

## CHAPTER I

### INTRODUCTION

#### 1.1 Background

Mass transfer between phases is common in chemical engineering processes, such as humidification, dehumidification, liquid–liquid extraction, leaching, distillation, absorption, and drying. Gas–liquid contact can occur in various ways, for example, when a liquid flows as a thin film along a column wall while gas flows upward from the column base. Mass transfer may occur from gas to liquid or liquid to gas. In humidification, water moves from the liquid phase into a gas mixture of air and water vapor, with concentration gradients and diffusion occurring only in the gas phase. In absorption, mass transfer occurs from gas to liquid, with gradients and diffusion in both phases.

The Wetted Wall Column (WWC) is a device used to study mass transfer in both directions—liquid to gas and gas to liquid. It enables accurate determination of the interfacial area between fluids, unlike packed columns where liquid film thickness is uncertain. Using WWC, the gas-to-liquid ( $\text{k}_{\text{gg}}$ ) or liquid-to-gas ( $\text{k}_{\text{gl}}$ ) mass transfer coefficients can be determined for a given system (Mardina, 2007). WWCs are widely applied in diffusion studies, including gas absorption, humidification, and extraction.

#### 1.2 Problem Statement

The Wetted Wall Column (WWC) experiment focuses on mass transfer between phases, namely gas and liquid. In this experiment, a humidification process is carried out in the wetted wall column to determine the liquid-phase mass transfer coefficient ( $\text{k}_{\text{gl}}$ ), as well as the operating conditions (temperature, pressure, air flow rate, and water flow rate) that can influence the value of  $\text{k}_{\text{gl}}$ , and the dimensionless number relationship, namely the Reynolds number with respect to the Sherwood number.

#### 1.3 Practicum Objectives

1. To determine the value of  $\text{k}_{\text{gl}}$  under various operating variables.
2. To determine the effect of operating variables on  $\text{k}_{\text{gl}}$ .
3. To determine the effect of operating variable on the dimensionless Reynolds number.
4. To determine the effect of the dimensionless Reynolds number on the Sherwood number.

#### **1.4 Practicum Benefits**

1. To identify the operating conditions that influence kgl.
2. To understand the phenomena occurring during the Wetted Wall Column experiment.

## CHAPTER II

### LITERATURE REVIEW

#### 2.1 Humidification

Humidification is the process of adding water vapor to air, which can occur when air comes into contact with water, causing evaporation of water into a gas mixture consisting of air and water vapor. Humidification can occur due to differences in the concentration or partial pressure of water vapor between the air and the water at the liquid–gas interface. In its process, humidification depends on several parameters, as follows:

- *Dry Bulb Temperature*

The dry-bulb temperature is the temperature measured by a thermometer without the influence of humidity. It represents the actual air temperature and therefore does not indicate the amount of water vapor present in the air.

- *Wet Bulb Temperature*

The wet-bulb temperature is the temperature recorded when a small amount of liquid evaporates into a large volume of unsaturated air–water vapor mixture until a steady state is reached (evaporation rate = cooling rate).

One method of measuring the wet-bulb temperature is by using a thermometer wrapped in cotton or a wet cloth, through which gas with a known dry-bulb temperature ( $T_{\text{dry bulb}}$ ) and humidity ( $H_0$ ) is passed. The temperature reading will decrease as water evaporates into the gas stream. This cooling continues until the temperature reaches a value lower than the dry-bulb temperature and remains constant upon reaching equilibrium. This equilibrium temperature is referred to as the wet-bulb temperature ( $T_{\text{wet bulb}}$ ). In practice, the wet-bulb temperature is used to determine the humidity of an air–water vapor mixture.

- *Dew Point*

The dew point is the temperature at which an air–water vapor mixture becomes saturated when cooled at constant pressure.

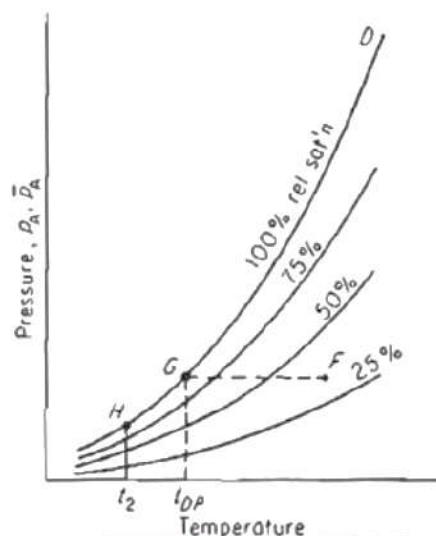


Figure 2.1 Dew point on a psychometric chart

As shown in Figure 2.1, when an air–water vapor mixture  $F$  is cooled at constant pressure ( $F \rightarrow G$ ), the mixture becomes increasingly saturated. Saturation is reached at the dew point temperature ( $T_{DP}$ ). If the temperature is further reduced, the water vapor will undergo a phase change to liquid through condensation.

- Enthalpy

Enthalpy is the amount of heat energy contained in air per unit mass.

- Relative humidity

Relative humidity is the ratio of the partial pressure of water vapor to the saturation vapor pressure at the dry-bulb temperature. It indicates the degree to which the air is saturated with water vapor.

$$RH = \left( \frac{P_{\text{Water vap}}}{P_{\text{sat}}} \right) \times 100\% \quad (2.1)$$

- Absolute humidity

Absolute humidity or saturation is the ratio of the actual mass of water vapor to the maximum (saturated) mass of water vapor that can be present in air.

$$\% \text{ absolut humidity} = \frac{Y'}{Y_s} \times 100\% \quad (2.2)$$

Absolute humidity is denoted as  $Y'$ , representing the ratio of the mass of water vapor to the mass of dry air, while  $Y_s'$  represents the saturated absolute humidity.

$$Y = \frac{P_A}{P_t - P_A} \quad (2.3)$$

$$Y' = Y \cdot \frac{P_A}{P_t - P_A} \frac{BM_A}{BM_A}$$
(2.4)

## 2.2 Wetted Wall Column

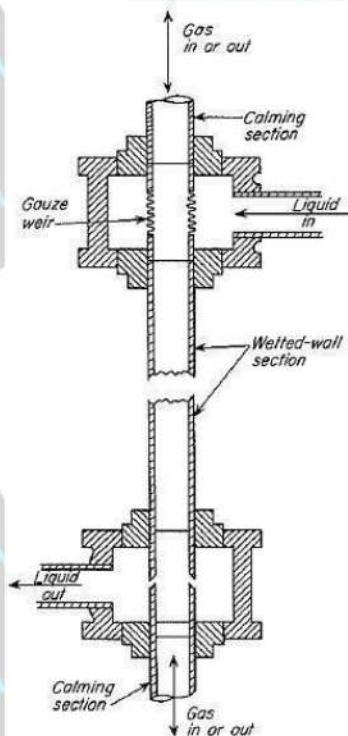


Figure 2.2 Wetted wall column

A wetted wall column is a vertical pipe column in which mass and heat transfer occur between two fluids flowing inside the column. Liquid flows from the top of the column, wetting the vertical wall and forming a thin film, while gas may flow either co-currently or counter-currently. The wetted wall column can be used as a model apparatus to study transfer phenomena occurring at the gas–liquid interface. It enables accurate determination of the interfacial area between fluids, unlike in packed columns where the liquid film thickness cannot be precisely determined. In a liquid film flowing downward along the vertical column wall, mass and heat transfer occur at the gas–liquid interface or the surface between the two fluids. Mass transfer may take place from gas to liquid (gas absorption) or from liquid to gas (humidification/evaporation). Humidification occurs when liquid evaporates into the air using heat released from the air, where the resulting air temperature drop corresponds to the latent heat of evaporation.

When the column wall is wetted and insulated from the surroundings, the system operates adiabatically. Water is introduced from the top of the column through a gauze weir, allowing it to flow along the wall surface and

form a thin film. Air flows from the bottom to the top of the column, contacting the water along the gas–liquid interface. This operational setup represents adiabatic humidification. The wetted column wall acts as an adiabatic humidifier, with the water temperature in the column controlled, and additional water supplied at a regulated temperature. It is assumed that the water temperature remains constant along the column. Mass transfer from the liquid occurs through evaporation, with the water requiring latent heat to vaporize. Heat from the air is used by the water as latent heat of evaporation, causing the air temperature to decrease and its humidity to increase. This process occurs without heat entering or leaving the system (adiabatic), as the total heat energy (enthalpy) in the air remains constant. As shown in Figure 2.3, the air temperature decreases along a constant enthalpy line (Montgomery & McDowell, 2008).

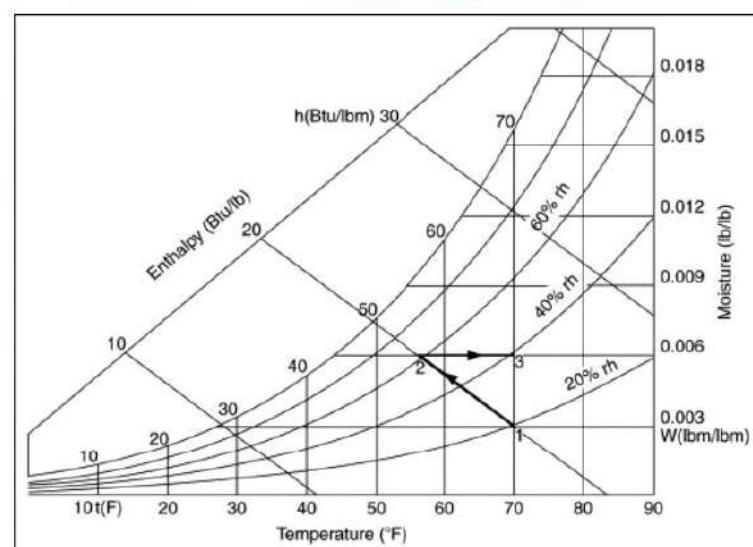


Figure 2.3 Proses humidifikasi pada *psychometric chart*

### 2.3 Bilangan Tak Berdimensi

Terdapat beberapa faktor bilangan yang mempengaruhi koefisien perpindahan massa (kg/l) diantaranya meliputi:

- Reynolds Number ( $N_{Re}$ )

In fluid mechanics, the Reynolds number is the ratio of inertial forces ( $\rho v_s L$ ) to viscous forces ( $\mu L$ ), which quantifies the relationship between these forces for a given flow condition. It is used to identify different types of flow, such as laminar and turbulent. The Reynolds number is expressed as:

$$Re = \frac{\rho v_s L}{\mu} = \frac{v_s L}{\nu} = \frac{\text{Inertial forces}}{\text{Viscous forces}} \quad (2.2)$$

Where:

- $v_s$  = Fluid velocity
- $L$  = Characteristic length
- $\mu$  = Absolute dynamic viscosity of the fluid
- $\nu$  = Kinematic viscosity of the fluid ( $\nu = \mu / \rho$ )
- $\rho$  = Fluid density
- Schmidt Number (Sc)

The Schmidt number is the ratio of momentum diffusivity to mass diffusivity. It is used to characterize fluid flows in which convection–diffusion processes of momentum and mass occur simultaneously. It is given by:

$$Sc = \frac{V}{D} = \frac{\mu}{\rho D} \quad (2.3)$$

Where:

- $V$  = kinematic viscosity ( $\mu/\rho$ ) in units of  $m^2/s$
- $D$  = mass diffusivity ( $m^2/s$ )
- $\mu$  = dynamic viscosity of the fluid ( $N \cdot s/m^2$ )
- $\rho$  = fluid density ( $kg/m^3$ )

- Sheerwood Number

The Sherwood number (analogous to the Nusselt number in heat transfer) is a dimensionless number used to determine the magnitude of the mass transfer coefficient ( $kg/l$ ). It represents the ratio of convective mass transfer to diffusive mass transfer and is defined as:

$$Sh = \frac{K \cdot L}{D} \quad (2.4)$$

Where:

- $L$  = length of the mass transfer column (m)
- $D$  = mass diffusivity ( $m^2/s$ )
- $K$  = mass transfer coefficient ( $m/s$ )

## 2.4 Mass Transfer

A process in which a key substance moves from a region of high concentration to a region of low concentration is referred to as mass transfer. This phenomenon can be observed by placing potassium permanganate ( $KMnO_4$ ) crystals into a beaker of water. The crystals dissolve, producing a purple coloration in the water surrounding them, indicating a high  $KMnO_4$  concentration in that region. The resulting concentration gradient causes  $KMnO_4$  to diffuse into areas of lower concentration. This process occurs

naturally and is independent of convection within the system. Such a process is defined as molecular diffusion.

In the mass transfer equation, the relationship between the flux of the diffusing substance and the concentration gradient is expressed as follows:

$$J_{Ay} = -D_{AB} \frac{d\tau_A}{dy} \quad (2.5)$$

$J_{Ay}$  represents the molar flux in the  $y$ -direction, indicating the change in concentration.  $D_{AB}$  is the mass diffusivity or the diffusivity coefficient of component A diffusing through component B.  $d\tau_A$  is the change in concentration within the system.  $dy$  is the change in position along the  $y$ -axis. Because mass transfer or diffusion occurs only within mixtures, the influence of each component must be considered. For example, determining the diffusion rate of each component relative to the mixture velocity requires calculating the mixture velocity from the average velocity of each component. The diffusivity coefficient depends on:

1. Pressure
2. Temperature
3. System composition

Diffusivity values vary for each phase: for gases, diffusivity ranges from  $5 \cdot 10^{-6} - 10^{-5}$   $\text{m}^2/\text{s}$ ; for liquid, from  $10^{-10} - 10^{-9}$   $\text{m}^2/\text{s}$  and for solid, from  $10^{-14} - 10^{-10}$   $\text{m}^2/\text{s}$ .

Mass transfer resulting from the movement of a fluid carrying dissolved substances is referred to as convective mass transfer. The fluid motion may be natural or forced. The equation for the rate of convective mass transfer is expressed as follows:

$$N_A = k\tau(\tau_{A0} - \tau_A) \quad (2.6)$$

$N_A$  = molar mass transfer rate of component A

$\tau_{A0} - \tau_A$  = concentration difference between the surface and the bulk fluid

$k\tau$  = convective mass transfer coefficient

The mechanism of mass transfer between a surface and a fluid includes molecular mass transfer through a thin layer of stagnant fluid and laminar flow.

Most mass transfer data between a pipe surface and a flowing fluid have been obtained using a wetted wall column. The primary reason for using a wetted wall column in mass transfer studies is its ability to provide precise determination of the interfacial area between the two phases.

## 2.5 Mass Transfer Coefficient

The mass transfer coefficient is an empirical quantity introduced to simplify problems involving interphase mass transfer. In this context, the focus is on the mass transfer coefficient from the liquid phase to the gas phase, and vice versa. This concept is illustrated in Figure 2.4.

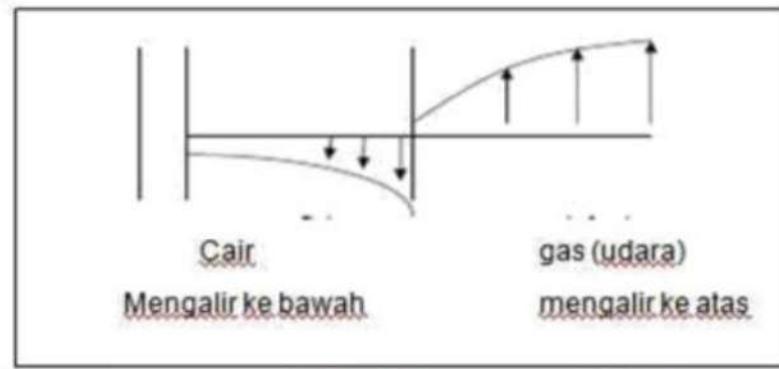


Figure 2.4 Effect of the Mass Transfer Coefficient from the Gas Phase to the Liquid Phase or from the Liquid Phase to the Gas Phase

The mass transfer coefficient is influenced by several factors:

1. Operating Conditions

Operating Conditions including flow rate, temperature, and pressure.

2. Equipment Conditions

Equipment Conditions such as the diameter and height/length of the equipment.

3. Material Properties

Material Properties including density, viscosity, and diffusivity

When mass transfer occurs from the liquid phase to the gas phase, or vice versa, across a flowing liquid–gas film interface, the mass transfer rate per unit interfacial area in the  $y$ -direction is expressed by Fick's second law as follows:

$$N_{Ay} = J_{Ay} + X_A(N_{Ay} + N_{By}) \quad (2.9)$$

where:

$N_{Ay}$  = mass flux of component A (in this case, water) in the  $y$ -direction due to bulk fluid motion ( $\text{g}\cdot\text{mol}/\text{cm}^2\cdot\text{s}$ )

$N_{By}$  = mass flux of component B (in this case, air) in the  $y$ -direction ( $\text{g}\cdot\text{mol}/\text{cm}^2\cdot\text{s}$ )

$X_A$  = mole fraction of A in the gas phase as a function of  $y$  and  $z$

$J_{Ay}$  = molecular diffusive mass flux of component A in the  $y$ -direction ( $\text{g}\cdot\text{mol}/\text{cm}^2\cdot\text{s}$ )

Equation (2.10) can thus be rewritten as:

$$N_{Ay} - X_A(N_{Ay} + N_{By}) = J_{Ay} \quad (2.10)$$

According to Treybal (1981), the fundamental flux equation is:

$$\text{Flux} = (\text{Coefficient}) \times (\text{Concentration difference}) \quad (2.11)$$

Based on this equation, the mass transfer coefficient is defined as follows:

$$J_{Ay} = k_{\text{loc}} (X_{Ao} - X_A) \quad (2.12)$$

Here,  $(X_{Ao} - X_A)$  represents the concentration difference, expressed in terms of mole fraction in the  $y$ -direction. This definition determines the proper expression for  $k_{\text{loc}}$  (the “loc” subscript denoting local, and the “g” referring to the gas phase). The term *local* implies that  $k_g$  can vary from one position to another along the gas–liquid interface where mass transfer occurs.

For practical application, the average mass transfer coefficient can be expressed as  $k_{gl}$ :

$$k_{gl} = \frac{\int_s^s k_{\text{loc}} ds}{\int_s^s ds} \quad (2.13)$$

According to equation expressed above, then  $k_{gl}$  = average value of  $k_{\text{loc}}$  over the entire mass transfer surface area  $s$ . The concentration difference  $(X_{Ao} - X_A)$  is generally defined as follows:

$X_{AO}$  = mole fraction of component A in the gas phase at the interface

$X_A$  = average mole fraction of component A in the bulk gas phase

## 2.6 Mass Transfer Analysis in a Wetted Wall Column

To analyze mass transfer within a wetted wall column, refer to Figure 2.5.

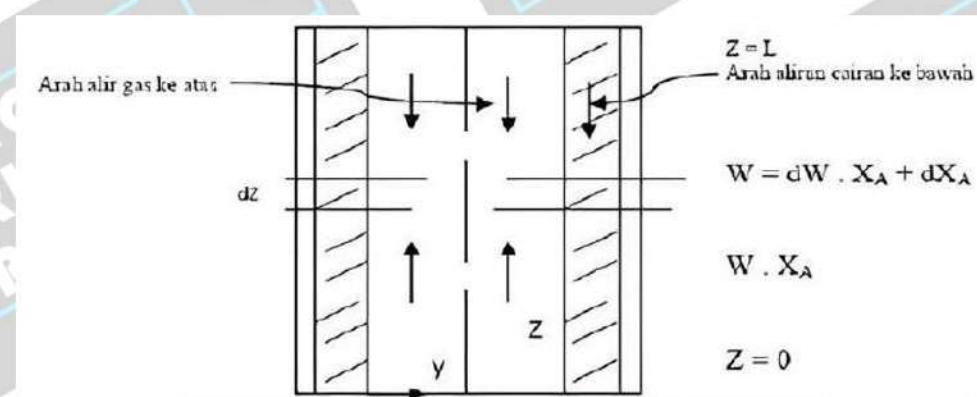


Figure 2.5 Longitudinal Section of a Wetted Wall Column

Consider a system segment of height  $dz$ . A material balance for component A yields the differential equation for the flux of component A as follows:

$$\frac{d(W.X_A)}{dz} = J_{AY} \cdot \pi \cdot D \quad (2.14)$$

where,  $W$  = molar gas flow rate in the  $z$ -direction (g mole/s)

The change in molar flow rate in the  $z$ -direction is solely due to the presence of the molecular mass flux  $J_{AY}$ . Thus, the total flux relationship for the system can be expressed as:

$$\frac{d(W)}{dz} = J_{AY}\pi.D \quad (2.15)$$

Equations (2.14) and (2.15) give the relationship:

$$W \frac{dX_A}{dz} = (1 - X_A)J_{AY}\pi.D \quad (2.16)$$

By substituting Equation (2.12), Equation (2.16) can be rewritten as:

$$\frac{dX_A}{(1-X_A)(X_{A0}-X_A)} = \frac{k g L o c \pi D}{W} dz \quad (2.17)$$

To solve Equation (2.17), it is assumed that the average value of  $X_A$  (see equation (2.13)) is applicable. Additionally, by neglecting any variation in the total flow rate  $W$  along the column, integration of Equation (2.17) from  $Z = 0$  to  $Z = L$  yields:

$$\frac{\int_{Z=0}^{Z=L} k g L o c \pi D dz}{W} = \frac{\int_{Z=0}^{Z=L} dX_A}{(X_{A0}-X_A)(1-X_A)} \quad (2.18)$$

The left-hand side corresponds to the definition of  $kgl$ , while the partial expansion on the right-hand side can be easily integrated to obtain:

$$kgl = \frac{W}{\pi.D.L(1-X_{A0})} \ln \frac{(X_{A0}-Z_A)(1-X_A)_L}{(X_{A0}-X_A)_L(1-X_A)_0} \quad (2.19)$$

With this equation,  $kgl$  can be determined from experimental data.

From dimensional empirical correlations, it is known that  $kgl$  is affected by  $N_{Re}$ ,  $N_{Sc}$ , and the geometric factor  $L/D$ . The influence of these parameters can be expressed as follows:

$$N_{Sh} = \frac{kgl D_x}{C D_{AB}} = f(N_{Re}, N_{Sc}, \frac{L}{D}) \quad (2.20)$$

$N_{Re}$  = Reynolds number for gas flow

$N_{Sc}$  = Schmidt number for the gas phase

$L/D$  = Ratio of column length to column diameter

## 2.7 Mass Transfer in a Falling Liquid Film (Gas Absorption)

Figure 2.6 shows a liquid flowing downward in laminar motion, forming a thin film along a vertical surface. The flowing liquid is in contact with gas  $A$ , which dissolves into the liquid at a concentration denoted by  $C_A$ .

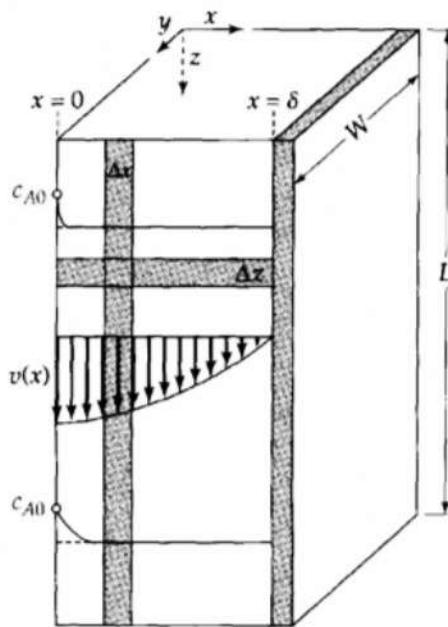


Figure 2.6 Gas *A* absorption in a falling liquid film

Figure 2.6 illustrates the phenomenon of gas *A* ( $\text{O}_2$ ) absorption into liquid *B* ( $\text{H}_2\text{O}$ ). Gas *A* has low solubility in water; therefore, the viscosity of the liquid is not significantly affected. From Figure 2.6, it can be seen that the liquid flows downward along the *z*-direction, forming a film in the *x*-direction. Gas *A* flows upward and first comes into contact with the liquid surface at the liquid–gas interface ( $x = 0$ ), then diffuses into the liquid bulk ( $x = \delta$ ). The concentration of dissolved gas *A*,  $C_A$ , varies with both *x* and *z*, and thus the diffusion process can be expressed by the second Fick's law:

$$v_z \frac{\partial C_A}{\partial z} = D_{AB} \frac{\partial^2 C_A}{\partial x^2} \quad (2.21)$$

By substituting the velocity distribution equation, the following equation is obtained:

$$v_{\max} \left[ 1 - \left( \frac{x}{\delta} \right)^2 \right] \frac{\partial C_A}{\partial z} = D_{AB} \frac{\partial^2 C_A}{\partial x^2} \quad (2.22)$$

This equation can be solved by applying the following boundary conditions:

B.C. 1:

when  $z = 0$ , then  $C_A = 0$

B.C. 2:

when  $x = 0$ , then  $C_A = C_{A0}$

B.C. 3:

when  $x = \delta$ , then  $\frac{\partial C_A}{\partial x} = 0$

The first boundary conditions shows initial condition ( $z = 0$ ), when the concentration of *A* is zero because no diffusion of gas *A* into the liquid has occurred yet. The second boundary conditions shows interface condition ( $x = 0$ ), when gas *A* first contacts the liquid surface, its concentration reaches a

maximum value  $C_{A0}$ , and diffusion begins due to the concentration gradient from the liquid–gas interface ( $x = 0$ ) toward  $x = \delta$ . The last boundary conditions shows bulk liquid condition ( $x = \delta$ ), when the concentration gradient becomes zero ( $\frac{\partial C_A}{\partial x} = 0$ ), indicating no significant mass transfer or that the concentration is already uniform. This also implies that  $A$  will not diffuse toward the wall surface and that diffusion has effectively stopped.

It is important to note that diffusion within the liquid film proceeds slowly, meaning that gas  $A$  does not penetrate deeply into the liquid film. Moreover, the residence time of the liquid flowing from inlet to outlet (exposure time) is relatively short, limiting the time available for gas  $A$  to diffuse further into the liquid

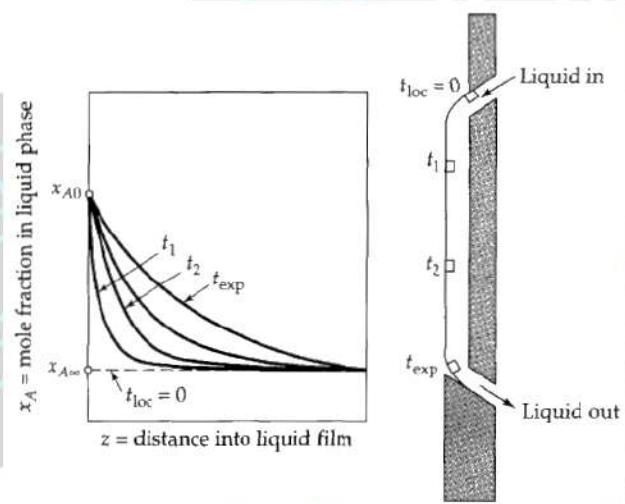


Figure 2.7 Diffusion in a falling liquid film

Several models have been developed to calculate mass transfer at the gas–liquid interface, depending on the conditions present in the system.

### 1. Film Theory

Nernst (Wen et al., 2020) first proposed the film theory. This theory assumes that mass transfer is concentrated within a thin stagnant film region at the interface between gas and liquid. Later, Whitman and Lewis extended this theory for application to gas–liquid interfaces. According to the film theory, mass transfer can be calculated on either the liquid side or the gas side using the following equation:

$$k_l/g = \frac{D_l/g}{\delta_l/g} \quad (2.23)$$

However, this model cannot be applied when both fluids at the interface are in motion, such as in the case of a falling liquid film.

### 2. Penetration Theory

Higbie proposed the penetration model to address the limitations of the film theory. In this model, the contact time between the two fluids for diffusion is short, preventing the system from reaching a steady state. This theory describes the situation when the two fluids come into contact, as illustrated in Figure 2.8, such as when a gas bubble rises through a liquid that absorbs the gas.

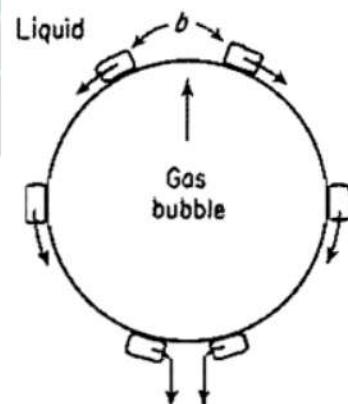


Figure 2.8 Penetration Theory

The penetration theory is based on the following assumptions:

- 1) Unsteady-state mass transfer occurs within the liquid element that comes into contact with the gas bubble.
- 2) Equilibrium is achieved at the gas–liquid interface.,
- 3) Each liquid element ( $b$ ) remains in contact with the gas bubble for the same duration.

The mass transfer coefficient in this theory can be calculated using the following equation over the interval  $t_c$ .

$$k_{l/g} = 2 \sqrt{\frac{D_a}{\pi t_c}} \quad (2.24)$$

### 3. Surface Renewal Theory

Danckwerts extended Higbie's penetration model by considering that, at the bubble surface, liquid elements are continuously replaced by new liquid elements due to eddy currents in the bulk liquid

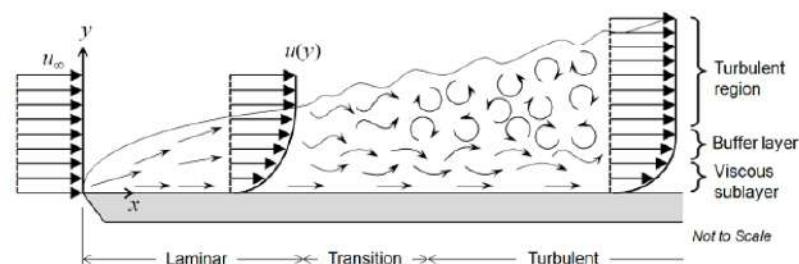


Figure 2.9 Eddy currents in turbulent flow

This theory is based on the following assumptions:

- 1) Liquid elements at the interface are randomly replaced by new elements from the bulk liquid.
- 2) At any instant, each interfacial liquid element has the same probability of being replaced by a new element.
- 3) Unsteady-state mass transfer occurs in a liquid element during its residence time at the interface.

The mass transfer coefficient can then be determined using the following equation:

$$N_{A,av} = (C_{Ai} - C_{A0}) \sqrt{s \times D_{AB}} \quad (2.25)$$

$$k_l / g_{,av} = \sqrt{s \times D_{AB}} \quad (2.26)$$

The parameter  $s$  represents the rate at which new elements are replaced ( $s^{-1}$ ).

(Treybal, 1980)

## CHAPTER III METHODOLOGY

### 3.1 Experimental Design

#### 3.1.1 Practicum Framework

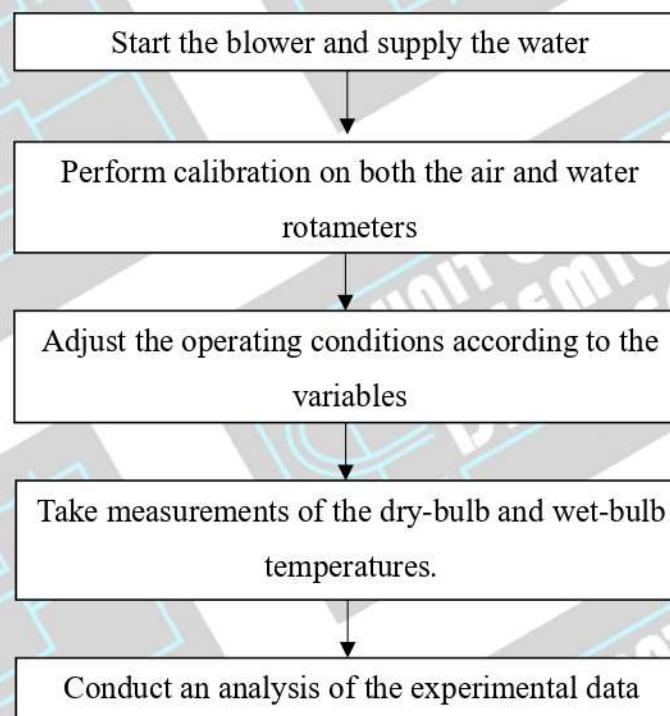


Figure 3.1 Experimental design schematic

#### 3.1.2 Variable Determination

- a. Controlled variable :
- b. Independent variable :

### 3.2 Materials and Equipment Used

#### 3.2.1 Materials

- a. Air
- b. Water

#### 3.2.2 Equipment

- a. Stopwatch
- b. Thermometer

### 3.3 Main Equipment Diagram

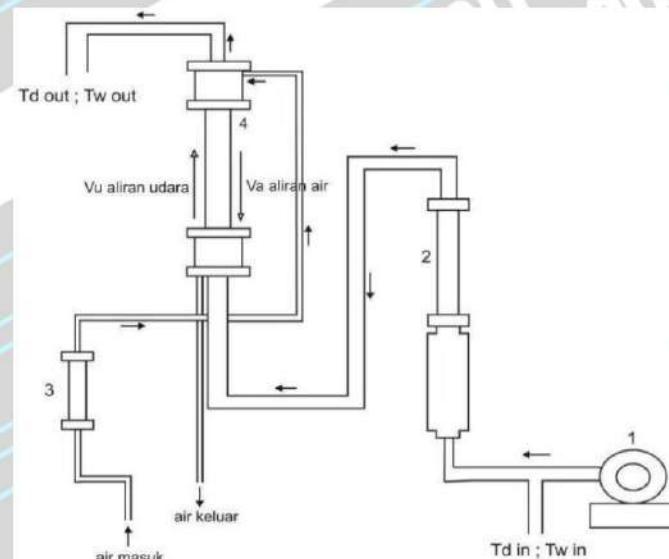


Figure 3.2 Equipment diagram for Wetted Wall Column

Description:

1. Blower
2. Gas rotameter
3. Water Rotameter
4. Mass Transfer Column

### 3.4 Response

1. Air Rotameter Calibration

Measure the time required (seconds) for one revolution of the wet gas meter with a volume of 10 L.

2. Water Rotameter Calibration

Measure the volume of water collected (mL) in 10 seconds at each flow rate.

3. Operating Stage

Measure the wet bulb and dry bulb temperatures ( $^{\circ}\text{C}$ ) at the bottom and top of the column for various water and air flow rates over a duration of 10 minutes.

4. Experimental Data Analysis

Students are expected to:

- a. Plot the relationship between the liquid mass transfer coefficient ( $k_{\text{L}} \text{gl}$ ) and flow rate, and explain the observed phenomena.
- b. Determine the influence of Reynolds number ( $N_{\text{Re}}$ ) on Sherwood number ( $N_{\text{Sh}}$ ).

- c. Determine constants  $a$  and  $b$  from the dimensionless correlation equation derived from the experiment..

### 3.5 Required Data

1. Time for one revolution of the wet gas meter needle (seconds)
2. Water volume collected in 10 seconds (mL)
3. Inlet dry bulb temperature ( $T_d$  in) and wet bulb temperature ( $T_w$  out)
4. Outlet dry bulb temperature ( $T_d$  out) and wet bulb temperature ( $T_w$  out)

### 3.6 Practicum Procedure

The procedure is divided into two stages: Preparation Stage and Operation Stage.

#### 3.7.1 Preparation Stage

1. Air Rotameter Calibration
  - a. Start the air rotameter.
  - b. Fill the wet gas meter with water to a certain level until the needle rotation is stable.
  - c. Connect the wet gas meter to the air outlet pipe.
  - d. Adjust the air rotameter scale.
  - e. Record the time required for the wet gas meter needle to complete one revolution.
  - f. Repeat the measurement three times.
  - g. Repeat the above steps for other air rotameter scale settings.
2. Water Rotameter Calibration
  - a. Allow water to flow by opening the valve to a fixed position.
  - b. Adjust the water rotameter scale.
  - c. Let the water flow for 10 seconds and collect it to determine the volume.
  - d. Measure the collected water volume.
  - e. Repeat the measurement three times.
  - f. Repeat the above steps for other water rotameter scale settings.

#### 3.7.2 Operation Stage

1. Flow water from the water supply at the selected water rotameter scale setting.
2. Flow air at the selected air rotameter scale setting.

3. Measure the wet bulb temperature (thermometer bulb wrapped in wet cotton) and dry bulb temperature at the top and bottom of the column.
4. Record the thermometer readings after 10 minutes.
5. Repeat steps 1–4 for four other scale settings..

## DAFTAR PUSTAKA

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