The University of Jordan

School of Engineering

Department of Chemical Engineering

Chemical Engineering Laboratory (3) (0915561)

Section no. (2)

Experiment no. (6)

Cooling Tower

Short Report

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ABSTRACT

The purpose of this experiment was to perform energy and mass balance on the cooling tower system. The overall mass transfer coefficient for a cooling tower will be calculated using measurements of the wet and dry bulb temperatures, as well as the air flow rates inlet and outlet of the tower and the mass flow rates of water and air. Several parameters, including water temperature and flow rate, relative humidity, air flow rate, and cooling load, can be changed to see how they affect water evaporation. The integration is used to determine the total number of units once the equilibrium circumstances and operational conditions are related graphically. After the findings were determined, it was determined that $\alpha = 84.353$, $\beta = 1.722$, and the following equation was produced $Ky.a = 84.35\left(\frac{G_s}{L}\right)^{1.722}$.

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- Run (1)

Table 1: Experimental Data for Run 1

Inlet Water Flow Rate (Kg/h)	200
Inlet Air Flow Rate (m^3/h)	230
Inlet Air Flow Rate (Kg/h)	266.8
Inlet Air Dry Bulb Temperature (^oC)	27
Inlet Air Wet Bulb Temperature (^oC)	15.5
Outlet Air Dry Bulb Temperature (^oC)	29
Outlet Air Wet Bulb Temperature (^oC)	26
Inlet Water Temperature (^oC)	37.5
Outlet Water Temperature (^oC)	21

Table 2: Data for Equilibrium Curve Fitting

Equilibrium Data	
T_L (^oC)	H* (KJ/Kg)
15.6	43.68
26.7	84
29.4	97.2
32.2	112.1
35	128.9
37.8	148.2
40.6	172.1
43.3	197.2
46.1	224.5
60	461.5

Table 3: Operating Line Fitting Data for Run 1

Operating Line			
T_{L1} (ºC)	21	H_{y1} (KJ/Kg)	43.5
T_{L2} (ºC)	37.5	H_{y2} (KJ/Kg)	95.288

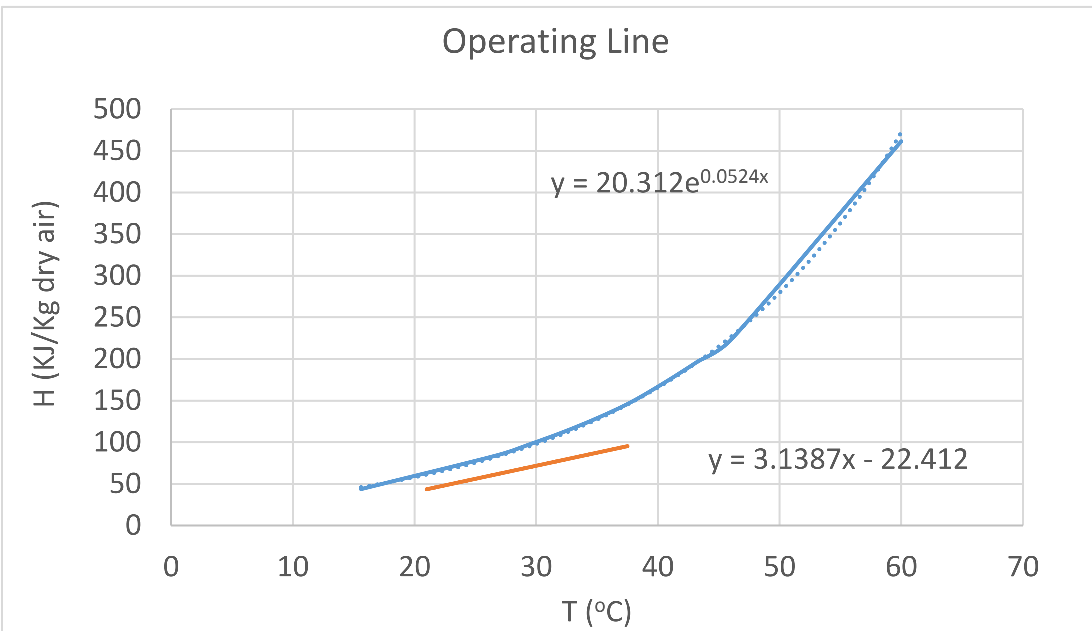

Figure 1: Operating Line for Run 1

Table 4: Data for NTU Calculation

T_L (ºC)	H* (KJ/Kg)	H (KJ/Kg)	H*- H	1/(H*-H)
21	61.045	43.501	17.544	0.057
26.5	81.436	60.764	20.672	0.048
32	108.637	78.026	30.611	0.033
37.5	144.924	95.289	49.635	0.020

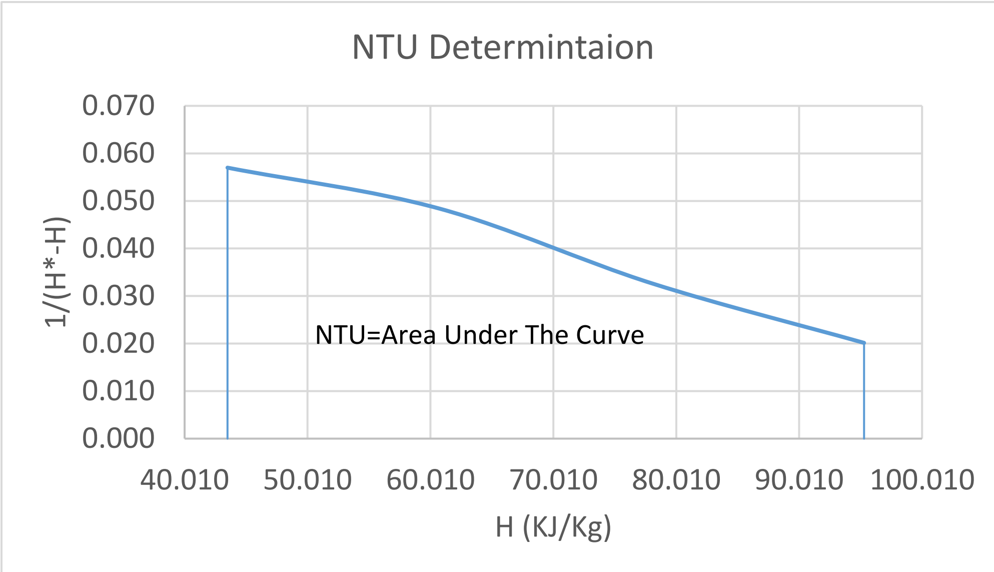

Figure 2: NTU Determination for Run 1

Table 5: Overall Mass Transfer Coefficient for Run 1

NTU	0.661
HTU	1.923
Kya	138.771

- Run (2)

Table 6: Experimental Data for Run 2

Inlet Water Flow Rate (Kg/h)	200
Inlet Air Flow Rate (m^3/h)	310
Inlet Air Flow Rate (Kg/h)	359.6
Inlet Air Dry Bulb Temperature (°C)	25
Inlet Air Wet Bulb Temperature (°C)	15.5
Outlet Air Dry Bulb Temperature (°C)	25
Outlet Air Wet Bulb Temperature (°C)	24
Inlet Water Temperature (°C)	37.5
Outlet Water Temperature (°C)	19

Table 7: Operating Line Fitting Data for Run 2

Operating Line			
T_{L1} (ºC)	19	H_{y1} (KJ/Kg)	42.968
T_{L2} (ºC)	37.5	H_{y2} (KJ/Kg)	86.049

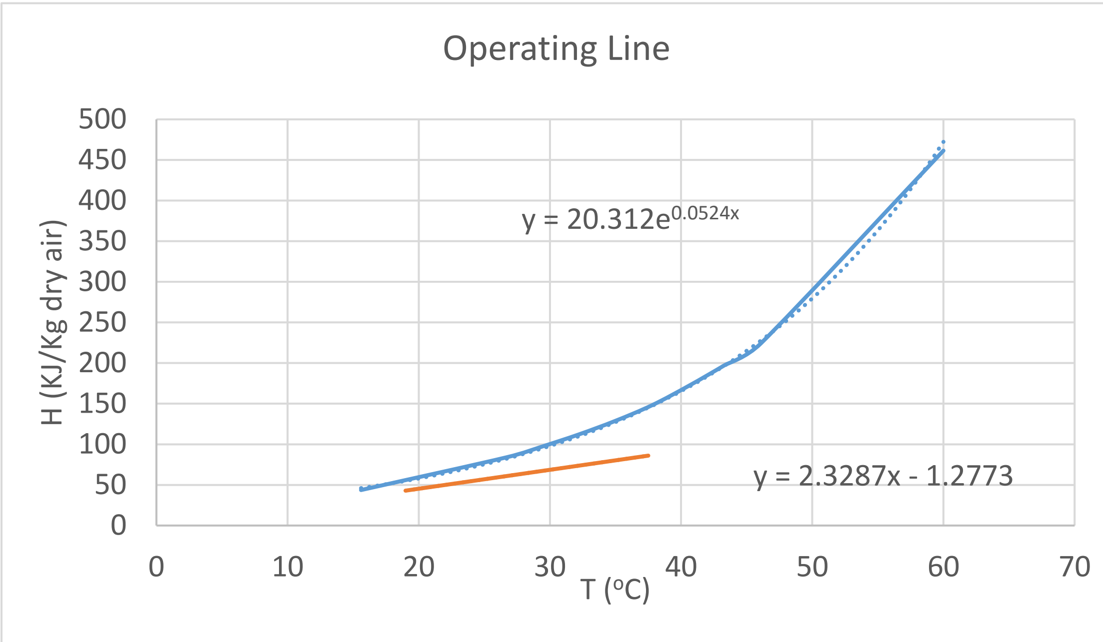

Figure 3: Operating Line for Run 2

Table 8: Data for NTU Calculation

T_L (ºC)	H* (KJ/Kg)	H (KJ/Kg)	H*- H	1/(H*-H)
19	54.971	42.968	12.003	0.083
25.16	75.914	57.313	18.601	0.054
31.32	104.834	71.658	33.177	0.030
37.48	144.773	86.002	58.770	0.017

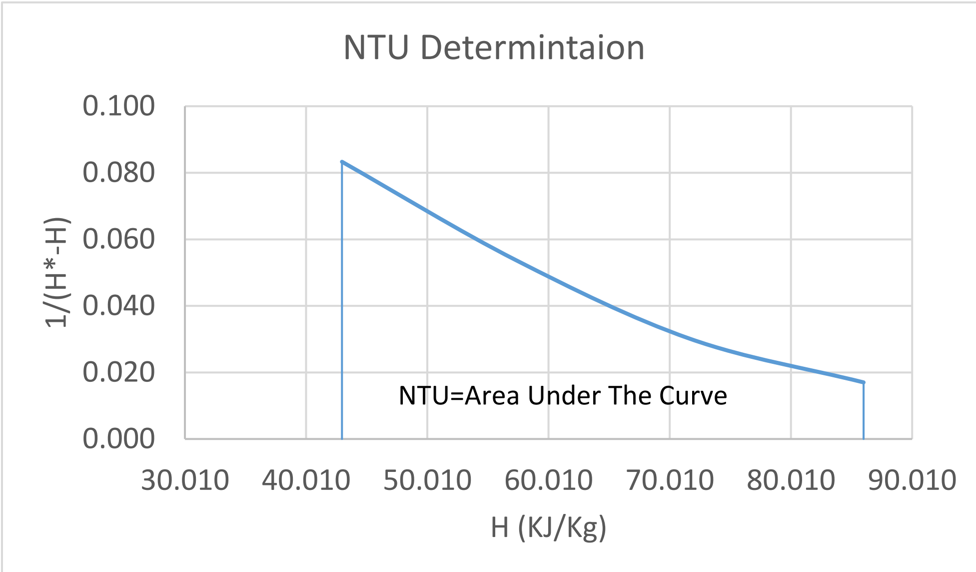

Figure 4: NTU Determination for Run 2

Table 9: Overall Mass Transfer Coefficient for Run 2

NTU	0.814
HTU	1.560
Kya	230.506

- Run (3)

Table 10: Experimental Data for Run 3

Inlet Water Flow Rate (Kg/h)	200
Inlet Air Flow Rate (m^3/h)	350
Inlet Air Flow Rate (Kg/h)	406
Inlet Air Dry Bulb Temperature (°C)	23
Inlet Air Wet Bulb Temperature (°C)	15
Outlet Air Dry Bulb Temperature (°C)	25
Outlet Air Wet Bulb Temperature (°C)	21.5
Inlet Water Temperature (°C)	37.5
Outlet Water Temperature (°C)	18

Table 11: Operating Line Fitting Data for Run 3

Operating Line			
T_{L1} (°C)	18	H_{y1} (KJ/Kg)	41.950
T_{L2} (°C)	37.5	H_{y2} (KJ/Kg)	82.102

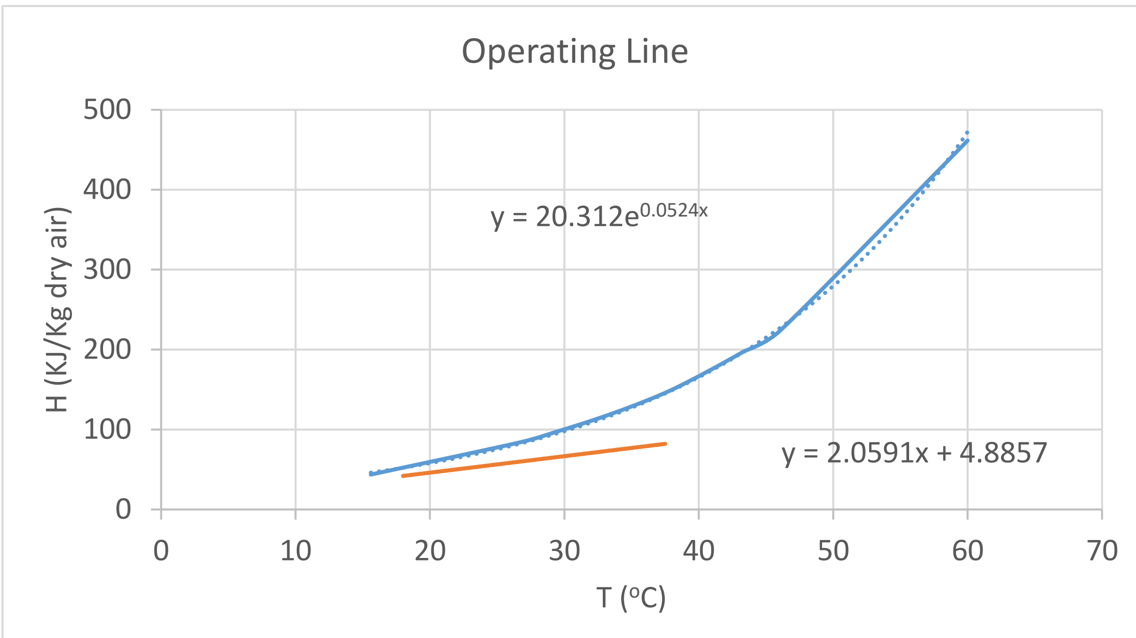

Figure 5: Operating Line for Run 3

Table 12: Data for NTU Calculation

T_L (°C)	H* (KJ/Kg)	H (KJ/Kg)	H*- H	1/(H*-H)
18	52.165	41.950	10.216	0.098
24.5	73.333	55.334	17.999	0.056
31	103.091	68.718	34.373	0.029
37.5	144.924	82.102	62.822	0.016

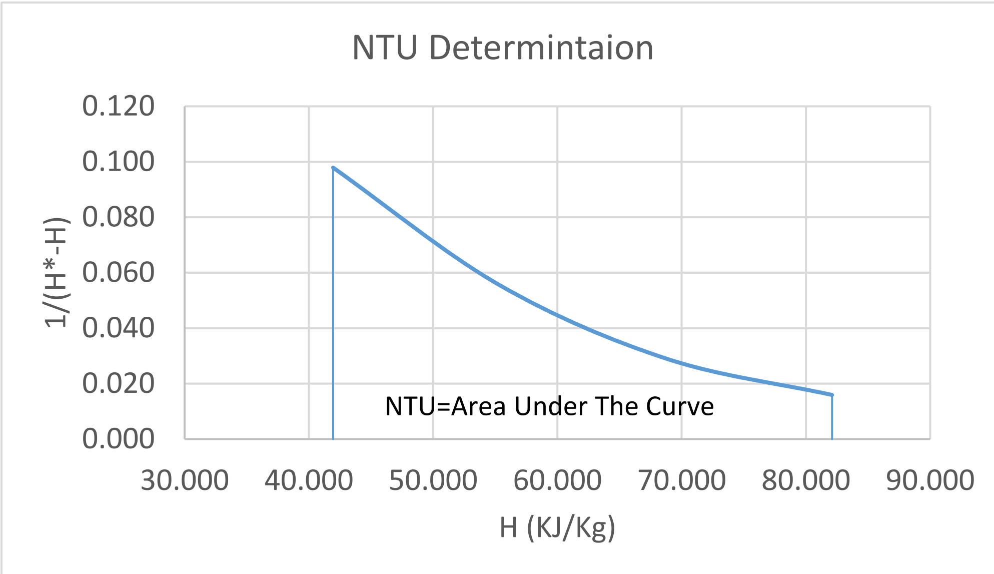

Figure 6: NTU Determination for Run 3

Table 13: Overall Mass Transfer Coefficient for Run 3

NTU	0.896
HTU	1.417
Kya	286.569

- Correlation Determination For Ky.A At Different Gas And Liquid Flow Rates

Table 14: Experimental and Calculated Data

Run	L	Gs (Kg/h)	Kya	log (Kya)	Gs/L	log (Gs/L)
1	200	266.8	138.771	2.142	1.334	0.125
2	200	359.6	230.506	2.363	1.798	0.255
3	200	406	286.569	2.457	2.030	0.307

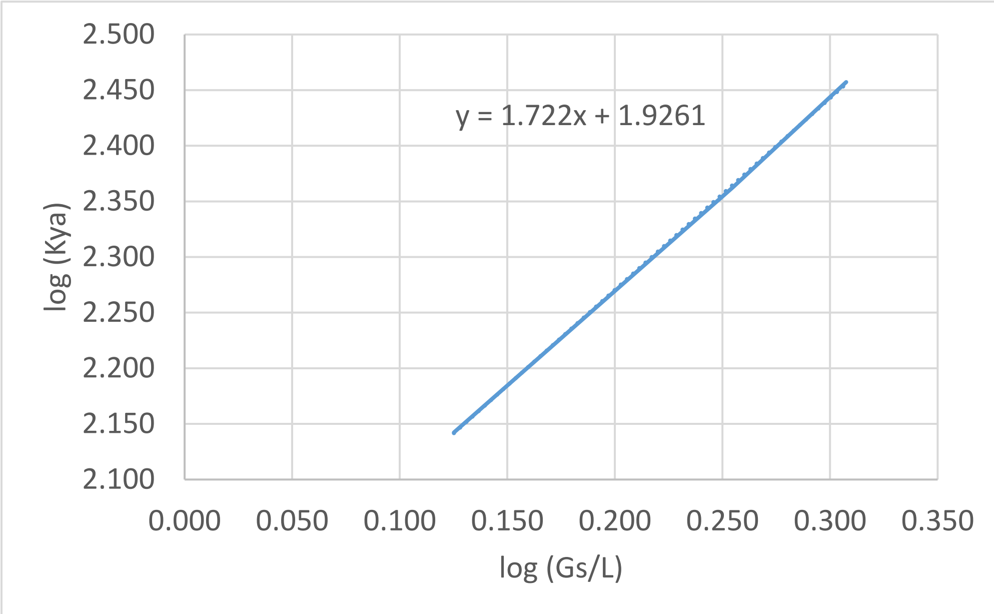

Figure 7: Correlation Constants Determination

Table 15: Correlation

Slope	1.722
β	1.722
Intercept	1.926
α	84.353
$Ky.a = 84.35\left(\frac{G_s}{L}\right)^{1.722}$	

DISCUSSION

This experiment involves a system comprising gas and liquid designed to cool water. Gas and liquid have a direct content. It features a feature that cools water. Cooling tower packing material, also referred to as heat transfer pack provides a large surface area for evaporative cooling to take place. It is located beneath the water distribution layer and above the sump of the cooling tower. Depending on the design of the tower, air is pushed through (forced draft) the packing layer. As the air passes over the film of water, evaporative cooling takes place, and the water is cooled.

The system involves air and water, with water entering from the top at around 40 degrees Celsius (TL>TG), while air enters from the bottom with low humidity (TG>TL). The water-cooling source involves both sensible and latent heat from vaporized water. At different positions down the column, mercury thermometers may be used to measure both the wet and dry temperatures for all scales.

The flow meter in this experiment measures the water flow rate. Two openings were used to regulate the air flow rate: one opened the fan to raise the air flow rate, while the other opened the tube to lower the air flow rate. Since it creates flow turbulence and the pressure difference in the manometer meter indicates that the purpose of this is to cool the water, the tube that was used to transport air from the outside to the tower is inverted. Measurements were made of the temperature of the air inside and outside, dry, and wet, and water. Raising the air flow rate raises the mass transfer coefficient and the (NTU).

In this experiment, the intake flow rate was fixed at (200 Kg/L), however the inlet air flow rate was altered as shown by (230, 310, 350 Kg/L). Tables (1), (6), and (10) reveal that increasing air flow rates result in lower outflow water temperatures. Consequently, raising the input air flow rate reduces the outlet enthalpy of air but increases outlet air humidity, as indicated in Tables (5), (9), and (13).

With increasing air flow rates, NTU and the mass transfer coefficient (ky.a) rise, leading to a decline in Heat Transfer Units (HTU). Drawing working and equilibrium lines involves equations related to air enthalpy at intake and outflow, utilizing experimental data. Determining the number of transfer units and computing each unit's height using the tower's height follows the line drawings.

Figure (7) reveals a plot of [log(Gs/L), log(Kya)], where α = 84.353 and β = 1.722, and obtain the following equation for the mass transfer coefficient: $Ky.a = 84.35\left(\frac{G_s}{L}\right)^{1.722}$.

CONCLUSION AND RECOMMENDATIONS

- The evaporative process caused the outlet water temperature to drop from the inflow temperature.
- The water-cooling source has two sources: sensible heat from evaporated water and latent heat.
- The humidification process raised the air's humidity.
- A cooling tower is an air comes from the bottom and water comes from the top in a countercurrent movement that distinguishes gas from liquid.
- As air flow rate rises, the mass transfer coefficient rises as well.
- As air flowrate increases, NTU values rise but HTU values fall.
- Because water humidifies the air, the air's entrance dry bulb and wet bulb temperatures were almost lower than its exit values.
- There was a reduction in the output enthalpy of air when the intake air flow rate was raised.
- It is possible to alter several factors to observe how they impact water evaporation, including cooling load, relative humidity, water temperature and flow rate, and air flow rate.

REFERENCES

1. Christie John Geankoplis, A. Allen Hersel and Daniel H. Lepek, Transport Processes and Separation Process Principles, Fifth Edition.

2. Chemical Engineering Laboratory (3) Manual Sheet. (2022). 1st ed. University of Jordan School of Engineering Department of Chemical Engineering.

3. https://www.accessengineeringlibrary.com/highwire_display/entity_view/node/11282689/focus_view

APPENDICES

I. **Sample of Calculations**

For Run 1:

c_L= 4.187 KJ/Kg.°C
ρ_{air} at 681 mmHg= 1.16 Kg/m^3

$$G_s = 230\frac{m^3}{h} * 1.16\frac{Kg}{m^3} = 266.8\,Kg/h$$

- Operating Line Equation

$$H_y = \left(H_{y1} - T_{L1}\frac{Lc_L}{G_s}\right) + \frac{Lc_L}{G_s}T_L$$

Inlet Air Dry Bulb Temperature: 27 °C
Inlet Air Wet Bulb Temperature: 15.5 °C
T_{L1}: 21 °C

→From the psychrometric chart H_{y1} is found to be 43.5 KJ/Kg dry air

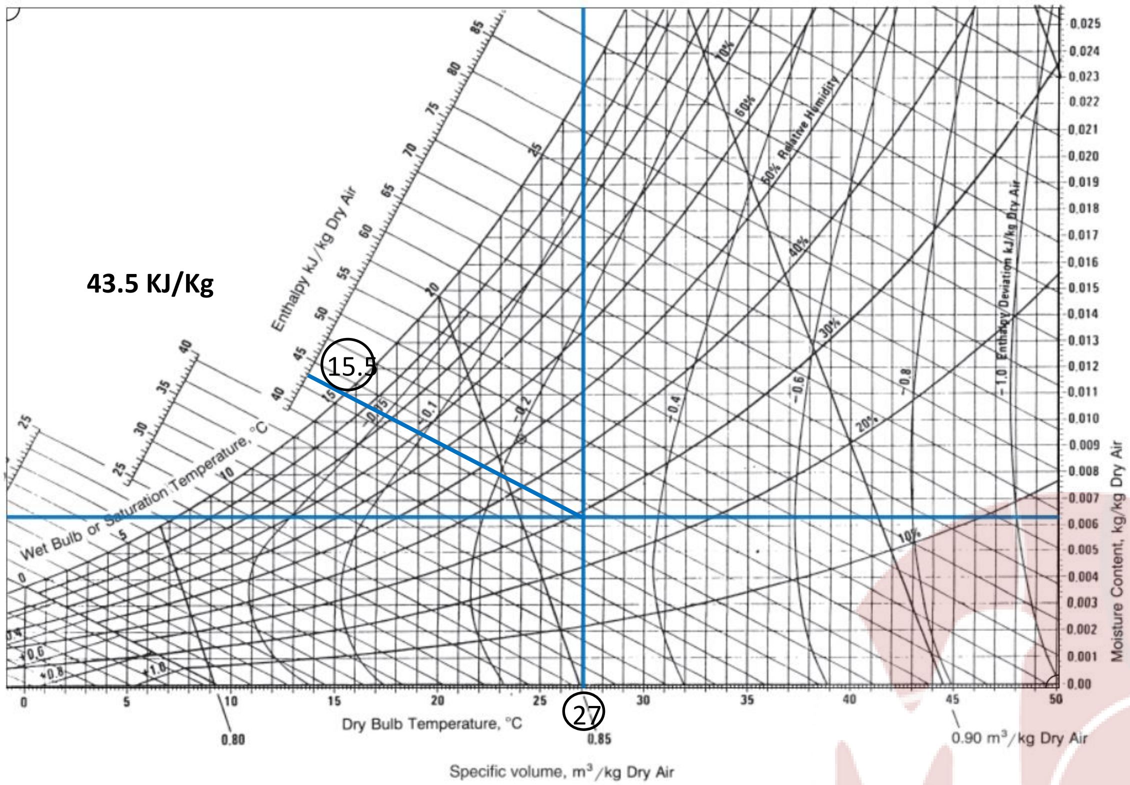

Figure 8: Psychrometric Chart

$$\text{Slope} = \frac{Lc_L}{G_s} = \frac{200 * 4.187}{266.8} = 3.14$$

$$\text{Intercept} = H_{y1} - T_{L1}\frac{Lc_L}{G_s} = 43.5 - 21 * 3.14 = -22.412$$

Operating Line:

$$H_y = 3.14\, T_L - 22.412$$

- Equilibrium Curve Equation

By fitting an exponential model to the data in table (2), the following equation is obtained:

$$H^* = 20.312e^{0.0524T_L}$$

- Number of Transfer Units (NTU)

$$N_{tOG} = \int_{H1}^{H2} \frac{dH}{H^* - H}$$

H must be found from the operating line equation and *H** from the equilibrium curve equation, for the temperatures range from T_{L1} (21ºC) to T_{L2} (37.5 ºC).

→ Temperature step size of 5.5 is chosen to generate table (4).

For T_L= 37.5 ºC

$$H = 3.14\, T_L - 22.412 = 3.14 * 37.5 - 22.412 = 95.23\ KJ/Kg$$
$$H^* = 20.312e^{0.0524T_L} = 20.312e^{0.0524*37.5} = 144.92\ KJ/Kg$$

$$\frac{1}{H^* - H} = \frac{1}{144.92 - 95.23} = 0.02$$

NTU is calculated either by plotting 1/(H*-H) vs. H where NTU equals the area under the curve, or by numerical integration which is shown below.

Using Simpson's 3/8 rule:

$$\int_a^b f(x)dx = \frac{3}{8}h[f(a) + 3f(a+h) + 3f(a+2h) + f(b)]$$

$$NTU = \frac{3 * 5.5}{8} * (0.057 + 3 * (0.048 + 0.033) + 0.02) = 0.661$$

- Height of Transfer Unit (HTU)

$$H_{tOG} = \frac{Z}{N_{tOG}} = \frac{1.27}{0.661} = 1.923\ m$$

- Overall Mass Transfer Coefficient

$$k_y.a = \frac{G_S}{H_{tOG}} = \frac{266.8}{1.923} = 138.8\frac{Kg}{m.h}$$

- Correlation That Relates The Overall Mass Transfer Coefficient With The Gas And Liquid Flow Rates

$$Ky.a = \alpha\left(\frac{G_s}{L}\right)^{\beta}$$
$$\log(Ky.a) = \log\alpha + \beta\log\left(\frac{G_s}{L}\right)$$

→By calculating $\log(Ky.a)$ and $\log\left(\frac{G_s}{L}\right)$ values for each run and plotting the data

$\log(Ky.a) = \log 138.771 = 2.1420$

$\log\left(\frac{G_s}{L}\right) = \log\left(\frac{266.8}{200}\right) = 0.125$

→Then linearizing the data, the following equation is obtained:

y = 1.722x + 1.9261

$Slope = \beta = 1.722$

$Intercept = \log\alpha$
$\alpha = 10^{1.926} = 84.353$

$$Ky.a = 84.35\left(\frac{G_s}{L}\right)^{1.722}$$

II. Data Sheet

Patm = 681 mmHg

October, 2021

Water Cooling Tower

ρ_{H_2O} at 21°C = 0.99802 kg/L

Raw Data Sheet

Run No.	1	2	3	4	5
Inlet water Flow Rate(kg/hr)	200	200	200		
Outlet water Flow Rate(kg/hr)	1698 ml 38 sec, 71	157.9 L/h 157.6 kg/h			
Inlet air Flow Rate (m^3/hr)	230	310	350		
Inlet air dry bulb temperature (°C)	27	25	28		
Inlet air wet bulb temperature (°C)	15.5	15.5	15		
Outlet air dry bulb temperature (°C)	29	25	25		
Outlet air wet bulb temperature (°C)	26	24	21.5		
Inlet water temperature (°C)	37.5	37.5	37.5		
Outlet water temperature (°C)	21	19	18		

Instructor's Signature:	[signature]
Date:	19/12/2023

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