates that an increase in the aeration rate led to an increase in the mass transfer rate (as represented by k_La). However, the fact is that k_L actually decreased with or remained almost constant independent of the superficial velocity (u_{sg}), and hence, an observed increase in k_La was mostly contributed from an increase in a. This was, indeed, a result from an increase in the gas holdup. This finding is shown graphically in Figure 4.12.

4.3 Influence of salinity on large scale airlift contactor performance

In this section, the investigation was performed to observe the effect of salinity on hydrodynamic properties and the overall volumetric mass transfer coefficient. To ease the readers in following the discussion, only experiments at u_{sg} of 0.8 cm/s were reported.

4.3.1 Effect of salinity on overall gas holdup

Figure 4.13 illustrates that the overall gas holdup in the system operated with tap water was smaller than those in saline water. Due to some complex interactions between the pressure acting on the bubbles, bubbles generated in saline water were generally smaller than those in the tap water. And as small bubbles moved more slowly than large bubbles, they stayed longer in the system resulting in a larger gas holdup. However, the different levels of salinity did not seem to impose different effects on bubble sizes and this was reflected in the plot in Figure 4.13 where the overall gas holdup only varied within a small range of 0.010-0.011. Ruen-ngam (2007) stated that the bubble size was not significantly affected by salinity (as long as there was salinity) particularly at low superficial velocity as used in this work. This could be the reason why the effect of salinity on gas holdup was not distinguishable in this experiment.

Note that the difference in overall gas holdup became less significant as the number of draft tubes increased. This was due primarily to the destruction of internal liquid circulation which promoted a more distributed movement of bubbles and therefore enhancing the gas holdup especially in the system running with tap water where internal circulation was significant.

4.3.2 Effect of salinity on riser liquid velocity

Figure 4.14 shows that salinity did not have great effect on riser liquid velocity. In this experiment, the differences in saline water levels from 15 to 45 ppt were not found to influence riser liquid velocity. In addition, the observed riser liquid velocity was not greatly affected by salinity and the resulting liquid velocity in each system remained constant independent of the salinity at each particular superficial velocity and at each particular contactor configuration.

4.3.3 Effect of salinity on overall volumetric mass transfer coefficient

Although previous sections demonstrated that gas holdup and liquid velocity did not vary significantly with salinity, it could exert significant effects on the overall volumetric mass transfer (k_La) as observed in Figure 4.15. To illustrate this point more clearly, it is proposed here to divide the discussion into three sub-sections as described below. Data used for this examination were from the experiments in ALC-5-A running at u_{sg} of 0.8 cm/s.

<u>(I) Effect of salinity on specific surface area</u>

The information on bubble size was needed for the estimate of specific surface area. Ruen-ngam (2007) suggested that, at low range of salinity, the size of bubble in saline solution was only slightly smaller than that in the tap water. In this work, this bubble size was assumed from visual observation and past experience of the researchers in the airlift team (Ruen-ngam, 2007) to be 0.6 cm. Table 4.3 shows the results from the evaluation of this mass transfer property. In this table, the values of specific surface were obtained from Equation (4.1) with information on the gas holdups from direct measurement in the airlift as detailed in Chapter III.

The results illustrated that the system with saline solution was operated with a higher level of specific area for gas-liquid mass transfer than the tap water system. However, the different salinity concentrations did not seem to have great effects on this quantity and a remained approximately constant at 0.108 cm^2/cm^3.

<u>(II) Effect of salinity on gas-liquid mass transfer coefficient</u>

Generally the gas-liquid mass transfer coefficient depends significantly on the properties of the liquid/gas films which act as a bubble/liquid interface. In saline solution, the density and viscosity of the fluid is slightly higher than pure water. This negatively affects the mass transfer from gas to liquid. However, the differences in the fluid properties were only quite small at the salinity level employed in this work. The resulting k_L therefore remained quite constant independent of the salinity. This finding agreed well with the reports by Ruen-ngam (2007) who also mentioned that the differences could only be obvious at high level of superficial velocity ($u_{sg} \geq 3$ cm/s).

(III) Effect of salinity on the overall volumetric mass transfer coefficient

k_La is the product of the specific surface area (a) and the gas-liquid mass transfer coefficient, and the experiments revealed that this quantity increased steadily with the salinity, i.e. k_La was equal to 0.0031 s^{-1} in pure water and to 0.0048 s^{-1} in the system with 45 ppt of salinity. However, k_La from all cases operated with saline solutions were in a similar range with the same order of magnitude and the differences among k_La from the various experiments were only marginal.

4.4 Empirical models for the prediction of hydrodynamic properties and gas-liquid mass transfer

From the results obtained above, the relationships between the various parameters with the superficial gas velocity and the number of draft tube could be formulated and these are summarized in this section.

For tap water cases:

(I) Relationship between overall gas holdup and u_{sg} and the number of draft tube

$$\varepsilon = 0.002u_{sg}^{0.95}(n_D + 9)^{0.7} \qquad (4.2)$$

(II) Relationship between riser liquid velocity and u_{sg} and the number of draft tube

$$v_{Lr} = 6.5u_{sg}^{0.6}(n_D + 12)^{0.57} \qquad (4.3)$$

(III) Relationship between k_La and u_{sg} and the number of draft tube

$$k_La = 0.0015u_{sg}^{0.65}(n_D + 9)^{0.4} \qquad (4.4)$$

For saline water at 30 ppt

(I) Relationship between overall gas holdup and u_{sg} and the number of draft tube

$$\varepsilon = 0.008u_{sg}^{0.9}(n_D + 4)^{0.24} \qquad (4.5)$$

(II) Relationship between riser liquid velocity and u_{sg} and the number of draft tube

$$v_{Lr} = 6.4 u_{sg}^{045} (n_D + 12)^{0.57} \tag{4.6}$$

(III) Relationship between $k_L a$ and u_{sg} and the number of draft tube

$$k_L a = 0.0018 u_{sg}^{0.83} (n_D + 12)^{0.5} \tag{4.7}$$

The constants and coefficients presented in Equations (4.2)-(4.7) were within the reported range as summarized in Table 4.4. This demonstrates that the results from this work were consistent with other works, despite of the different contactor sizes.

Table 4.1 Estimates of a and k_L in ALCs with different draft tube configurations, at u_{sg} = 0.5 cm/s

Configuration	k_La (1/s)	d_b (cm)	ε (-)	a (cm^2/cm^3)	k_L (cm/s)
ALC-1	0.001860	0.8	0.004503	0.033923	0.054830
ALC-3	0.001840	0.8	0.004847	0.036533	0.050366
ALC-4	0.001967	0.8	0.006223	0.046967	0.041873
ALC-5-A	0.002267	0.8	0.006567	0.049581	0.045717
ALC-5-B	0.002233	0.8	0.006911	0.052190	0.042792
ALC-6-A	0.002067	0.8	0.007596	0.057404	0.036002
ALC-6-B	0.002133	0.8	0.007939	0.060019	0.035544

Table 4.2 Relationship between u_{sg} and k_La in ALC-1

u_{sg} (cm/s)	a (cm^2/cm^3)	k_L (cm/s)	k_La (1/s)
0.4	0.028704	0.054348	0.00156
0.5	0.033923	0.054830	0.00186
0.6	0.044361	0.046211	0.00205
0.7	0.052190	0.044261	0.00231
0.8	0.065238	0.037401	0.00244
0.9	0.075677	0.037401	0.00283

Table 4.3 Estimate of a in ALC-5-A at u_{sg} = 0.8 cm/s

Salinity	d_b(cm)	k_La (1/s)	k_L (cm/s)	a (cm^2/cm^3)
0	0.8	0.003133	0.040023	0.078288
15	0.6	0.004000	0.037085	0.107861
30	0.6	0.004733	0.043884	0.107861
45	0.6	0.004767	0.044193	0.107861

Table 4.4 Summary of constants and coefficients in empirical correlations for various hydrodynamic parameters in airlift contactors

Parameter	Formula	*a*	*b*
ε	au_{sg}^{b} (variable function)	0.017 - 2.47	-0.5 – 1
v_{Lr}	au_{sg}^{b} (variable function)	0.23 - 33.868	0.233 - 0.4
$k_{L}a$	au_{sg}^{b} (variable function)	0.0002 - 0.46	0.525 - 0.82

Ref: Shah et al. (1982); Akita and Kaweasaki (1983); Kimura and Kubota (1984); Bello et al. (1984); Godbole et al. (1984); Popovic and Robinson (1984); Siegel et al. (1986); Popovic and Robinson (1987); Cristi and Young (1988); Popovic and Robinson (1988); Assa and Bar (1991); Cai et al.(1992); Choi and Lee (1993); Choi (1996); Bentifraouine et al. (1997); Couvert et al. (1999); Korpijarbi et al. (1999).

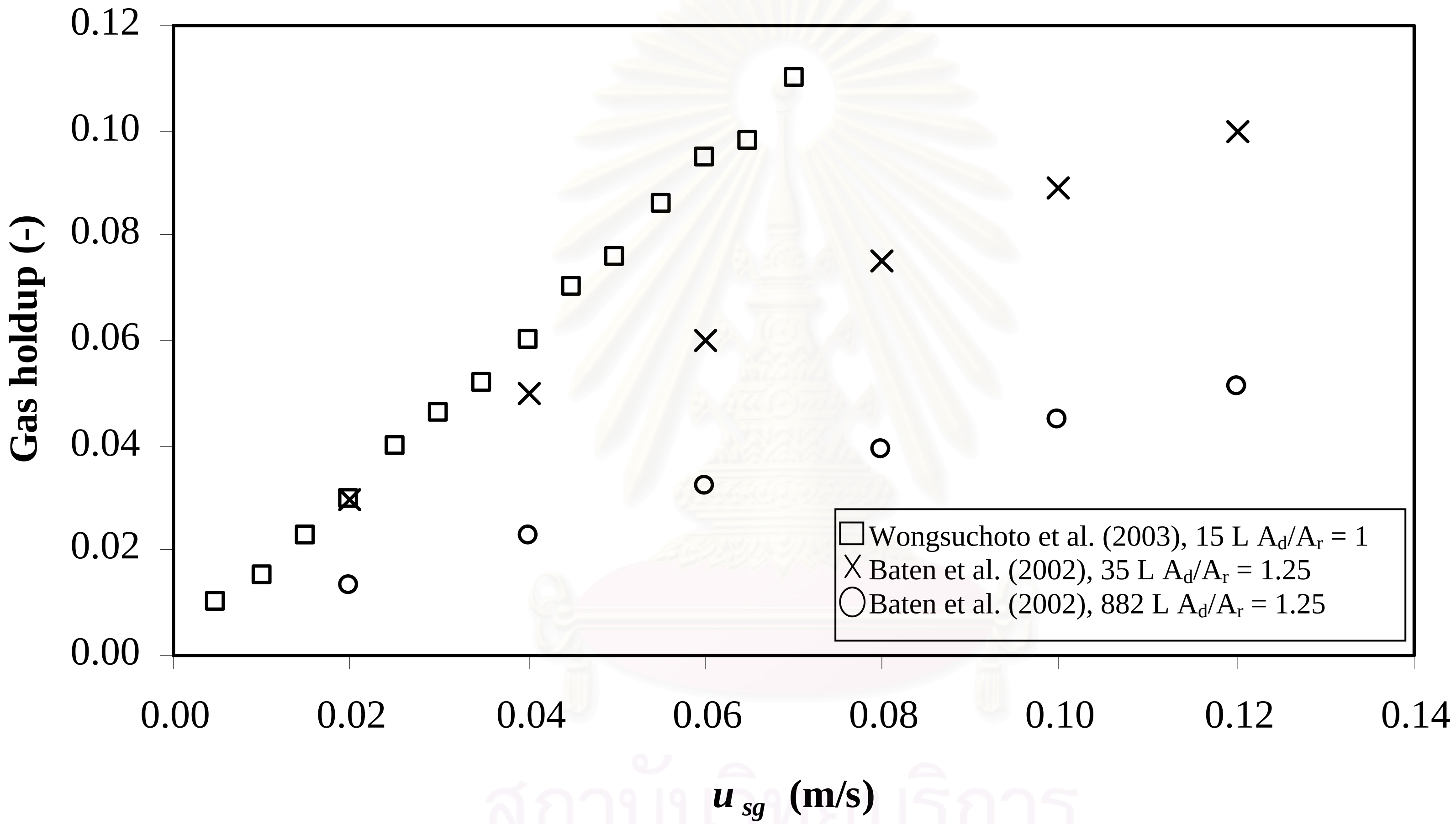

Figure 4.1 Overall gas holdups in air lift contactors in different sizes

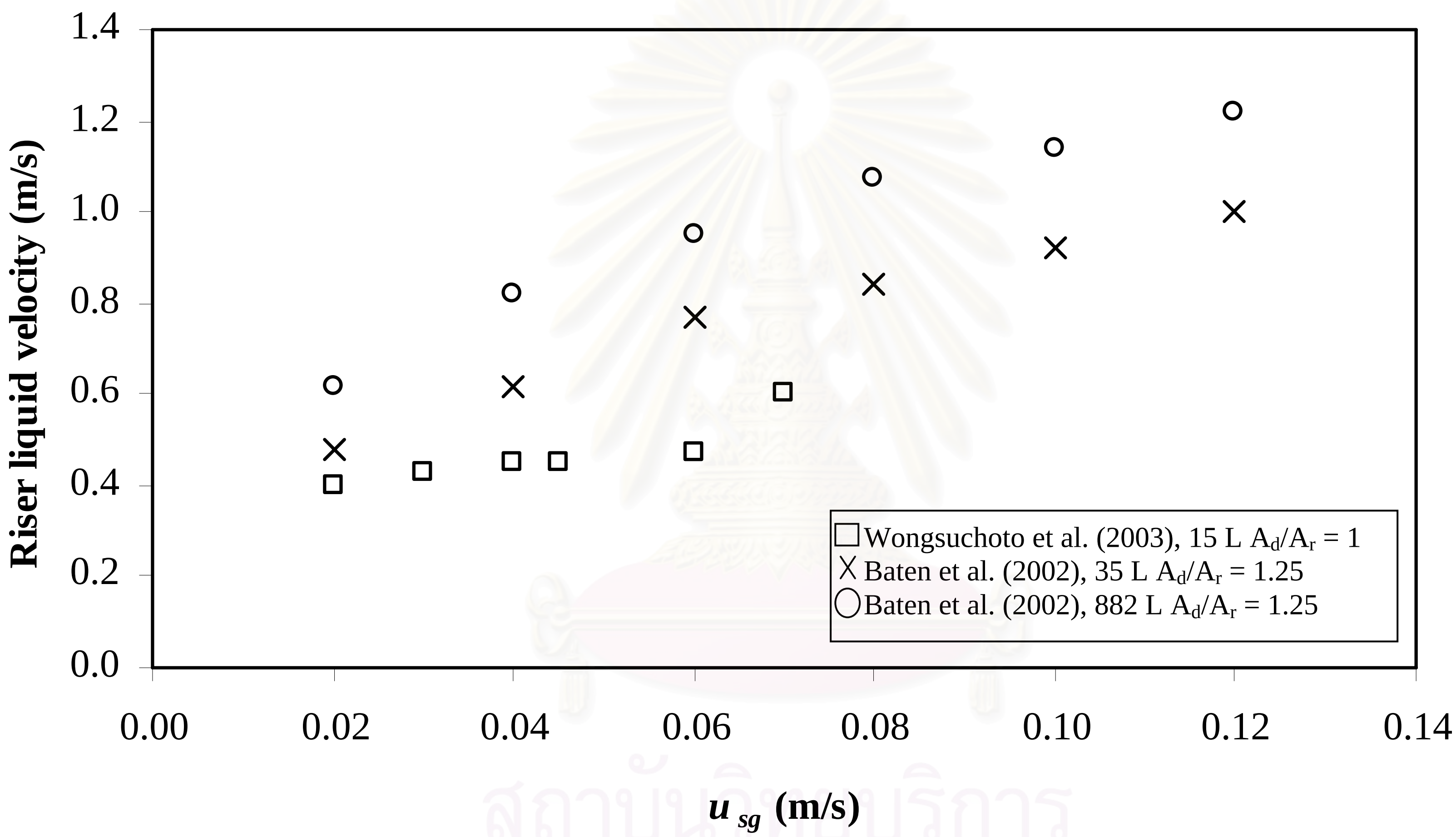

Figure 4.2 Riser Liquid velocities in airlift contactors with different sizes

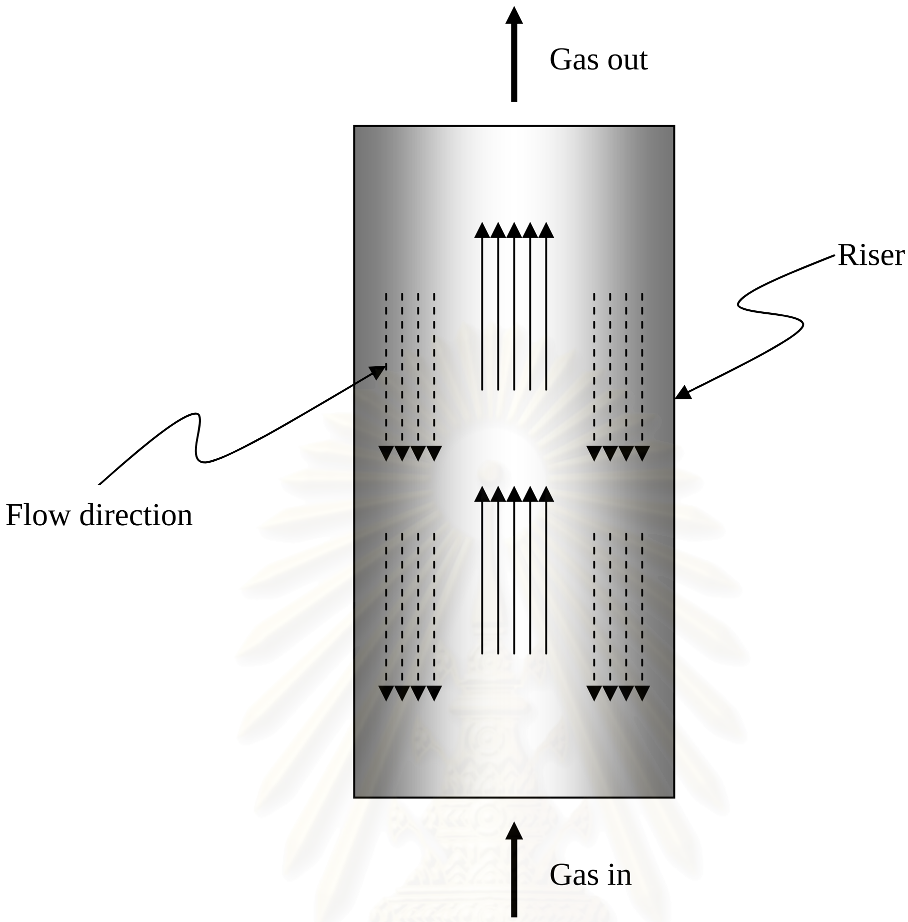

Figure 4.3 Model for liquid flow in riser with internal liquid circulation

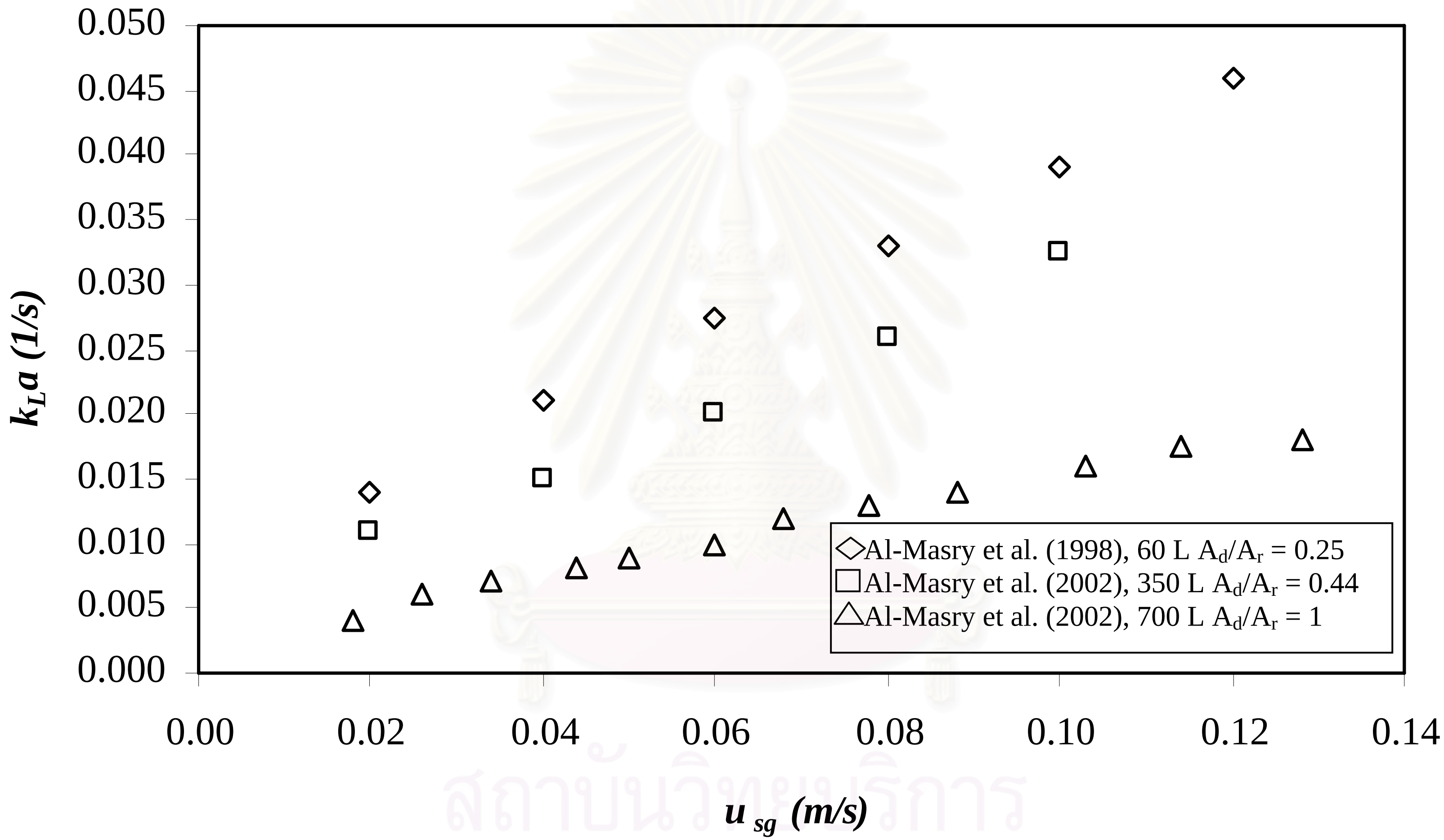

Figure 4.4 Overall volumetric mass transfer coefficients in airlift contactors with different sizes

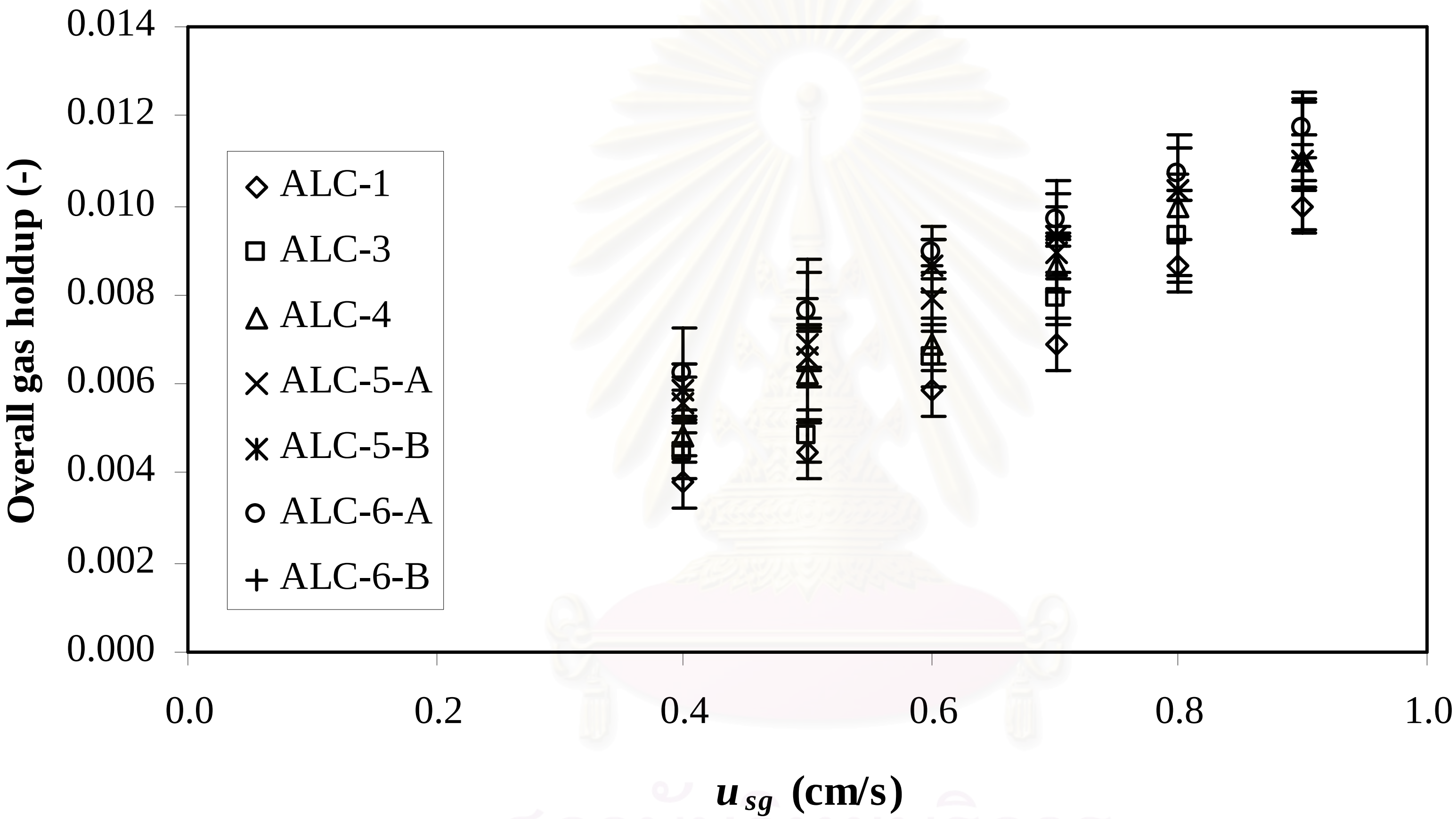

Figure 4.5 Overall gas holdups in airlift systems operating with tap water

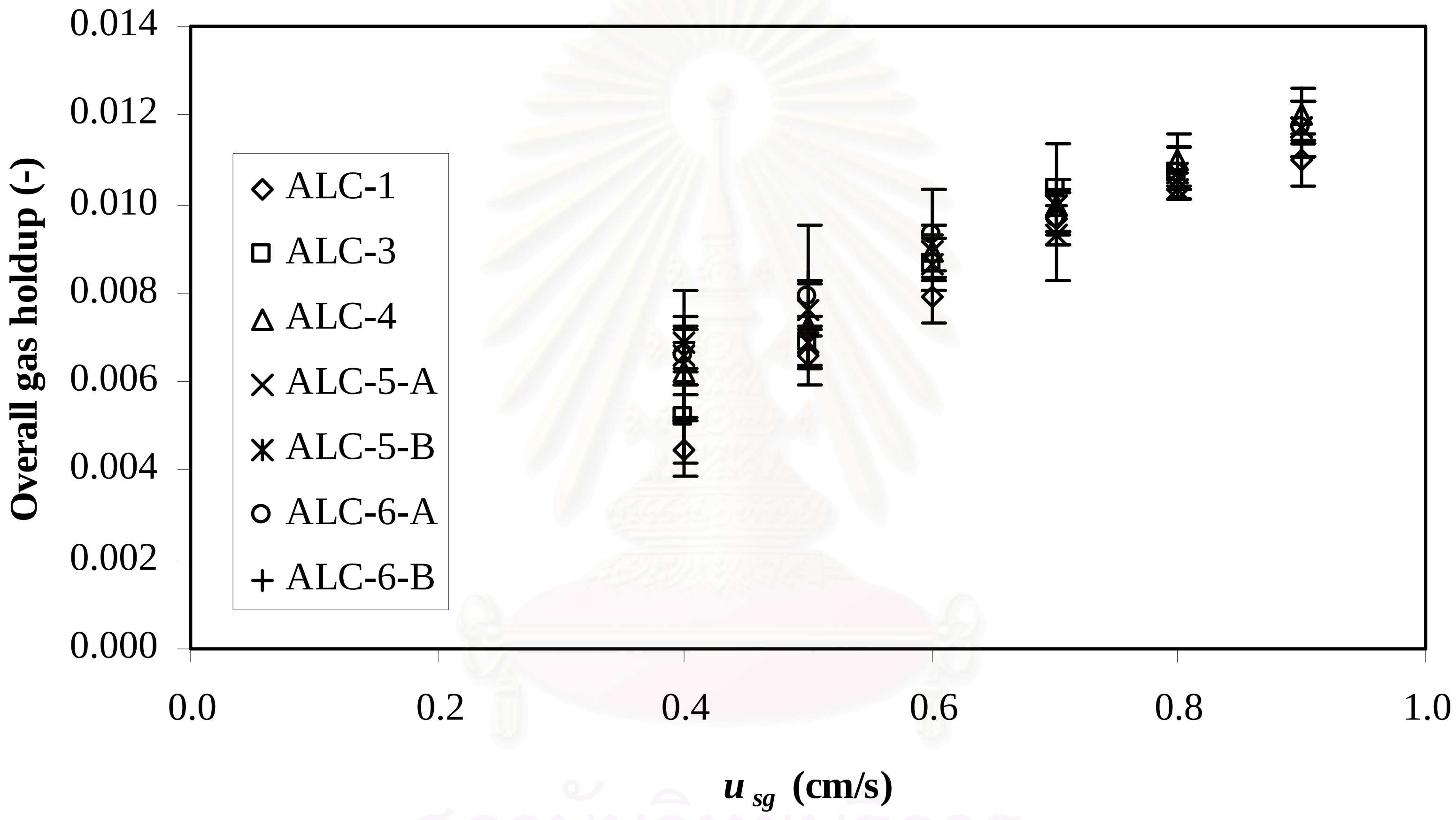

Figure 4.6 Overall gas holdups in airlift systems operating with saline water at 30 ppt

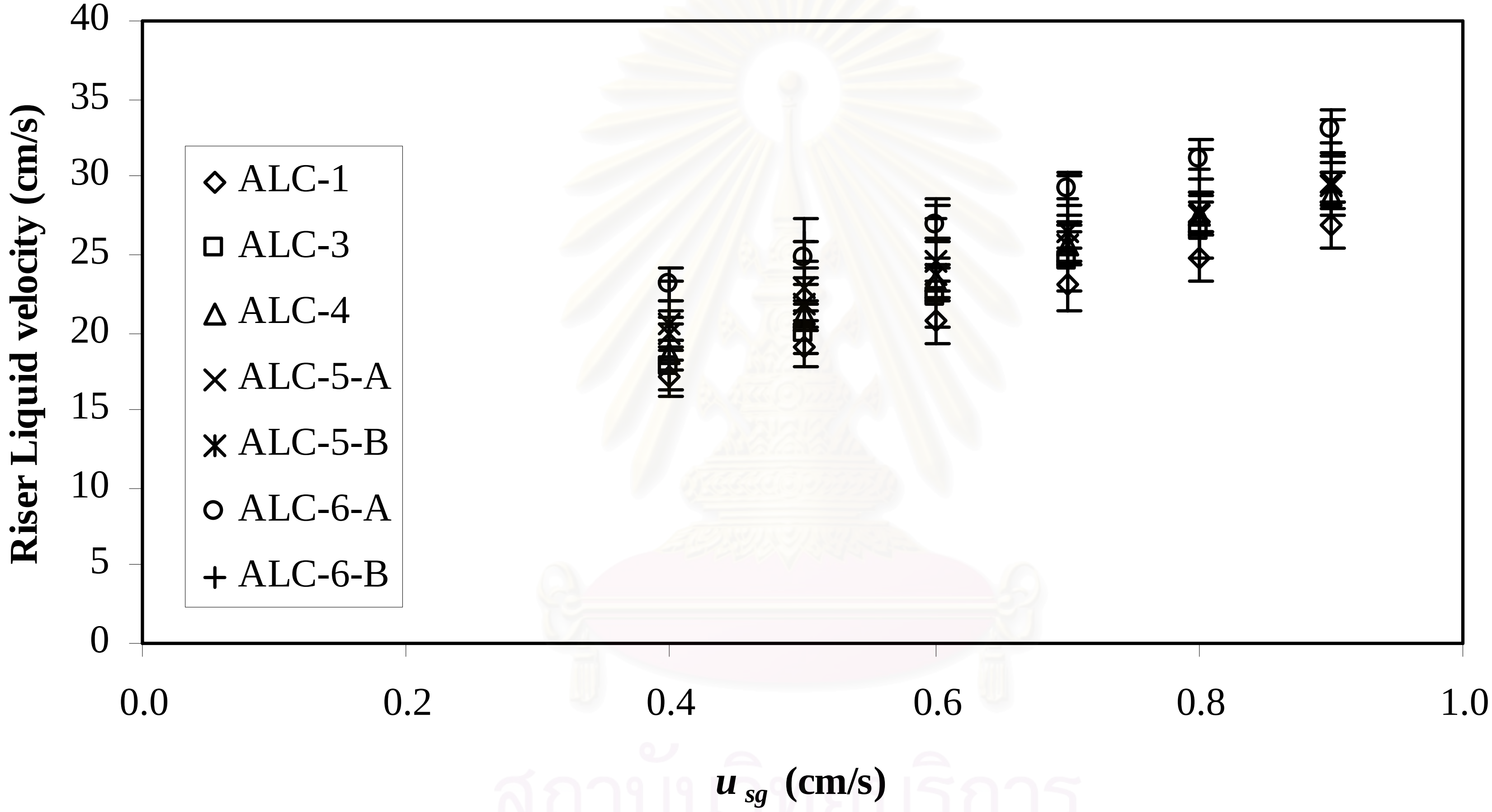

Figure 4.7 Riser liquid velocities in airlift systems operating with tap water

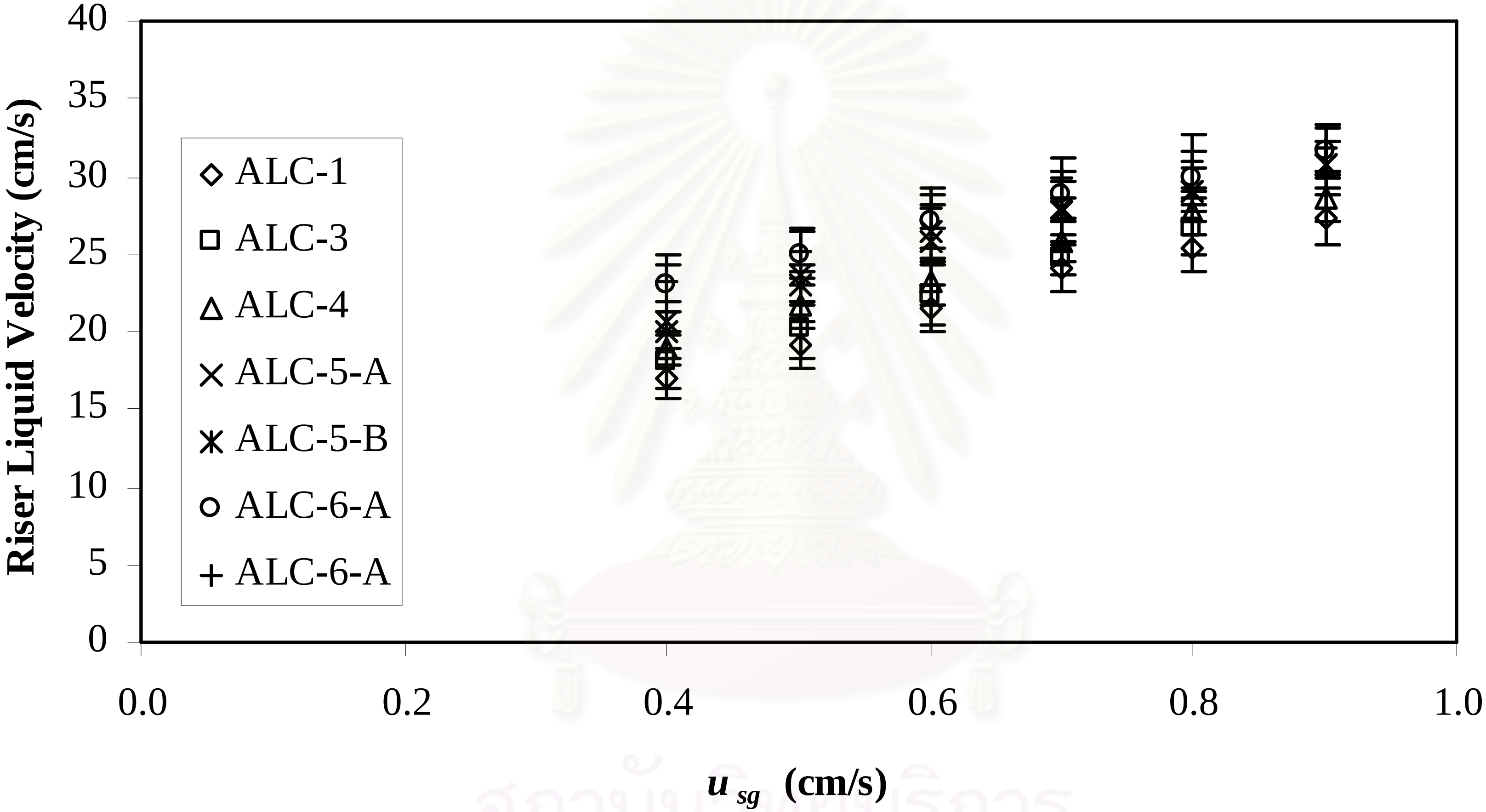

Figure 4.8 Riser liquid velocities in airlift systems operating with saline water at 30 ppt

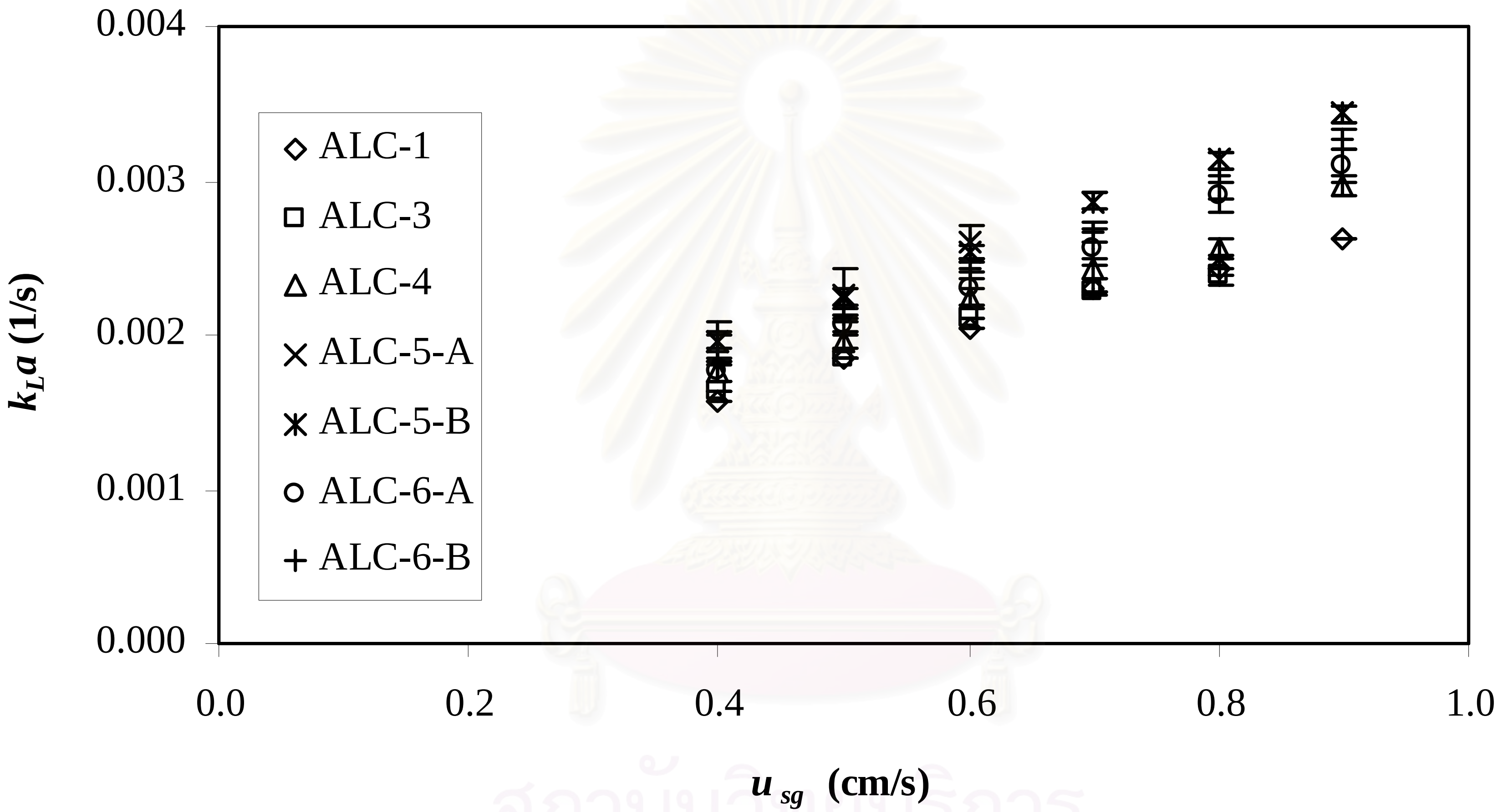

Figure 4.9 Overall volumetric mass transfer coefficients in airlift systems operating with tap water

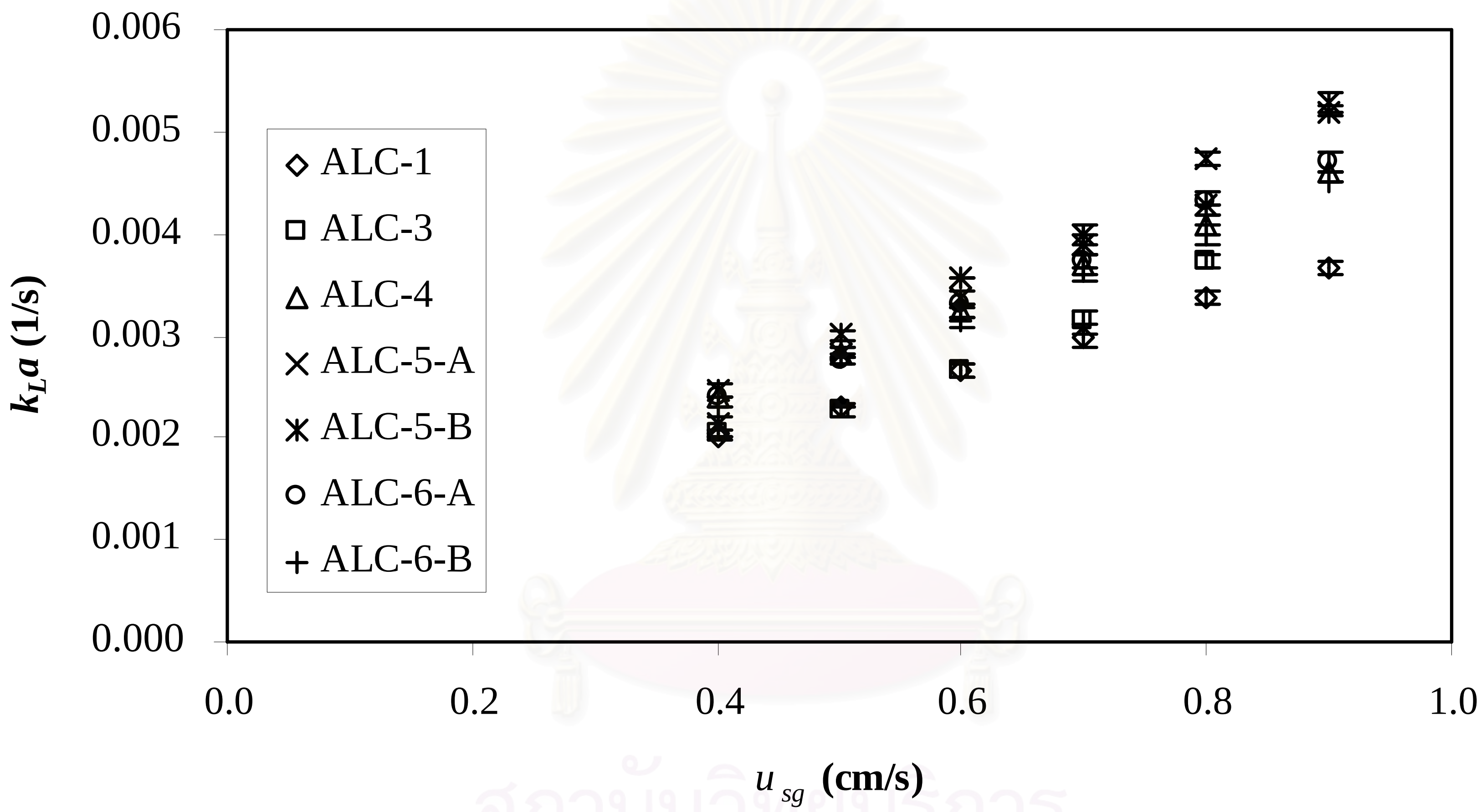

Figure 4.10 Overall volumetric mass transfer coefficients in airlift systems operating with saline water at 30 ppt

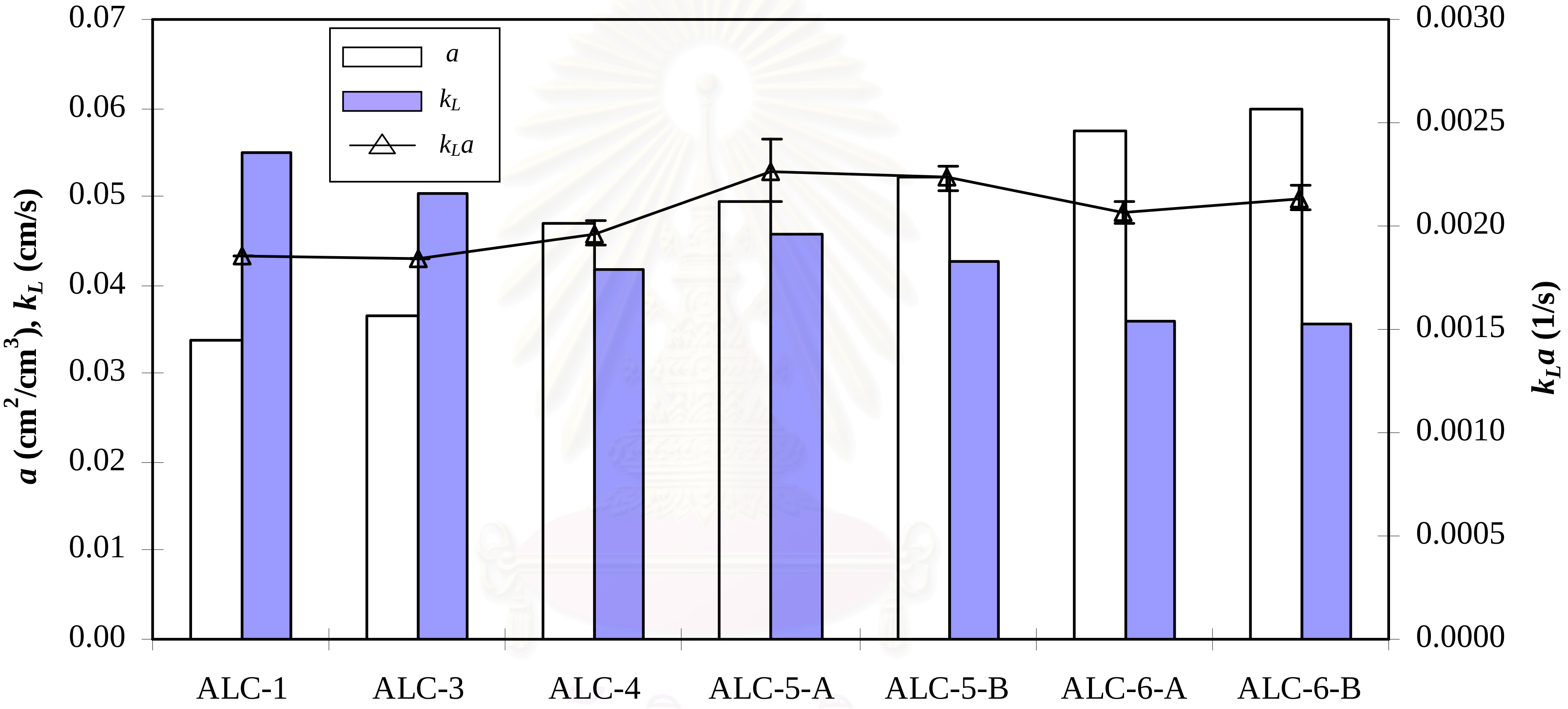

Figure 4.11 Relationship between a and k_L, and $k_L a$ in different configurations (u_{sg} = 0.5 cm/s)

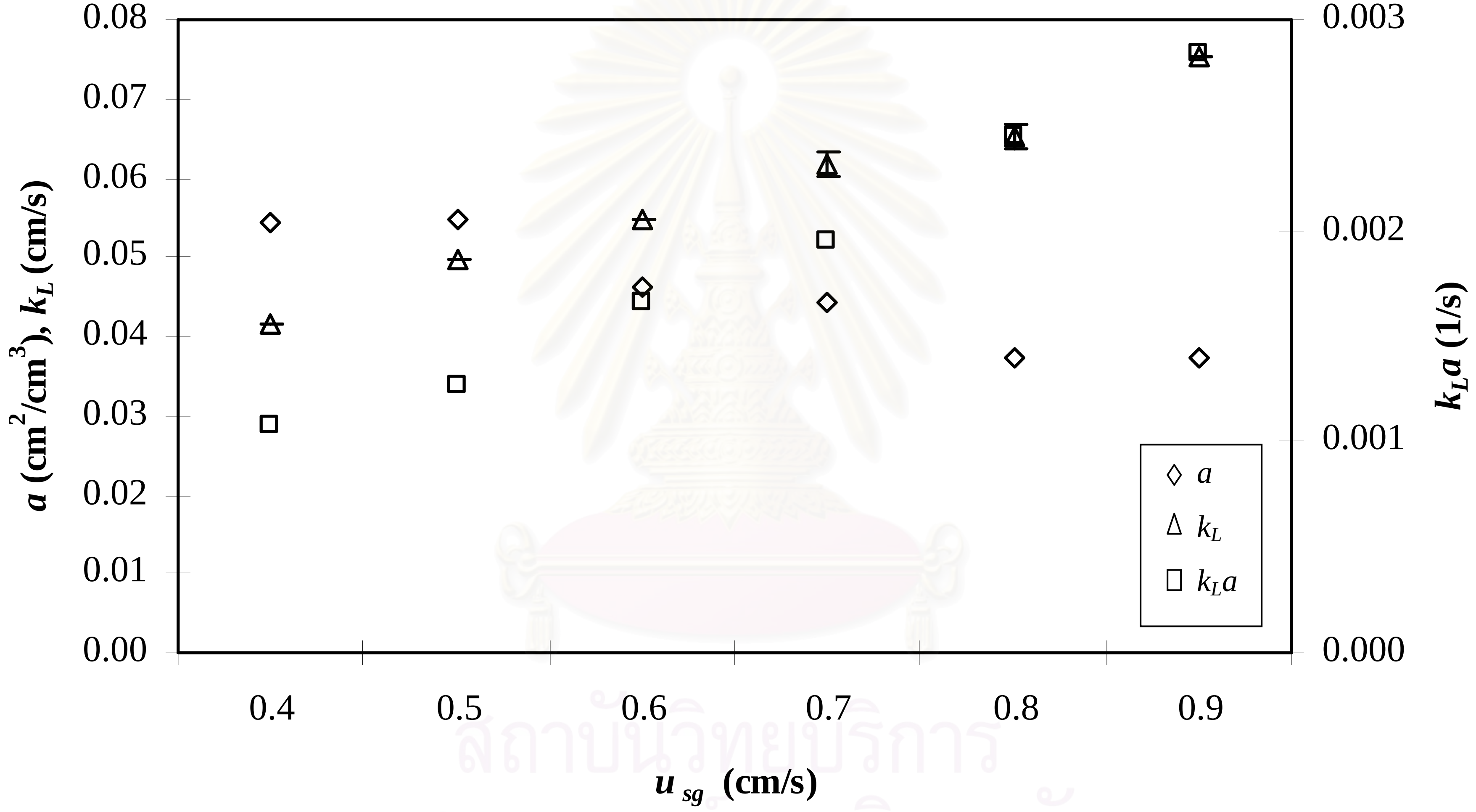

Figure 4.12 Relationship between *a* and k_L, and k_La in ALC-1 (tap water)

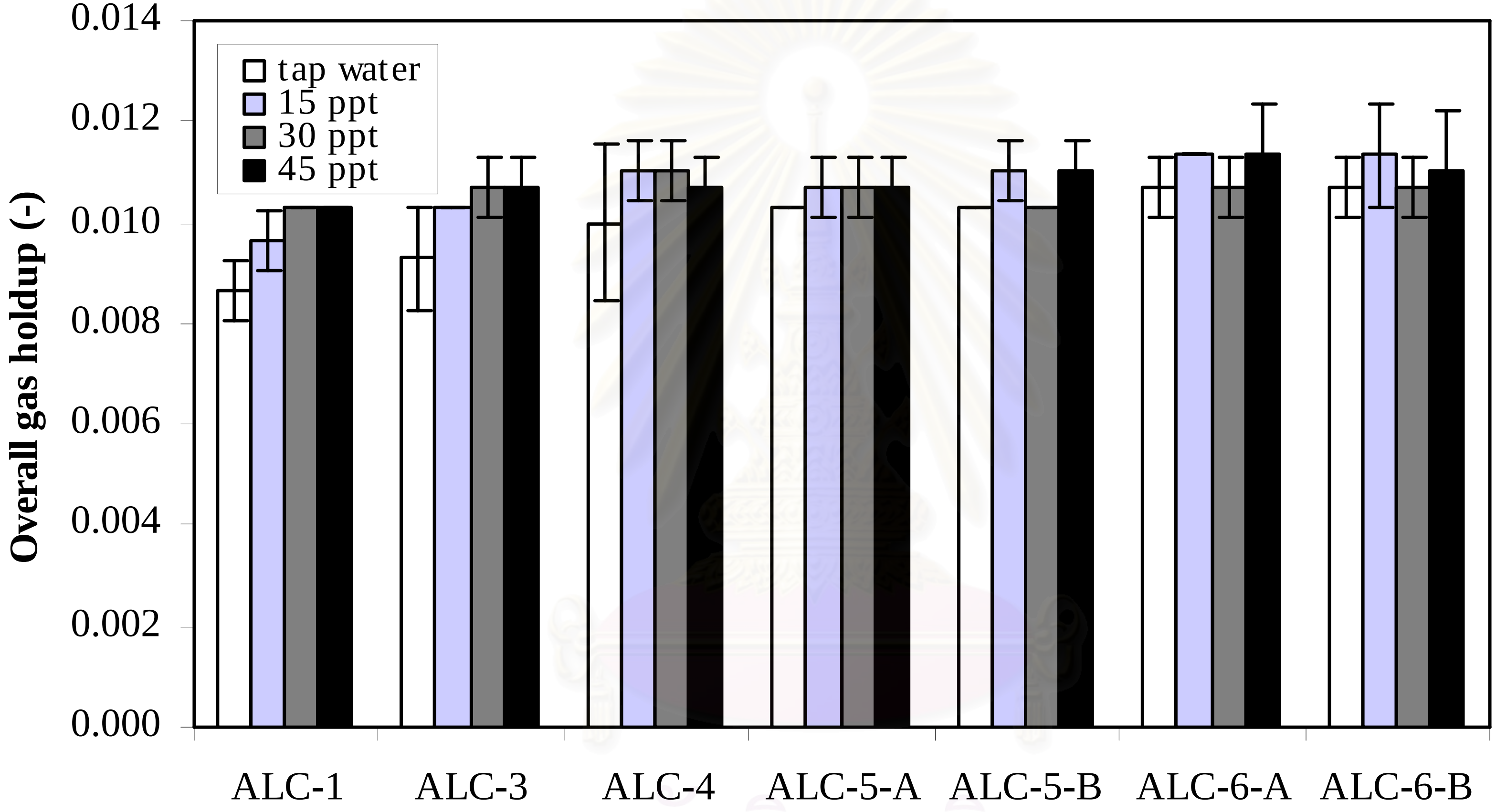

Figure 4.13 Overall gas holdup in airlift systems employed in this work (u_{sg} = 0.8 cm/s)

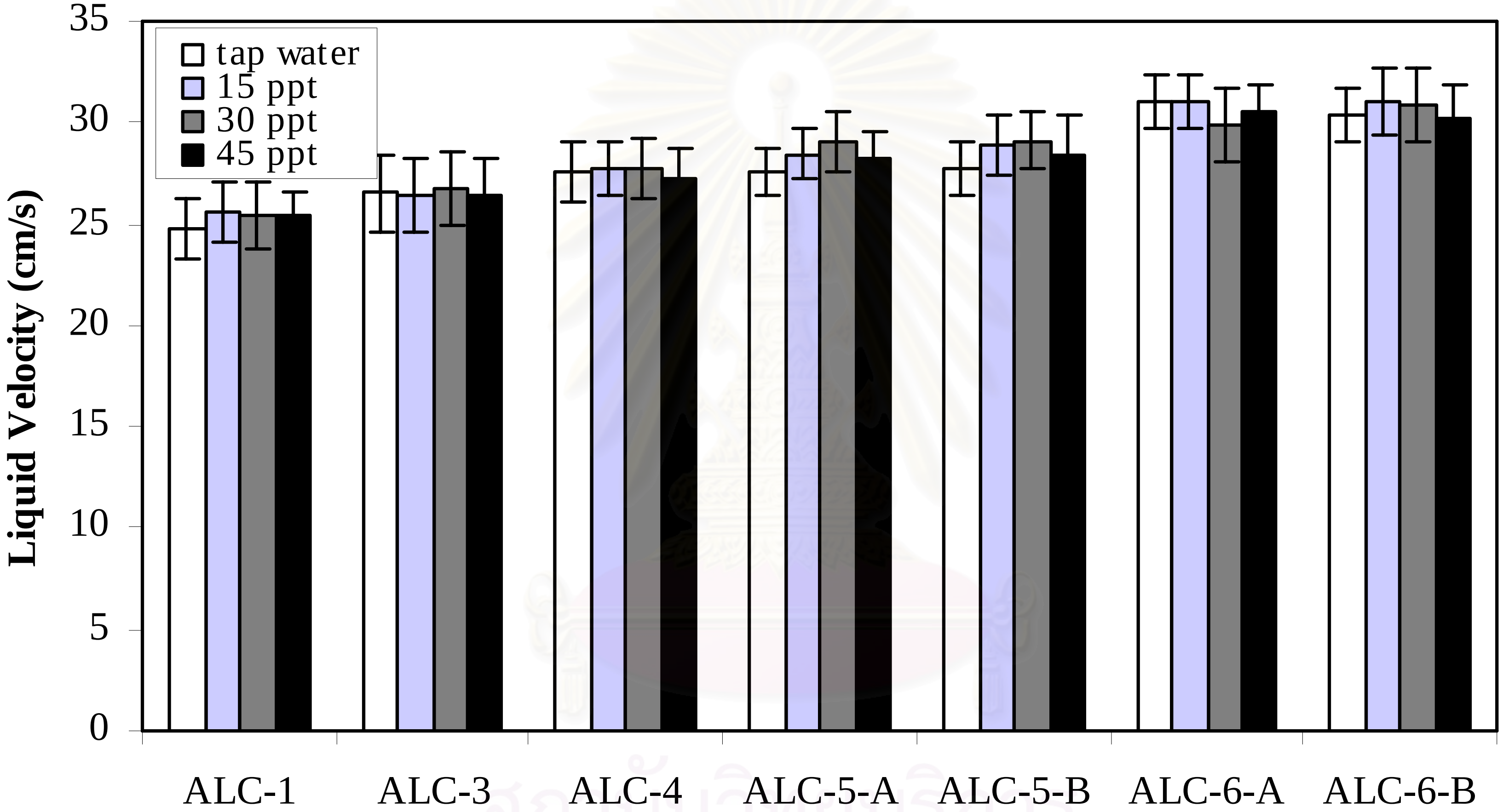

Figure 4.14 Riser liquid velocities in airlift systems employed in this work (u_{sg} = 0.8 cm/s)

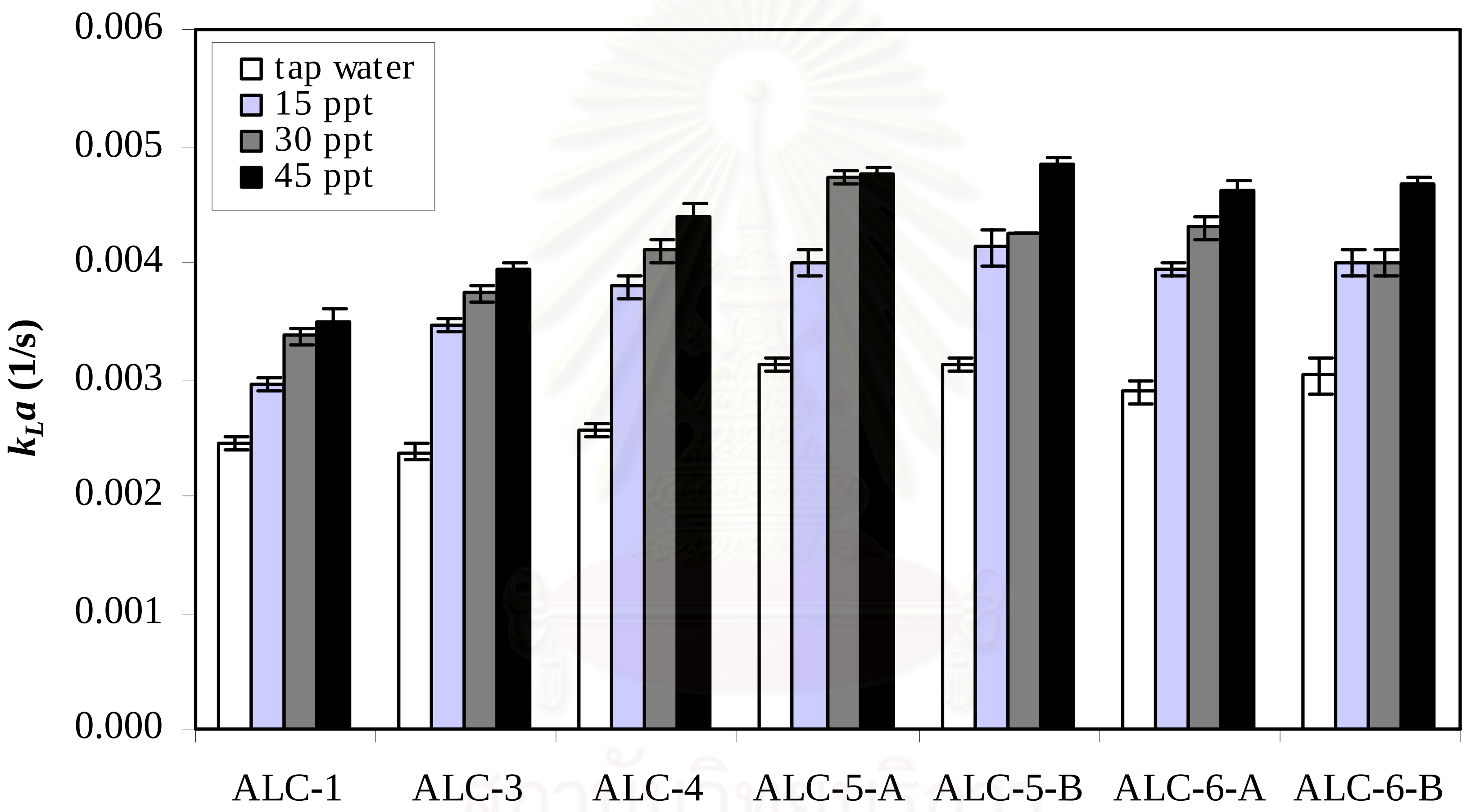

Figure 4.15 Overall volumetric mass transfer coefficient in airlift systems employed in this work (u_{sg} = 0.8 cm/s)

CHAPTER V

CONCLUSIONS & RECOMMENDATIONS

5.1 Achievements & Contributions

In 2004, Tunthikul studied multiple draft tube airlift contacts on hydrodynamic properties and mass transfer and found that an increase in the number of the draft tubes in the large scale airlift contactor led to an improved liquid circulation and gas-liquid mass transfer. However, Tunthikul had limited her work to the system with four draft tubes where it was concluded that this four draft tube system provided a better performance than the one and two draft tube airlift. This thesis was an extension of such work which aimed to provide a more complete picture of the performance of the multiple draft tube airlift system. The criterion used in making decision on which system was good or bad was the gas-liquid mass transfer rate. Problems were encountered in the design of airlift with more than four draft tubes as there were more than one symmetrical configurations available and therefore two patterns of such airlift were proposed as detailed in Chapters III and IV. Salinity came into consideration as recent applications of airlift systems involved the cultivation of sea water diatom which created a number of doubts whether the system would run smoothly if the medium was not fresh water.

Results from this work revealed a number of important findings. Firstly, it was shown that the liquid velocity and the gas holdup could be, to certain extent, manipulated just by changing the configuration of draft tubes in the large scale airlift. Gas-liquid mass transfer could also be partially controlled by having different number and configuration of draft tubes. Salinity seemed not to have great effects on the contactor performance as the level of salinity examined in this work was still quite low and did not have great impacts on the fluid properties. However, it seems that the mass transfer in the saline solution occurred more rapidly than that in pure water. It should be noted, however, that the equilibrium constant for the dissolution of various gas molecules in the saline water was lower than those in pure water systems.

5.2 Limitations & Recommendations

- Superficial gas velocity employed in this work was still quite low. This was, in fact, limited by the size of the air compressor employed in this work. The next step should extend this study to focus on the system operating at high superficial gas velocity.

- During the measurement of riser liquid velocity, the tracer injection method was used where the tracer could be easily distributed in all directions. This resulted in significant error in the measurement. In this work, this error was compensated by conducting a large number of measurements. However, new research might be directed towards the development of the measurement technique for such liquid movement.

- Similarly the measurements of bubble size in large scale systems have always attracted research attention. However, there seemed to have no other alternatives available at this present time. There should also be some kind of research work that focuses on this matter.

- In addition, the investigation of the scale-up of airlift contactors should be focused on how to reduce the local or internal liquid circulation, particularly in the riser with large diameter. The study as conducted in this measurement might find its constraint as new sets of experiments must be performed every time the contactor changes its size. Perhaps a better way out is to examine the relationship between the nature of the internal liquid circulation and the draft tube size and the characteristics of sparger. This would lead to a design of each single draft tube with the lowest possible internal liquid circulation which would be installed in the outer layer of the large scale airlift of variable size. The might help reduce the number of experiments required to investigate the scale-up of such airlift system.

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Appendix A

Mass Transfer Calculation Results

Table A-1 Estimates of a and k_L in different configurations at u_{sg} = 0.4 cm/s (tap water)

Configuration	k_La (1/s)	d_b (cm)	ε (-)	a (cm^2/cm^3)	k_L (cm/s)
ALC-1	0.001560	0.8	0.003813	0.028704	0.054348
ALC-3	0.001640	0.8	0.004503	0.033923	0.048345
ALC-4	0.001767	0.8	0.004847	0.036533	0.048359
ALC-5-A	0.001967	0.8	0.005536	0.041752	0.047104
ALC-5-B	0.001967	0.8	0.005880	0.044361	0.044333
ALC-6-A	0.001767	0.8	0.006223	0.046967	0.037615
ALC-6-B	0.001900	0.8	0.005880	0.044361	0.042830

Table A-2 Estimates of a and k_L in different configurations at u_{sg} = 0.5 cm/s (tap water)

Configuration	k_La (1/s)	d_b (cm)	ε (-)	a (cm^2/cm^3)	k_L (cm/s)
ALC-1	0.001860	0.8	0.004503	0.033923	0.054830
ALC-3	0.001840	0.8	0.004847	0.036533	0.050366
ALC-4	0.001967	0.8	0.006223	0.046967	0.041873
ALC-5-A	0.002267	0.8	0.006567	0.049581	0.045717
ALC-5-B	0.002233	0.8	0.006911	0.052190	0.042792
ALC-6-A	0.002067	0.8	0.007596	0.057404	0.036002
ALC-6-B	0.002133	0.8	0.007939	0.060019	0.035544

Table A-3 Estimates of a and k_L in different configurations at u_{sg} = 0.6 cm/s (tap water)

Configuration	k_La (1/s)	d_b (cm)	ε (-)	a (cm^2/cm^3)	k_L (cm/s)
ALC-1	0.002050	0.8	0.005880	0.044361	0.046211
ALC-3	0.002100	0.8	0.006567	0.049581	0.042355
ALC-4	0.002233	0.8	0.006911	0.052190	0.042792
ALC-5-A	0.002533	0.8	0.007939	0.060019	0.042209
ALC-5-B	0.002600	0.8	0.008623	0.065238	0.039854
ALC-6-A	0.002300	0.8	0.008965	0.067848	0.033899
ALC-6-B	0.002433	0.8	0.008623	0.065238	0.037299

Table A-4 Estimation value of a and k_L in different configurations at u_{sg} = 0.7 cm/s (tap water)

Configuration	k_La (1/s)	d_b (cm)	ε (-)	a (cm^2/cm^3)	k_L (cm/s)
ALC-1	0.00231	0.8	0.006911	0.05219	0.044261
ALC-3	0.00227	0.8	0.007939	0.060019	0.037821
ALC-4	0.002433	0.8	0.008623	0.065238	0.037299
ALC-5-A	0.002867	0.8	0.008965	0.067848	0.042251
ALC-5-B	0.002867	0.8	0.009307	0.070459	0.040685
ALC-6-A	0.002567	0.8	0.009648	0.073067	0.035128
ALC-6-B	0.002667	0.8	0.009989	0.075677	0.035238

Table A-5 Estimates of a and k_L in different configurations at u_{sg} = 0.8 cm/s (tap water)

Configuration	k_La (1/s)	d_b (cm)	ε (-)	a (cm^2/cm^3)	k_L (cm/s)
ALC-1	0.002440	0.8	0.008623	0.065238	0.037401
ALC-3	0.002380	0.8	0.009306	0.070454	0.033781
ALC-4	0.002567	0.8	0.009988	0.075666	0.033921
ALC-5-A	0.003133	0.8	0.010331	0.078288	0.040023
ALC-5-B	0.003133	0.8	0.010331	0.078288	0.040023
ALC-6-A	0.002900	0.8	0.010671	0.080896	0.035849
ALC-6-B	0.003033	0.8	0.010671	0.080896	0.037497

Table A-6 Estimates of a and k_L in different configurations at u_{sg} = 0.9 cm/s (tap water)

Configuration	k_La (1/s)	d_b (cm)	ε (-)	a (cm^2/cm^3)	k_L (cm/s)
ALC-1	0.002620	0.8	0.009989	0.075677	0.034621
ALC-4	0.002967	0.8	0.011011	0.083506	0.035527
ALC-5-A	0.003433	0.8	0.011010	0.083495	0.041120
ALC-5-B	0.003433	0.8	0.011011	0.083506	0.041115
ALC-6-A	0.003100	0.8	0.011692	0.088725	0.034940
ALC-6-B	0.003267	0.8	0.011351	0.086112	0.037935

Table A-7 Estimates of a and k_L in different configurations at u_{sg} = 0.8 cm/s (15 ppt)

Configuration	k_La (1/s)	d_b (cm)	ε (-)	a (cm^2/cm^3)	k_L (cm/s)
ALC-1	0.002967	0.6	0.009648	0.097423	0.030451
ALC-3	0.003467	0.6	0.010331	0.104384	0.033211
ALC-4	0.003800	0.6	0.011011	0.111341	0.034129
ALC-5-A	0.004000	0.6	0.010671	0.107861	0.037085
ALC-5-B	0.004133	0.6	0.011011	0.111341	0.037123
ALC-6-A	0.003933	0.6	0.011352	0.114823	0.034256
ALC-6-B	0.004000	0.6	0.011351	0.114815	0.034839

Table A-8 Estimation value of a and k_L in different configurations at u_{sg} = 0.4 cm/s (30 ppt)

Configuration	k_La (1/s)	d_b (cm)	ε (-)	a (cm^2/cm^3)	k_L (cm/s)
ALC-1	0.002000	0.6	0.004503	0.045231	0.044218
ALC-3	0.002033	0.6	0.005191	0.052185	0.038964
ALC-4	0.002400	0.6	0.006223	0.062623	0.038324
ALC-5-A	0.002133	0.6	0.006567	0.066108	0.032271
ALC-5-B	0.002467	0.6	0.006911	0.069587	0.035447
ALC-6-A	0.002400	0.6	0.006567	0.066108	0.036304
ALC-6-B	0.002300	0.6	0.006910	0.069580	0.033056

Table A-9 Estimates of a and k_L in different configurations at u_{sg} = 0.5 cm/s (30 ppt)

Configuration	k_La (1/s)	d_b (cm)	ε (-)	a (cm^2/cm^3)	k_L (cm/s)
ALC-1	0.002300	0.6	0.006567	0.066108	0.034792
ALC-3	0.002267	0.6	0.006911	0.069587	0.032573
ALC-4	0.002833	0.6	0.007254	0.073069	0.038776
ALC-5-A	0.002833	0.6	0.006911	0.069587	0.040716
ALC-5-B	0.003000	0.6	0.007596	0.076546	0.039192
ALC-6-A	0.002767	0.6	0.007938	0.080011	0.034579
ALC-6-B	0.002800	0.6	0.008282	0.083507	0.033530

Table A-10 Estimates of a and k_L in different configurations at u_{sg} = 0.6 cm/s (30 ppt)

Configuration	k_La (1/s)	d_b (cm)	ε (-)	a (cm^2/cm^3)	k_L (cm/s)
ALC-1	0.002667	0.6	0.007939	0.080025	0.033323
ALC-3	0.002667	0.6	0.008623	0.086984	0.030657
ALC-4	0.003233	0.6	0.008965	0.090464	0.035742
ALC-5-A	0.003367	0.6	0.008623	0.086984	0.038704
ALC-5-B	0.003567	0.6	0.008965	0.090464	0.039426
ALC-6-A	0.003300	0.6	0.009306	0.093939	0.035129
ALC-6-B	0.003133	0.6	0.009306	0.093939	0.033355

Table A-11 Estimates of a and k_L in different configurations at u_{sg} = 0.7 cm/s (30 ppt)

Configuration	k_La (1/s)	d_b (cm)	ε (-)	a (cm^2/cm^3)	k_L (cm/s)
ALC-1	0.003000	0.6	0.009648	0.097423	0.030794
ALC-3	0.003133	0.6	0.010330	0.104377	0.030019
ALC-4	0.003700	0.6	0.009989	0.100902	0.036669
ALC-5-A	0.003900	0.6	0.009306	0.093939	0.041517
ALC-5-B	0.004000	0.6	0.009989	0.100902	0.039642
ALC-6-A	0.003733	0.6	0.009648	0.097423	0.038321
ALC-6-B	0.003667	0.6	0.009989	0.100902	0.036339

Table A-12 Estimation of a and k_L in different configurations at u_{sg} = 0.8 cm/s (30 ppt)

Configuration	k_La (1/s)	d_b (cm)	ε (-)	a (cm^2/cm^3)	k_L (cm/s)
ALC-1	0.003367	0.6	0.010331	0.104384	0.032253
ALC-3	0.003733	0.6	0.010671	0.107861	0.034612
ALC-4	0.004100	0.6	0.011011	0.111341	0.036824
ALC-5-A	0.004733	0.6	0.010671	0.107861	0.043884
ALC-5-B	0.004267	0.6	0.010331	0.104384	0.040875
ALC-6-A	0.004300	0.6	0.010671	0.107861	0.039866
ALC-6-B	0.004000	0.6	0.010671	0.107861	0.037085

Table A-13 Estimates of *a* and k_L in different configurations at u_{sg} = 0.9 cm/s (30 ppt)

Configuration	k_La (1/s)	d_b (cm)	ε (-)	a (cm^2/cm^3)	k_L (cm/s)
ALC-1	0.003667	0.6	0.011011	0.111341	0.032932
ALC-4	0.004600	0.6	0.012031	0.121779	0.037773
ALC-5-A	0.005300	0.6	0.011692	0.118300	0.044801
ALC-5-B	0.005200	0.6	0.011692	0.118300	0.043956
ALC-6-A	0.004700	0.6	0.011692	0.118300	0.039730
ALC-6-B	0.004500	0.6	0.011352	0.114823	0.039191

Table A-14 Estimates of *a* and k_L in different configurations at u_{sg} = 0.8 cm/s (45 ppt)

Configuration	k_La (1/s)	d_b (cm)	ε (-)	a (cm^2/cm^3)	k_L (cm/s)
ALC-1	0.003500	0.6	0.010331	0.104384	0.033530
ALC-3	0.003933	0.6	0.010671	0.107861	0.036467
ALC-4	0.004400	0.6	0.010671	0.107861	0.040793
ALC-5-A	0.004767	0.6	0.010671	0.107861	0.044193
ALC-5-B	0.004833	0.6	0.011011	0.111341	0.043410
ALC-6-A	0.004633	0.6	0.011351	0.114815	0.040355
ALC-6-B	0.004667	0.6	0.011011	0.111334	0.041916

Table A-15 Relationship between u_{sg} and k_La in ALC-1 (tap water)

u_{sg} (cm/s)	a (cm^2/cm^3)	k_L (cm/s)	k_La (1/s)
0.4	0.028704	0.054348	0.00156
0.5	0.033923	0.054830	0.00186
0.6	0.044361	0.046211	0.00205
0.7	0.052190	0.044261	0.00231
0.8	0.065238	0.037401	0.00244
0.9	0.075677	0.037401	0.00283

Table A-16 Relationship between u_{sg} and k_La in ALC-3 (tap water)

u_{sg} (cm/s)	a (cm^2/cm^3)	k_L (cm/s)	k_La (1/s)
0.4	0.033923	0.048345	0.00164
0.5	0.036533	0.050366	0.00184
0.6	0.049581	0.042355	0.00210
0.7	0.060019	0.037821	0.00227
0.8	0.070454	0.033781	0.00238

Table A-17 Relationship between u_{sg} and k_La in ALC-4 (tap water)

u_{sg} (cm/s)	a (cm^2/cm^3)	k_L (cm/s)	k_La (1/s)
0.4	0.036533	0.048359	0.001767
0.5	0.046967	0.041873	0.001967
0.6	0.052190	0.042792	0.002233
0.7	0.065238	0.037299	0.002433
0.8	0.075666	0.033921	0.002567
0.9	0.083506	0.035527	0.002967

Table A-18 Relationship between u_{sg} and k_La in ALC-5-A (tap water)

u_{sg} (cm/s)	a (cm^2/cm^3)	k_L (cm/s)	k_La (1/s)
0.4	0.041752	0.047104	0.001967
0.5	0.049581	0.045717	0.002267
0.6	0.060019	0.042209	0.002533
0.7	0.067848	0.042251	0.002867
0.8	0.078288	0.040023	0.003133
0.9	0.083495	0.041120	0.003433

Table A-19 Relationship between u_{sg} and k_La in ALC-5-B (tap water)

u_{sg} (cm/s)	a (cm^2/cm^3)	k_L (cm/s)	k_La (1/s)
0.4	0.044361	0.044333	0.001967
0.5	0.05219	0.042792	0.002233
0.6	0.065238	0.039854	0.0026
0.7	0.070459	0.040685	0.002867
0.8	0.078288	0.040023	0.003133
0.9	0.083506	0.041115	0.003433

Table A-20 Relationship between u_{sg} and k_La in ALC-6-A (tap water)

u_{sg} (cm/s)	a (cm^2/cm^3)	k_L (cm/s)	k_La (1/s)
0.4	0.046967	0.037615	0.001767
0.5	0.057404	0.036002	0.002067
0.6	0.067848	0.033899	0.002300
0.7	0.073067	0.035128	0.002567
0.8	0.080896	0.035849	0.002900
0.9	0.088725	0.034940	0.003100

Table A-21 Relationship between u_{sg} and k_La in ALC-6-B (tap water)

u_{sg} (cm/s)	a (cm^2/cm^3)	k_L (cm/s)	k_La (1/s)
0.4	0.046967	0.04283	0.002012
0.5	0.054802	0.035544	0.001948
0.6	0.067848	0.037299	0.002531
0.7	0.075677	0.035238	0.002667
0.8	0.083506	0.037497	0.003131
0.9	0.091334	0.037935	0.003465

Table A-22 Relationship between u_{sg} and k_La in ALC-1 (30 ppt)

u_{sg} (cm/s)	a (cm^2/cm^3)	k_L (cm/s)	k_La (1/s)
0.4	0.045231	0.044218	0.00200
0.5	0.066108	0.034792	0.002300
0.6	0.080025	0.033323	0.002667
0.7	0.097423	0.030794	0.003000
0.8	0.104384	0.032253	0.003367
0.9	0.111341	0.032932	0.003667

Table A-23 Relationship between u_{sg} and k_La in ALC-3 (30 ppt)

u_{sg} (cm/s)	a (cm^2/cm^3)	k_L (cm/s)	k_La (1/s)
0.4	0.052185	0.038964	0.002033
0.5	0.069587	0.032573	0.002267
0.6	0.086984	0.030657	0.002667
0.7	0.104377	0.030019	0.003133
0.8	0.107861	0.034612	0.003733

Table A-24 Relationship between u_{sg} and k_La in ALC-4 (30 ppt)

u_{sg} (cm/s)	a (cm^2/cm^3)	k_L (cm/s)	k_La (1/s)
0.4	0.062623	0.038324	0.002400
0.5	0.073069	0.038776	0.002833
0.6	0.090464	0.035742	0.003233
0.7	0.100902	0.036669	0.003700
0.8	0.111341	0.036824	0.004100
0.9	0.121779	0.037773	0.004600

Table A-25 Relationship between u_{sg} and $k_L a$ in ALC-5-A (30 ppt)

u_{sg} (cm/s)	a (cm^2/cm^3)	k_L (cm/s)	$k_L a$ (1/s)
0.4	0.066108	0.032271	0.002133
0.5	0.069587	0.040716	0.002833
0.6	0.086984	0.038704	0.003367
0.7	0.093939	0.041517	0.0039
0.8	0.107861	0.043884	0.004733
0.9	0.1183	0.044801	0.0053

Table A-26 Relationship between u_{sg} and $k_L a$ in ALC-5-B (30 ppt)

u_{sg} (cm/s)	a (cm^2/cm^3)	k_L (cm/s)	$k_L a$ (1/s)
0.4	0.069587	0.035447	0.002467
0.5	0.076546	0.039192	0.003000
0.6	0.090464	0.039426	0.003567
0.7	0.100902	0.039642	0.004000
0.8	0.104384	0.040875	0.004267
0.9	0.118300	0.043956	0.005200

Table A-27 Relationship between u_{sg} and $k_L a$ in ALC-6-A (30 ppt)

u_{sg} (cm/s)	a (cm^2/cm^3)	k_L (cm/s)	$k_L a$ (1/s)
0.4	0.066108	0.036304	0.002400
0.5	0.080011	0.034579	0.002767
0.6	0.093939	0.035129	0.003300
0.7	0.097423	0.038321	0.003733
0.8	0.107861	0.039866	0.004300
0.9	0.118300	0.039730	0.004700

Table A-28 Relationship between u_{sg} and $k_L a$ in ALC-6-B (30 ppt)

u_{sg} (cm/s)	a (cm^2/cm^3)	k_L (cm/s)	$k_L a$ (1/s)
0.4	0.069580	0.033056	0.002300
0.5	0.083507	0.033530	0.002800
0.6	0.093939	0.033355	0.003133
0.7	0.100902	0.036339	0.003667
0.8	0.107861	0.037085	0.004000
0.9	0.114823	0.039191	0.004500

BIOGRAPHY

Mr. Chenwit Linthong was born on 16th December, 1981 in Samutprakarn. His native home was Samutprakarn province. He finished her secondary school from Satree Samutprakarn School in 2000. He got bachelor degree from Chemical Engineering in Faculty of Engineer at Burapha University in 2004. He continued his further study for master's degree in Chemical Engineering at Chulalongkorn University. He participated in the Biochemical Engineering Research Group and achieved completed his Master's degree in October, 2007.