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## MASS TRANSFER COEFFICIENTS IN A TOWER OF HUMIDIFICATION IN A LABORATORY OF TRANSPORT PHENOMENA

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### ABSTRACT

*The mass transfer coefficients are a variable present in the mass transfer operations and they are part of many correlations. Most of these coefficients are calculated through correlations, others are obtained through experiments. This article presents a tower of humidification that has been used by the students of Chemical Engineering in the Laboratory of Transport Phenomena in the Faculty of Chemistry at the Universidad Nacional Autónoma de México, UNAM to get some mass transfer coefficients.*

**KEYWORDS:** *Mass transfer coefficients, Tower of humidification, Transport Phenomena, Competences.*

### 1. INTRODUCTION

In the laboratory of Transport Phenomena of the Faculty of Chemistry at the *Universidad Nacional Autónoma de México* (UNAM) the students of chemical engineering receive a practical education based in competences. Competency-based education displaces the teaching of traditional content, as they do not have a practical use and expire quickly in this abundant knowledge generation. The competencies in the jobs include the professionals, those that enable flexible, creative and competitive performance in a specific professional field, and promote the continuous improvement of being, knowing and doing. In these article we present an experimentation in a humidification tower that we believe promotes the acquisitions of competences.

The mass transfer coefficients are a very important variable in the mass transfer operations, since they are inside of many correlations implicitly or explicitly. Therefore knowing its value is essential and when this is not the case they must be obtained experimentally.

### 1.1 Theoretical foundations:-

Coefficients of mass transfer from the humidification tower can be studied at the industry or in a laboratory. The main reason for the use of this type of equipment is to cool and humidify air, this it is usually done in packed towers. Generally in this type of equipment, the transfer of water to air is measured by the humidity and as this is a function of the partial pressure of water in air, the operation is complicated by the fact that there is a simultaneous transfer of heat and mass.

In the case of the cooling and humidification of air we have [1]

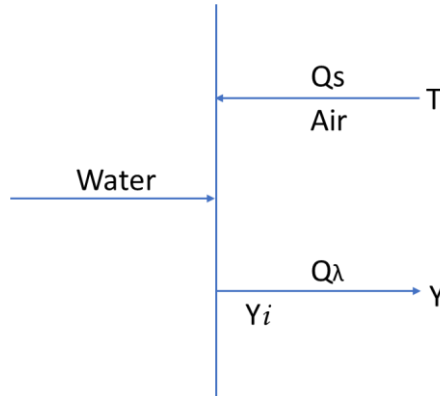


Fig. 1 - Humidification of air

The operation can take place in a packed tower Fig. 2

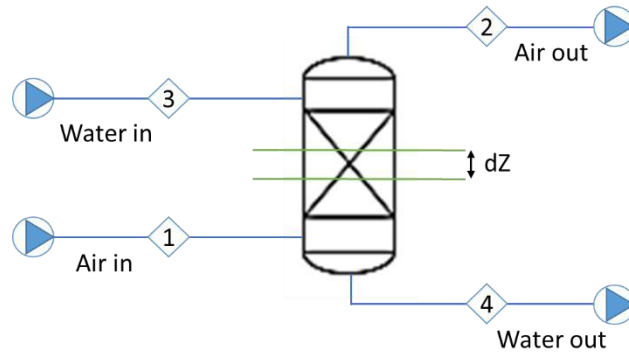


Fig. 2 - A humidification tower

Taking a  $dZ$ .

Water transfer:  $dL = G_s dY$  (1)

Sensible heat transfer:

$$\frac{G_s}{A} C_H dT = h_{Ga} (T - T_i) dZ \quad (2)$$

Latent heat transfer:

$$\frac{G_s}{A} (\lambda dY) = k_{Ya} (Y_i - Y) \lambda dZ \quad (3)$$

Total heat transfer

$$\frac{G_s}{A} dH = \frac{G_s}{A} (C_H dT + \lambda dY) = [h_{Ga} (T - T_i) + \lambda k_{Ya} (Y_i - Y)] dZ \quad (4)$$

Where:

$G_s$  = dry air flow;  $L$  = water flow;  $Z$  = height of tower;  $C_H$  = wet heat of air.

$T$  = temperature of air,  $T_i$  = interface air temperature;  $h_{Ga}$  = heat transfer coefficient of air phase;

$A$  = cross sectional area;  $\lambda$  = latent heat of water;  $Y$  = humidity of air;  $Y_i$  = interface humidity of air;

$k_{Ya}$  = mass transfer coefficient.

But for the air-water system:

$$C_H = \frac{h_{Ga}}{k_{Ya}} \quad (5)$$

Then:

$$\frac{G_s}{A} dH = k_{Ya} [(\lambda Y + C_H T) - (\lambda Y_i + C_H T_i)] dZ \quad (6); \quad \frac{G_s}{A} dH = k_{Ya} (H - H_i) dZ \quad (7)$$

Integrating:

$$Z = \frac{G_s}{A k_{Ya}} \int_{H_1}^{H_2} \frac{dH}{H - H_i} \quad (8)$$

$$\text{The tie line is: } -\frac{h_{La}}{k_{Ya}} = \frac{H - H_i}{T - T_i} \quad (9);$$

The operation line is:

$$G_s (H_1 - H_2) = L C_{pL} (T_3 - T_4) \quad (10)$$

This can be drawn in a diagram as Fig. 3

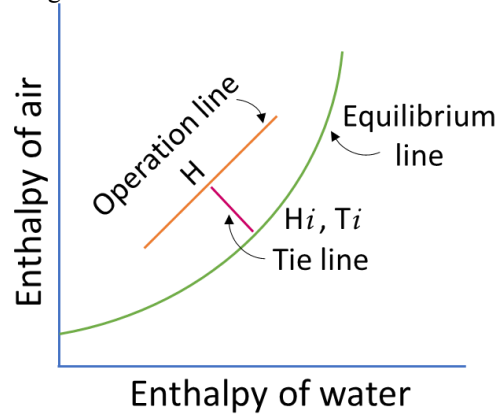


Fig. 3 - Representation of the lines in an operation of humidification

If the tie line is vertical

$$h_{La} \gg k_{Ya}$$

$$\text{Then: } Z = \frac{G_s}{A k_{Ya}} \int_{H_1}^{H_2} \frac{dH}{H - H^*} \quad (11)$$

And the operation can be represented by fig. 4

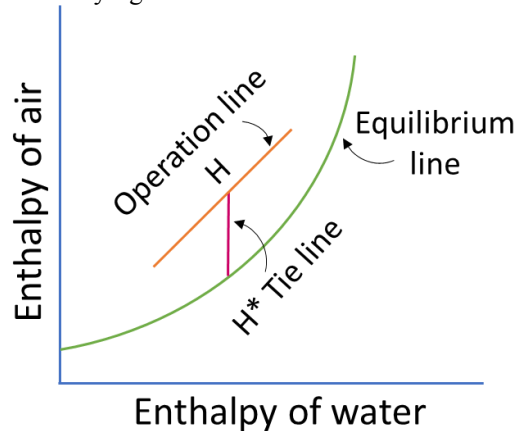


Fig. 4 - Operating lines in humidification with a vertical tie line

The above equation is usually written as:

$$Z = \text{HUT} * \text{NUT} \quad (12)$$

Where:

HUT = height of a transfer unit; NUT = number of transfer units

K<sub>ya</sub> = overall mass transfer coefficient; H\* = enthalpy in the equilibrium, h<sub>La</sub> = liquid heat transfer coefficient;

H = enthalpy of the gas phase; H<sub>i</sub> = enthalpy of the gas phase in the interface.

It should be noted that the mass transfer area is the interfacial area, this area is difficult to calculate, and therefore we usually use volumetric coefficients.

## 2. DESCRIPTION OF THE USED EQUIPMENT



**Fig. 5 - Humidification tower**

The equipment used in the laboratory of transport phenomena (Fig. 5) in the faculty of chemistry, enable the students to obtain experimentally the mass transfer coefficients and consist of a packed column of 0.12 m diameter and 1.4 m of height [2]. The column is packed with ceramic Rasching rings of  $\frac{1}{2}$  inch. The equipment is provided with two rotameters, one for air and the other for water, and U manometer to measure de pressure drop between the entrance and the inlet of the column, a preheater to heat the air with steam and a compressor.

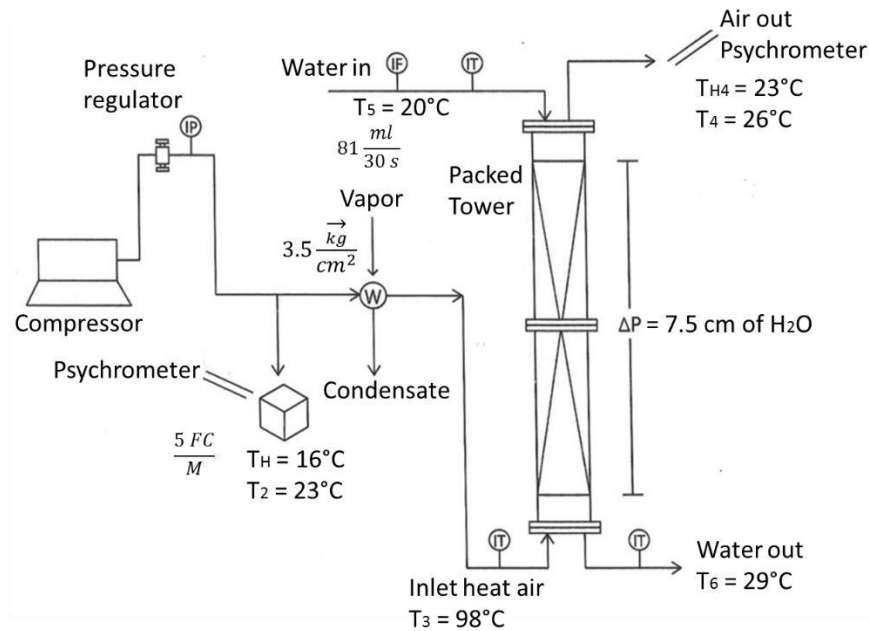
### 2.1. Experimental work:-

To enable the students to obtain experimentally the mass transfer coefficients they must [3], [4], [5]

1. -Turn up the compressor and select the rate of air.
2. - Pass the air through the pre heater till the air reaches a temperature between 90 and 105 ° C
3. - Feed the water and select the flow.
4. -Take the wet bulb and dry bulb temperatures of the entering and departing air.
5. - Take the temperature of the inlet and outlet water.
6. - Allow the equipment to reach the steady state.
7. -Take the new values of flow and temperatures.

### 3. EXPERIMENTAL DATA AND CALCULATIONS

In an experiment the student obtained the following results:



#### 3.1. Calculation of the air moisture:-

##### 3.1.1. Humidity of the atmospheric air:-

Wet bulb temperature 16°C, dry bulb temperature 23°C, atmospheric pressure 586 mm de Hg. From the humidity chart at 586 mm Hg of pressure they found:

$$Y=0.0118 \frac{\text{kg water vapor}}{\text{kg dry air}} = Y_1 \cong Y_2 \cong Y_3$$

##### 3.1.2. Humidity of the outlet air:-

Wet bulb temperature 23 °C; Dry bulb temperature 26 °C  
From the humidity chart at 586 mm Hg of pressure they found:  
 $Y_4=0.0216 \text{ kg /kg.}$

#### 3.2. Enthalpies:-

##### 3.2.1. Enthalpy of atmospheric air:-

$$H = C_H + \lambda Y \quad ; \quad C_H = 0.24 + 0.46 Y$$

$$C_{H1} = 0.24 + 0.46(0.0118) = C_{H2} = C_{H3} \frac{\text{kcal}}{\text{kg dry air} \cdot ^\circ\text{C}}$$

##### 3.2.2. Enthalpy of the air entering in the tower at $T_3 = 98^\circ\text{C}$ :-

$$H_3 = 0.2454(98) + 597(0.0118) = 31.0938 \text{ kcal/kg dry air.}$$

##### 3.2.3. Enthalpy of the air at $T_4 = 26^\circ\text{C}$ :-

$$C_H = 0.24 + 0.46(0.0218) = 0.25 \text{ kcal/kg}^\circ\text{C}$$

$$H_4 = 0.25(26) + 597(0.0218) = 19.515 \text{ kcal/kg}$$

##### 3.2.4. Enthalpy of the incoming water at $T_5 = 20^\circ\text{C}$

$$H = C_p \Delta T = 1(20) = 20 \text{ kcal/kg} = H_5$$

##### 3.2.5. Enthalpy of the outgoing water at $T_6 = 29^\circ\text{C}$ :-

$$H_6 = 29 \text{ kcal /kg}$$

### 3.3. Streams:-

#### 3.3.1. Water stream:-

$$Ca_5 = 81 \frac{mL}{30 s} \times \frac{3600s}{1 h} \times \frac{1L}{1000mL} = 9.72 \frac{L}{h}$$

Density of water at 20°C = 0.99843 kg /L (from tables)

$$L\% = 9.72 \frac{L}{h} \times 0.99843 \frac{kg}{L} = 9.7 \frac{kg}{h}$$

#### 3.3.2. Gas stream:-

$$Ca_1 = 5 \frac{ft^3}{min} \times \frac{60 min}{h} \times \frac{(0.305)^3}{1ft^3} \times m^3 = 8.51 \frac{m^3}{h}$$

Wet volume of air.

$$V_{H^1} = \left( \frac{1}{29} + \frac{0.0118}{18} \right) \frac{0.082(23+273)}{586} \times 760 = 1.1061 \frac{m^3}{kg \text{ dry air}}$$

#### 3.3.3. Dry air entering the system:-

$$G_1 = G_2 = G_3 = G_4$$

$$G_1 = 8.51 \frac{m^3}{h} \times \frac{kg \text{ dry air}}{1.1061m^3} = 7.6936 \frac{kg \text{ dry air}}{h}$$

### 3.4. Balances:-

#### 3.4.1. Dry air balance:-

$$G_1 = G_2 = G_3 = G_4 = 7.6936 \text{ kg dry air /h}$$

#### 3.4.2. Water balance:-

$$G_5(Y_4 - Y_3) = \Delta L$$

$$7.6936(0.0218 - 0.0118) = 0.0769 \text{ kg of water/h}$$

So we can say  $L_5 \cong L_6$

#### 3.4.3. Enthalpy balance:-

$$G_5(H_3 - H_4) = L(H_6 - H_5)$$

#### 3.4.4. Slope of the operating line

$$\frac{L}{G_s} \text{ experimental} = \frac{9.7}{7.6936} = 1.26$$

$$\frac{L}{G_s} \text{ theoretical} = \frac{31.09 - 19.515}{29 - 20} = 1.286$$

### 3.5. Mass transfer units

The design equation is:

$$Z = \frac{G_s}{AK_y a} \int_{H_4}^{H_3} \frac{dH}{H - H^*}$$

Also  $Z = \text{HUT} * \text{NUT}$

Where  $G_s$  is the dry air flux kg/h

$A$  = Transversal area of the equipment  $m^2$

$K_y a$  = Overall volumetric mass transfer Coefficient

$H$  = Enthalpy of air in the operating line

$H^*$  = Enthalpy of air in the equilibrium line

$Z$  = Height of packing in the tower m

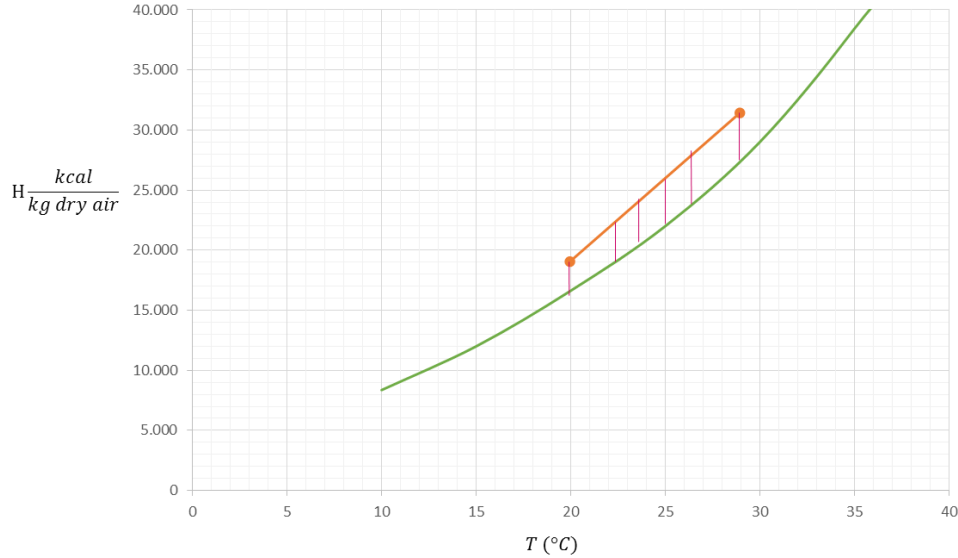
HUT = Height of the transfer unit base in the gas phase

NUT = Number of transfer units gas phase

#### 3.5.1. Number of transfer units:-

To calculate the NUT we must integrate graphically using an equilibrium graph of enthalpy of air versus enthalpy of water.

From the graph (1) the students obtained the data to create the table (1):



**Graph 1. - Graphical representation of the driving forces**

**Table 1. - Number of unit operations**

H	H*	$\frac{1}{H - H^*}$	Media	$\Delta H$	$\int$
31.0938	28	0.323			
30	26.8	0.3125	0.31775	1.0938	0.3475
28	24.8	0.3125	0.3125	2	0.625
26	23	0.333	0.3229	2	0.6458
24	21	0.333	0.333	2	0.666
22	19.7	0.4347	0.384	2	0.768
19.515	17.2	0.4319	0.4333	2.485	1.0767

So the NUT is **4.1296**

**3.5.2. Height of the transfer unit:-**

From the equipment data the students get:

Z = 1.4 m

D = 0.12 m

D of the Raschig rings ½ inches

Cross area of the equipment =  $\frac{\pi}{4} (0.12)^2 = 0.11304 \text{ m}^2$

Therefore:

$$1.4 = \frac{7.6936}{0.011304 Kya} (4.1296)$$

Kya = 2007.6 kg/h m<sup>3</sup>

The height of the transfer unit is

HUT =  $\frac{7.6936}{0.011304(2007.6)} = 0.339 \text{ m}$

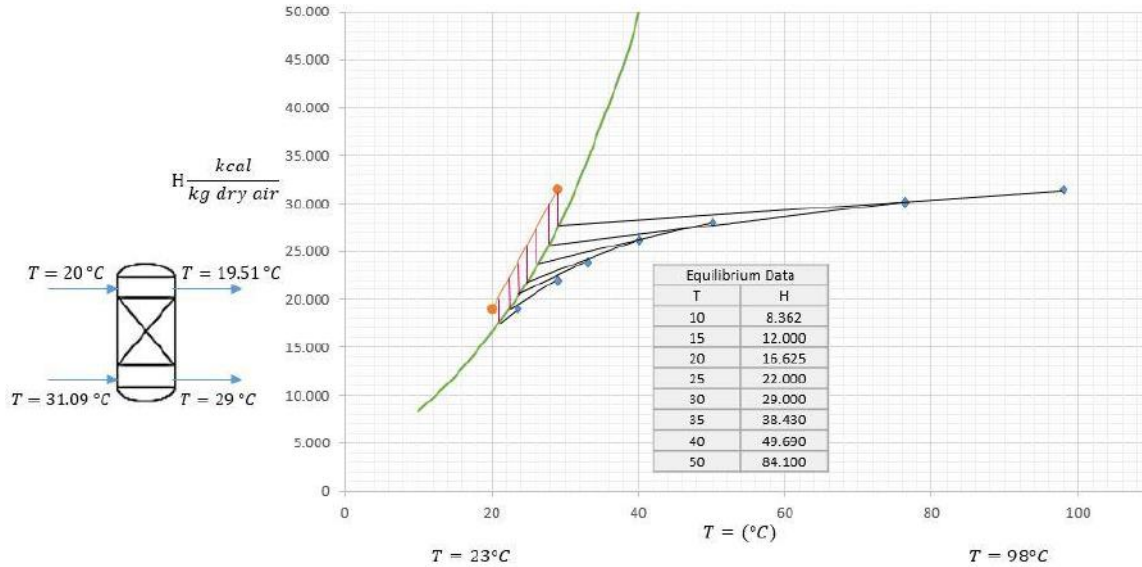
**3. 6. Theoretical temperature of the outgoing air:-**

Using the Mickley [6] method and taking the tie line as a vertical. So,  $\frac{-hL}{kya} = \infty$

We are supposing that the heat transfer coefficient of water is much bigger than the mass transfer coefficient of air. Graph 2.

From the graph the student found that the outgoing temperature of air was 23°C.





Graph 2. - Mickley method solution

## CONCLUSIONS

The humidification tower equipment used in the laboratory of Transport Phenomena is simple and easy to operate, although the calculations are no so simple and the student must use their skills to manipulate charts and graphs in order to get results. Experimental results obtained by the students are consistent with those that can be obtained through correlations. In addition to that, we could perceive that the students had to use competences in the field of knowledge (they had to remember about heat and mass transfer, and humidification), skills (they had to manipulate wet and dry thermometers, use tables, graphs and draw graph, lines and slopes, make calculations, etc.), and handle attitudes in order to work together and obtain results [7].

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