CHAPTER I
INTRODUCTION

1.1 Background

A reactor is the main piece of equipment in industrial processes used to convert raw materials into products. Reactors can be classified based on their mode of operation, geometry, and reaction phase. In terms of operation, reactors are known as batch, semi-batch, and continuous. In terms of geometry, they are distinguished into stirred tank reactors, column reactors, and fluidized bed reactors. Meanwhile, based on the reaction phase involved, reactors are classified into homogeneous and heterogeneous reactors.

A heterogeneous reactor is a reactor used to react components consisting of at least two phases, such as gas-liquid phases. Reactors used for gas-liquid contact include the bubble column reactor and the air-lift reactor. This type of reactor is widely used in chemical industry processes involving very slow reactions, in production processes utilizing microbes (bioreactors), and in biological wastewater treatment units using activated sludge.

In reactor design, knowledge of reaction kinetics must be studied comprehensively alongside mass, heat, and momentum transfer phenomena in order to optimize reactor performance. Hydrodynamic phenomena, including gas and liquid hold-up as well as circulation rate, are important factors related to the rate of mass transfer. This experiment will study the hydrodynamics of an air-lift reactor, particularly with regard to the effects of air flow rate, viscosity, and density on hold-up, circulation rate, and gas-liquid mass transfer coefficient in a sequential batch system.

1.2 Problem Statment

(To be completed by the student)

1.3 Objectives

After conducting this experiment, students are expected to be able to:

1. Determine the effect of operating condition variables on gas hold-up (ε).
2. Determine the effect of operating condition variables on circulation rate (U_L).
3. Determine the effect of operating condition variables on the volumetric gas-liquid mass transfer coefficient (K_{La}).

4. Determine the effect of Na_2SO_3 residence time on the volumetric gas-liquid mass transfer coefficient (K_La).

1.4 Benefits of the Experiment

1. Students are able to determine the effect of operating condition variables on gas hold-up (ε).
2. Students are able to determine the effect of operating condition variables on circulation rate (U_L).
3. Students are able to determine the effect of operating condition variables on the volumetric gas-liquid mass transfer coefficient (K_La).
4. Students are able to determine the effect of Na_2SO_3 residence time on the volumetric gas-liquid mass transfer coefficient (K_La).

CHAPTER II
LITERATURE REVIEW

2.1 Bubble Column Reactor and Air-Lift Reactor

A reactor is a device in which a chemical reaction takes place to convert a material into another material with a higher economic value. A bubble column reactor is a heterogeneous reactor that reacts two substances in different phases, namely the liquid-gas phase. An air-lift reactor is a specific type of bubble column reactor that has liquid circulation resulting from the air flow entering the reactor (Im *et al*., 2019). A bubble column reactor has a very simple design, consisting of a single zone with a sparger installed at the bottom of the reactor. This sparger produces fine gas bubbles that enable mixing and aeration. The simple design of the bubble column reactor gives it the advantage of lower cost. Unlike the bubble column reactor, the air-lift reactor consists of two interconnected zones. These two zones consist of the riser, where the sparger is located and gas is injected with an upward flow, and the other zone called the downcomer, which does not receive gas and has a downward flow. The circulation in an air-lift reactor provides an advantage in mixing efficiency without the need for physical agitation (Uyar *et al*., 2023). In the downcomer or riser zone, screening plates may be present on the wall, with one or two baffles. Therefore, there are many possible reactor configurations, each offering different advantages depending on the application and purpose (Widayat, 2004).

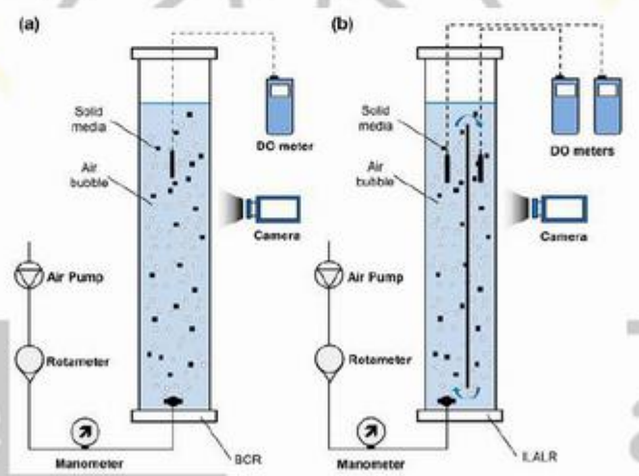

Figure 2.1 Bubble column reactor and air-lift reactor

In general, air-lift reactors are classified into two types: air-lift reactors with an internal loop and those with an external loop (Christi, 1989; Williams, 2002). An internal-loop air-lift reactor is a bubble column divided into two sections, namely the riser and downcomer, separated by an internal baffle,

where the top and bottom of the riser and downcomer are interconnected. An external-loop air-lift reactor is a bubble column in which the riser and downcomer are two separate tubes connected horizontally at the top and bottom of the reactor. In addition, air-lift reactors are also classified based on the type of sparger used, namely static and dynamic. In an air-lift reactor with a dynamic sparger, the sparger is placed in the riser and/or downcomer and its position can be adjusted (Christi, 1989; Williams, 2002).

Theoretically, air-lift reactors are used for various gas-liquid or slurry contact processes. This reactor is commonly used for aerobic fermentation, wastewater treatment, and similar operations.

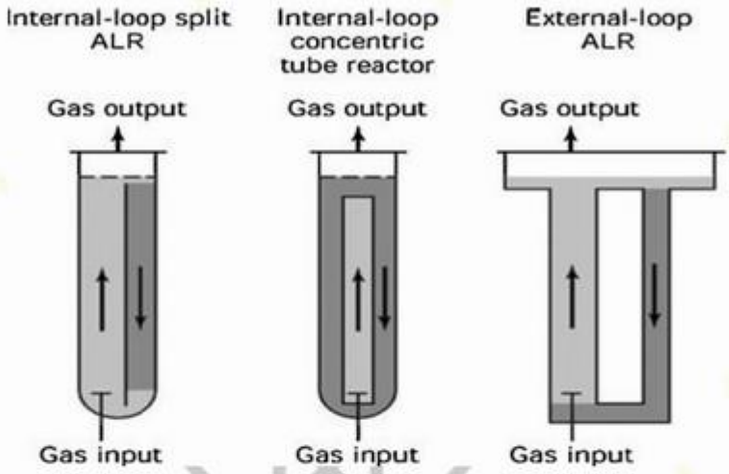

Figure 2.2 Types of air-lift reactors

The advantages of using an air-lift reactor compared to other conventional reactors include:

1. Simple design, as it does not use moving mechanical components.

   The air-lift reactor has a relatively simple construction because it is not equipped with mechanical agitators such as impellers or agitator shafts. Fluid circulation within the reactor is generated by the density difference between the riser and downcomer regions due to gas injection. This simple design results in lower maintenance costs, minimizes the risk of mechanical failure, and improves operational reliability, particularly for continuous processes (Li *et al.*, 2022).

2. Fluid circulation and mixing can be easily controlled by adjusting the gas flow rate.

   The mixing process in an air-lift reactor occurs due to the natural circulation flow generated by gas bubbles. The intensity of circulation can be regulated by changing the air flow rate entering the reactor, allowing the level of mixing and fluid distribution to be adjusted according to process requirements. This system produces good mixing

without requiring mechanical agitation, resulting in relatively lower energy consumption compared to stirred reactors (Li *et al*., 2022).

3. Relatively more uniform residence time distribution.

   The air-lift reactor has a fluid circulation pattern that can produce a relatively more uniform residence time distribution of the liquid phase. This condition allows the fluid within the reactor to experience a more even residence time, so that the process occurring within the reactor can proceed more consistently (Ham *et al*., 2021).

4. High gas-liquid contact area with relatively low energy requirements.

   The air flowing through the sparger forms small bubbles that increase the contact surface area between the gas and liquid phases. This large contact area accelerates the transfer of oxygen and other gas components into the liquid. Since mixing is achieved through aeration without mechanical agitation, the energy required to generate gas-liquid contact is relatively lower (Li *et al*., 2022).

5. High gas-liquid mass transfer efficiency.

   Good fluid circulation combined with a large gas-liquid contact surface area results in a relatively high volumetric mass transfer coefficient (K_La) in the air-lift reactor. This condition increases the rate of oxygen transfer into the liquid, making it highly suitable for processes requiring a high oxygen supply, such as aerobic fermentation and biological wastewater treatment (Li *et al*., 2022).

6. Enables the use of large-capacity reactors to increase product output.

   The air-lift reactor has a simple construction and does not use moving mechanical agitation components, giving it the potential to be developed for larger reactor capacities. Increasing reactor capacity allows a larger volume of material to be processed, thereby increasing product output. However, the scale-up process must still take into account hydrodynamic and mass transfer characteristics to maintain reactor performance at larger scales (Li *et al*., 2022).

Disadvantages of the air-lift reactor include:

1. Investment costs may increase for large reactor capacities.

   Although the construction is simple, building a large-scale air-lift reactor requires more complex materials and air distribution systems, which can increase initial investment costs. In addition, the need for supporting equipment such as blowers and gas distribution systems also affects the reactor construction cost (Li *et al*., 2022).

2. Higher air pressure is required for larger reactors.

The taller the liquid column within the reactor, the greater the hydrostatic pressure that the injected air must overcome. Therefore, larger reactors require higher air pressure to ensure that air can still enter and effectively form bubbles at the bottom of the reactor (Li *et al.*, 2022).

3. Aeration energy requirements increase at larger capacities.

At industrial scale, an increase in reactor volume also increases the air requirement, so the blower must work harder to maintain the desired gas flow rate. As a result, energy consumption in the aeration system can become a significant component of operating costs (Li *et al.*, 2022).

4. Potential for foam formation.

In certain processes, especially those involving microorganisms, foam formation can occur due to continuous aeration. Excessive foaming can disrupt gas-liquid separation, reduce operational efficiency, and increase the risk of media loss from the reactor, often requiring the use of antifoam agents or foam control systems (Campenhausen *et al.*, 2023).

In the application of the air-lift reactor, two aspects underlie its working mechanism, namely hydrodynamics and volumetric gas-liquid mass transfer.

2.2 Reactor Hydrodynamics

In bioreactor design, the factors that have the greatest influence are reactor hydrodynamics, volumetric mass transfer, process rheology, and organism productivity morphology. Reactor hydrodynamics studies the changes in fluid dynamics within the reactor resulting from the incoming flow rate and the characteristics of the fluid. Reactor hydrodynamics includes gas hold-up (the gas fraction during dispersion) and liquid circulation rate. Liquid circulation velocity is controlled by gas hold-up, while gas hold-up itself is influenced by the bubble rise velocity. Circulation also affects turbulence, mass and heat transfer coefficients, as well as the power generated.

Gas hold-up, or the gas void fraction, is the volume fraction of the gas phase in a gas-liquid dispersion or slurry. The overall gas hold-up (ε) is given by:

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

where:

ε = gas hold-up

V_G = gas volume (cm^3)

V_L = liquid volume (cm^3)

Gas hold-up is used to determine the residence time of gas within the liquid. Gas hold-up and bubble size affect the gas-liquid surface area required for mass transfer. Gas hold-up depends on the bubble rise velocity, bubble surface area, and flow pattern. An inverted manometer is used to determine the difference in liquid height caused by gas flow, which is subsequently used to calculate the gas hold-up (ε) in the riser and downcomer. The gas hold-up in the riser and downcomer can be calculated using the following equations:

$$\varepsilon = \frac{\rho_L}{\rho_L - \rho_\varepsilon} \times \frac{\Delta h}{z} \tag{2.2}$$

$$\varepsilon_r = \frac{\rho_L}{\rho_L - \rho_g} \times \frac{\Delta h_r}{z} \tag{2.3}$$

$$\varepsilon_d = \frac{\rho_L}{\rho_L - \rho_g} \times \frac{\Delta h_d}{z} \tag{2.4}$$

where:

ε = gas hold-up

ε_r = riser gas hold-up

ε_d = downcomer gas hold-up

ρ_L = liquid density (g/cm^3)

ρ_g = gas density (g/cm^3)

Δh_r = manometer height difference in the riser (cm)

Δh_d = manometer height difference in the downcomer (cm)

z = distance between pressure taps

The total gas hold-up in the reactor can be calculated from the dispersion height once the incoming gas flow has reached steady state. The equation for calculating the total gas hold-up is as follows:

$$\varepsilon = \frac{h_0 - h_i}{h_0} \tag{2.5}$$

where:

ε = gas hold-up

h_0 = height of the gas-liquid mixture after reaching steady state (cm)

h_i = initial liquid height in the reactor (cm)

The relationship between riser gas hold-up (ε_r) and downcomer gas hold-up (ε_d) can be expressed by Equation 2.6:

$$\varepsilon = \frac{A_r \times \varepsilon_r + A_d \times \varepsilon_d}{A_r + A_d} \tag{2.6}$$

where:

A_r = cross-sectional area of the riser zone (cm^2)

A_d = cross-sectional area of the downcomer zone (cm^2)

Liquid circulation in the air-lift reactor is caused by the difference in gas hold-up between the riser and downcomer. This fluid circulation can be observed from the change in fluid behavior, namely the rising flow in the riser and the descending flow in the downcomer. The liquid circulation rate in the downcomer (U_{Ld}) is given by Equation 2.7, and the liquid circulation rate in the riser is given by Equation 2.8.

$$U_{Ld} = \frac{L_C}{t_C} \tag{2.7}$$

where:

U_{Ld} = liquid circulation rate in the downcomer (cm/s)

L_C = flow path length within the reactor (cm)

t_C = time (s)

Since the liquid height and volumetric flow in the riser and downcomer are equal, the relationship between the liquid flow rates in the riser and downcomer is:

$$U_{Lr} \times A_r = U_{Ld} \times A_d \tag{2.8}$$

where:

U_{Lr} = liquid circulation rate in the riser (cm/s)

U_{Ld} = liquid circulation rate in the downcomer (cm/s)

A_r = cross-sectional area of the riser zone (cm^2)

A_d = cross-sectional area of the downcomer zone (cm^2)

The residence times t_{Ld} and t_{Lr} of liquid circulation in the riser and downcomer depend on the gas hold-up, as shown in the following equation:

$$\frac{t_{Lr}}{t_{Ld}} = \frac{A_r}{A_d} \frac{1-\varepsilon_r}{1-\varepsilon_d} \tag{2.9}$$

where:

t_{Lr} = liquid circulation residence time in the riser (s)

t_{Ld} = liquid circulation residence time in the downcomer (s)

A_r = cross-sectional area of the riser zone (cm^2)

A_d = cross-sectional area of the downcomer zone (cm^2)

ε_r = riser gas hold-up

ε_d = downcomer gas hold-up

2.3 Mass Transfer

Mass transfer between the gas and liquid phases occurs due to a concentration difference between the two phases. The mass transfer that takes place is the transfer of oxygen from the gas phase to the liquid phase. The rate of this mass transfer can be determined using the mass transfer coefficient.

The volumetric mass transfer coefficient (K_La) is the specific rate of mass transfer (gas absorbed per unit time, per unit volume of liquid, per unit concentration difference). K_La depends on the physical properties of the system and the fluid dynamics. There are three terms related to the volumetric mass transfer coefficient, namely:

1. The liquid-phase mass transfer coefficient (K_L), which is influenced by the physical properties of the liquid and the hydrodynamic conditions near the gas-liquid interface.
2. The gas-liquid interfacial area per unit volume (a), which is influenced by bubble size and distribution as well as the gas hold-up within the reactor.

The relatively small dependence of K_La on the input energy, where the contact area is a function of physical properties, geometric design, and hydrodynamic conditions. The contact area is a bubble parameter that cannot be fixed at a set value. On the other hand, the mass transfer coefficient is, in fact, the proportionality factor between the mass flux of the substrate (or the chemical being transferred), N_s, and the gradient that drives the concentration difference phenomenon. This can be expressed by Equation 2.10.

$$N = K_La\,(C_1 - C_2) \tag{2.10}$$

where :

N = mass flux

K_La = volumetric mass transfer coefficient (1/s)

C_1 = inlet O_2 concentration (g/L)

C_2 = outlet O_2 concentration (g/L)

The transfer of oxygen mass into the liquid can be expressed as a process kinetics equation, as shown in Equation 2.11.

$$\frac{dC}{dt} = K_La\,(C_1 - C_2) \tag{2.11}$$

where :

C = air concentration (g/L)

The volumetric gas-liquid mass transfer coefficient is a function of the air flow rate or superficial gas velocity, viscosity, and the cross-sectional area of the riser and downcomer/equipment geometry.

Measurement of the volumetric gas-liquid mass transfer coefficient can be carried out using the following methods:

1. Off-Gas Analysis (OTR) Method

The off-gas analysis method is used to determine the Oxygen Transfer Rate (OTR) by analyzing the composition of the off-gas leaving the reactor. In this method, air is fed into the reactor using a flowmeter so that the gas flow rate can be measured and controlled. The oxygen content in the inlet and outlet gas is then measured using a gas analyzer or gas sensor. Based on the principle of oxygen mass balance, the OTR value is calculated from the difference between the amount of oxygen entering the reactor and the amount of oxygen leaving with the off-gas at a given flow rate. This difference indicates the amount of oxygen that has transferred from the gas phase to the liquid phase, allowing the oxygen transfer rate to be determined. This method is based on the mass transfer equation, which states that the rate of oxygen transfer from the gas phase to the liquid phase is proportional to the volumetric mass transfer coefficient (K_{La}) and the driving force, expressed as the difference between the saturated oxygen concentration in the liquid and the actual dissolved oxygen concentration. This relationship is expressed by the following equation.

$$OTR = K_{La}(C^* - C_L) \qquad (2.12)$$

where,

OTR = Oxygen Transfer Rate, the rate of oxygen transfer from the gas phase to the liquid phase (g/L·s)

K_{La} = volumetric gas-liquid mass transfer coefficient (1/s)

C^* = saturated oxygen concentration at equilibrium between the gas and liquid phases (g/L)

C_L = actual dissolved oxygen concentration in the liquid phase (g/L)

The value of C^* is influenced by temperature and pressure, while C_L can be obtained through two approaches. The first approach is to measure the dissolved oxygen concentration directly using a dissolved oxygen (DO) meter during the process. The second approach uses a chemical method, in which a chemical reaction consumes the dissolved

oxygen so that its concentration can be assumed to approach zero ($C_L \approx 0$) (Schulte *et al.*, 2025).

2. Dynamic Method

The Dynamic Method is one of the methods used to determine the volumetric gas-liquid mass transfer coefficient (K_La). This method is based on the change in dissolved oxygen concentration in the liquid phase over time after aeration begins. Before measurement, the solution is first deoxygenated until the oxygen concentration approaches zero, using an inert gas such as nitrogen or through a chemical reaction that consumes oxygen. Air is then introduced into the system, causing oxygen to diffuse from the gas phase into the liquid phase, gradually increasing the dissolved oxygen concentration until saturation is reached. This change in oxygen concentration is continuously recorded using a DO meter, and the resulting data is analyzed using the mass transfer equation to determine the K_La value (Ferro & Contreras, 2026).

3. Chemical Absorption Method

The Chemical Absorption Method is used to determine the volumetric gas-liquid mass transfer coefficient (K_La) by utilizing a chemical reaction between the absorbed gas (O_2 or CO_2) and an absorbing solution (Na_2SO_3 or Na_2CO_3). In this method, the gas transferred from the gas phase to the liquid phase immediately reacts with the absorbing solution, keeping the dissolved gas concentration in the liquid phase low or close to zero. This condition maintains a high driving force for mass transfer, allowing the mass transfer rate to be observed and analyzed more accurately. The K_La value is then determined based on the gas absorption rate, the change in solution concentration due to the chemical reaction, and the characteristics of the mass transfer system (Wang *et al.*, 2024).

4. Sulfite Method

This method is based on the reduction reaction of sodium sulfite. The reaction mechanism is as follows:

Reaction in the reactor :

$$Na_2SO_3 + 0{,}5O_2 \rightarrow Na_2SO_4 + Na_2SO_3\ (sisa)$$

Reaction during analysis :

$$Na_2SO_3\ (sisa) + KI + KIO_3 \rightarrow Na_2SO_4 + 2KIO_2 + I_2\ (sisa)$$

$$I_2\ (sisa) + 2Na_2S_2O_3 \rightarrow Na_2S_4O_6 + 2NaI$$

Initial mol of Na_2SO_3 (a)

$$= \frac{N\ Na_2SO_3}{eq} \times V\ reaktor \quad (2.13)$$

Excess mol of I_2 (b)

$$= \frac{N\ KI}{eq} \times V\ KI \quad (2.14)$$

Residual mol of Na_2SO_3 (c)

$$= b - \frac{1}{2}\left(\frac{N\ Na_2S_2O_3}{eq} \times V\ Na_2S_2O_3\right) \quad (2.15)$$

Mol of O_2 reacted (d)

$$= \frac{1}{2} \times (a\text{-}c) \quad (2.16)$$

O_2 entering the reactor (e)

$$= \frac{d \times BM\ O_2}{t \times 60 \times volume\ reaktor} \quad (2.17)$$

Volumetric mass transfer coefficient (K_{La})

$$= \frac{e}{0{,}00843} \quad (2.18)$$

The coefficient value of 0.00843 in the K_{La} equation is derived from the volumetric O_2 transfer coefficient equation as follows:

$$K_{La} = \frac{nO_2}{\Delta C} \quad (2.19)$$

where:

nO_2 = O_2 mass transfer flux

ΔC = concentration driving force between the two phases

In the sulfite oxidation method, the oxygen transferred into the liquid phase is immediately consumed through the sulfite oxidation reaction. Therefore, the dissolved oxygen concentration in the liquid can be assumed to approach zero ($C_L \approx 0$). Thus, the concentration driving force can be expressed as:

$$\Delta C = C^* - C_L \quad (2.20)$$

since $C_L \approx 0$, then:

$$\Delta C \approx C^* \quad (2.21)$$

The saturated oxygen concentration in water (C*) at 25°C and 1 atm is 8,43 mg/L (Merkel & Planer-Friedrich, 2008).

$$C^* = 8{,}43\ mg/L \quad (2.22)$$

Therefore:

$$\Delta C = 8{,}43\ mg/L = 0{,}00843\ g/L \quad (2.23)$$

Thus, the K_{La} value is:

$$K_{La} = \frac{nO_2}{\Delta C} = \frac{e}{0{,}00843} \quad (2.24)$$

CHAPTER III
EXPERIMENTAL METHODS

3.1 Experimental Design

3.1.1 Experimental Procedure Diagram

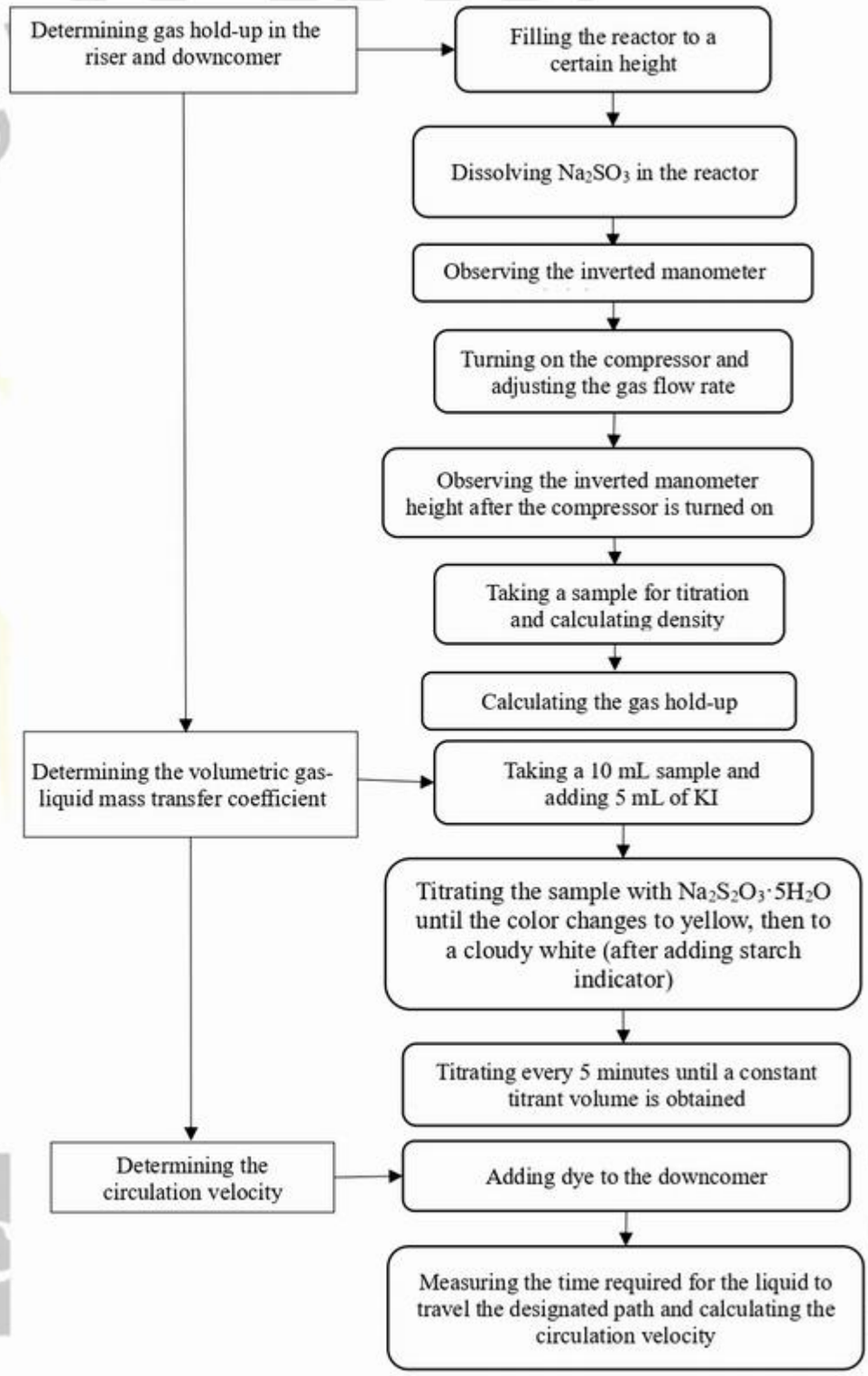

Figure 3.1 Experimental design flowchart

3.1.2 Variable Definition

a. Fixed variables :

b. Manipulated variables :

3.2 Materials and Equipment Used

3.2.1 Materials Used

1. $Na_2S_2O_3.5H_2O$
2. KI
3. Na_2SO_3
4. Starch solution
5. Dye
6. Aquadest

3.2.2 Equipment Used

1. Burette, stand, clamp
2. Watch glass
3. Beaker glass
4. Rotameter
5. Erlenmeyer flask
6. Inverted manometer
7. Measuring cylinder
8. Sparger
9. Dropper pipette
10. Liquid tank
11. Compressor
12. Reactor
13. Reagent spoon
14. Pycnometer

3.2.3 Equipment Diagram

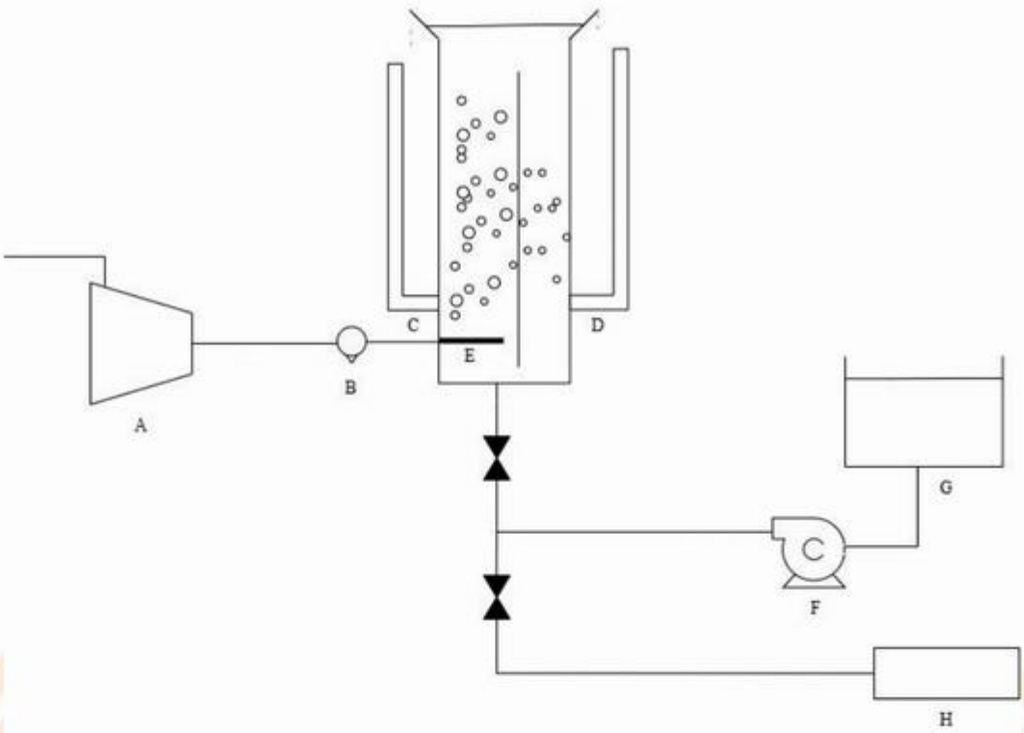

Figure 3.2 Reactor hydrodynamics equipment setup

Description:

A. Compressor
B. Flowmeter
C. Inverted manometer, riser area
D. Inverted manometer, downcomer area
E. Sparger
F. Pump
G. Collection tank
H. Reactor waste discharge

3.2.4 Experimental Procedure

1. Determining gas hold-up in the riser and downcomer
   a. Fill the reactor with water and turn on the pump; once the reactor is filled with water to a height of ... cm, turn off the pump.
   b. Add Na_2SO_3 ... N into the reactor and wait 5 minutes for the Na_2SO_3 solution to dissolve in the water.
   c. Observe the inverted manometer height.
   d. Turn on the compressor, then observe the inverted manometer height after the compressor is turned on.
   e. Take a sample for titration and calculate its density.

f. Calculate the gas hold-up value.

g. Repeat these steps for other operating variables.

2. Determining the volumetric gas-liquid mass transfer coefficient

a. Take a 10 mL sample.

b. Add 5 mL of KI to the sample.

c. Titrate with $Na_2S_2O_3 \cdot 5H_2O$ ... N until the color changes from dark brown to clear yellow.

d. Add 3 drops of starch indicator.

e. Titrate the sample again with $Na_2S_2O_3 \cdot 5H_2O$ ... N.

f. The endpoint is reached once the color turns cloudy white.

g. Record the titrant volume used.

h. Repeat the titration every 5 minutes until the titrant volume remains constant three times in a row.

i. Repeat these steps for other operating variables.

3. Determining the circulation velocity

a. Assemble the equipment to be used.

b. Fill the reactor with water and Na_2SO_3 ... N.

c. Turn on the compressor.

d. Add an appropriate amount of dye into the downcomer.

e. Measure the time required for the liquid, indicated by the dye, to travel the designated path.

f. Calculate the circulation velocity.

g. Repeat these steps for other operating variables.

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HAZARD IDENTIFICATION AND RISK ASSESSMENT

TOPIC: REACTOR HYDRODYNAMICS

HAZARD IDENTIFICATION (HI)

A	**Mechanical**		**D**	**Environment**		**E**	**Chemical**		**G**	**Other Hazards**	
A1	Manual handling	√	D1	Noise	√	E1	Toxic	√	G1	Compressed gas	√
A2	Moving parts	√	D2	Vibration	√	E2	Irritant	√	G2	Ionizing radiation	
A3	Rotating parts	√	D3	Lighting		E3	Corrosive	√	G3	UV radiation	
A4	Cutting		D4	Humidity		E4	Carcinogenic		G4	Fatigue	
B	**Biological**		D5	Temperature		E5	Flammable		G5	Confined space	
B1	Bacteria		D6	Travel hazards		E6	Explosive		G6	Overcrowding	
B2	Virus		D7	Slippery surfaces	√	E7	Cryogenics		G7	Thermometer	
B3	Fungi		D8	Solid waste		**F**	**Equipment**				
C	**Electrical**		D9	Air quality		F1	Pressure vessel				
C1	High voltage		D10	Solitary work		F2	Hot equipment				
C2	Static electricity	√	D11	Splashing/dripping/flooding	√	F3	Laser				

RISK DETAIL

HI	Risk (after control measures)				Hazard Identification	Control Measures to Minimize Risk	First Aid Measures
	High	Moderate	Low	Minimal			
1. PREPARATION / INITIAL STAGE							
		√			- Reagent spillage while weighing - Reagent spillage while filling the burette with titrant - Reagent spillage while measuring density with a pycnometer - Exposure to reagent	Using complete personal protective equipment (PPE) such as a lab coat, latex gloves, safety goggles, mask, and shoes.	- Stop the source of the spill - Move away from the spilled reagent - Clean up the spilled reagent - If inhaled, move to a location with fresh air - If in contact with skin or eyes, rinse thoroughly with water - If swallowed, drink 2 glasses of water - Remove any clothing contaminated with the reagent
		√			- Water spillage while filling the collection bucket, which may cause slipping - Water spillage while filling the reactor, which may cause slipping	- Fill the water carefully - Open the valve slowly so that water flows at a low rate	- Move away from the spilled water - Clean up the spilled water - If injured, clean and treat with first aid (P3K)

	√	- Falling while adding reagent - Falling while taking a sample	- Climb the chair carefully - Ensure the chair used is sturdy and not fragile - Ask another person to hold the chair steady	If injured, clean and treat with first aid (P3K)
	√	- Risk of electric shock or pump fire when turning on the pump	- Ensure the electrical cable and plug are not wet or damaged - Wear complete PPE	- Cut off the electrical power source - Push the victim's body away using an insulating object - Seek medical attention if burns occur - Use a fire extinguisher (APAR) if the pump catches fire
2. MAIN EXPERIMENT				
	√	- Risk of electric shock/short circuit or compressor fire when turning on the compressor - Risk of electric shock when turning on the electric stove - Noise from the compressor	- Ensure the electrical cable and plug are not wet or damaged - Wear complete PPE - Use ear plugs	- Cut off the electrical power source - Push the victim's body - Seek medical attention if burns occur - Use a fire extinguisher (APAR) if the pump catches fire

			- Turn off the source of noise - Rest the ears periodically
√	- Falling while adding dye - Falling while taking a sample	- Climb the chair carefully - Ensure the chair used is sturdy and not fragile - Ask another person to hold the chair steady	If injured, clean and treat with first aid (P3K)
3. ANALYSIS / FINAL STAGE			
√	- Contact with titrant droplets during titration	Using complete personal protective equipment (PPE) such as a lab coat, latex gloves, safety goggles, mask, and shoes..	- If in contact with skin or eyes, rinse thoroughly with water - If swallowed, drink 2 glasses of water
√	- Water spillage during the drainage process, which may cause slipping, which can result in maximum discharge directly to the disposal area	Open the valve according to procedure so that the discharged water flows out at maximum rate directly to the disposal point	- Move away from the spilled water - Clean up the spilled water - If injured, clean and treat with first aid (P3K)