

**Design of thermal system**

***IN SEMESTER (INDIVIDUAL) ASSIGNMENT 2***



May 15, 2021

ASSIGNMENT 2

**Q1.**

A 2-shell pass heat exchanger is designed to heat water flowing at X\* kg/s in 12-tube pass with ethylene glycol as shown in Figure Q1. The inlet and outlet temperature values of water and ethylene are given with the figure. The overall inside heat transfer coefficient of the tube is 280 W/m2 °C. By considering the necessary assumptions and stating them, determine

**(a)** the rate of heat transfer, and **(10 marks)**

(b) the heat transfer area of tube surface. **(10 marks)**

**Total: (20 marks)**

Consider: The specific heat capacity of water, Cp = 4180 J/kg . °C

The specific heat capacity of ethylene glycol, Cp = 2680 J/kg . °C.



***Solution:***

Given overall inside heat transfer coefficient of the tube U = 280 W/m2 °Cmin

specific heat capacity of water, Cpw = 4180 J/kg °C

specific heat capacity of ethylene glycol, Cpg = 2680 J/kg °C

Here NTU is unknown and can be find out by finding Effectiveness Є and

Heat capacity rates can be find out by

Equating the energy balance equation

Therefore, Cmin = Cglycol = 4012.8

Heat transfer rate

Max possible heat transfer rate, *Qmax*  is given by,

***Therefore, max possible heat transfer rate, Qmax = 353.126 kW***

Effectiveness,

Therefore,

But

***Therefore, heat transfer area of surface, A = 19.55 m2***

**Q2.**

A counter-flow consentric pipe heat exchanger is designed to cool ethylene glycol (Cp = 2560 J/kg.°C) from 80°C to 40°C flowing with mass flowrate of 3.5 kg/s by using water (Cp = 4180 J/kg.°C) (Figure Q2). The water enters to the heat exchanger at 20°C and leaves at 55°C. If the overall heat transfer is 250 W/m2 . °C, by considering and stating the necessary assumptions determine,

(a) the rate of heat transfer, **(8 marks)**

**(b)** the mass flow rate of water, **(5 marks)**

(c) the heat transfer surface area of the inner side of the tube. **(7 marks)**

(d) Considering the effect of fouling during operation through time and the heat transfer resistance would be affected, discuss the design and operation considerations to minimize the fouling problem on the opertion of the heat exchanger during design and operation stages.

Discuss also cost and performance optimization considerations when one tries to consider the design and operation measures to be taken in order to minimize the effect of fouling. **(10 marks)**

**Total: (30 marks)**

***Properties:*** The specific heats of water and ethylene glycol are given to be 4.18 and 2.56

kJ/kg°C, respectively.



***Solution*:**

Given data,

Cpgly = 2560 J/kg C

Cpwat = 4180 J/kg C

Mgly = 3.5 kg/s

Tiwat = 200C Towat = 550C

Tigly = 800C Togly = 400C

Overall heat transfer coefficient U = 250W/m2 0C

Heat capacity rates can be find out by

Therefore,

Max possible heat transfer rate, Qmax

***Therefore, max possible heat transfer rate, Qmax = 537.6 kW***

***Mass flow rate of water, mwater = 3.43 kg/s***

Heat transfer rate,

Effectiveness,

Now heat transfer area,

***Therefore, heat transfer area of surface, A = 19.55 m2***

***Fouling Factor in Heat exchanger***

Heat exchanger performance degrades as the deposits accumulate on the surface of heat exchanger. Layer of deposits create additional resistance to heat transfer and cause rate of heat transfer to decrease.

Types of fouling- Precipitation, corrosion and chemical fouling.

Precipitation- Caused by hard water

To avoid such type of fouling, the water is extensively treated before entry into heat exchanger. Such treatment increases the cost of operation but at the same time effectiveness of heat exchanger also increases.

Corrosion and chemical fouling- Caused by accumulation of products of chemical reaction.

Such type of fouling can be avoided by either coating metal pipe with glass or using plastic pipes instead of metal. For such type of treatment the cost of treating increases but the effectiveness also increase.

**Q3.**  In heat exchanger design there is no unique solution that one can followed in the design process as the process is complex and multidisciplinary.

Discuss the major heat exchanger design problems, variables to be considered and the steps of sizing the heat exchanger. **(10 marks)**

***Solution***: For designers, the goal for designing heat exchanger is to heat or cool the certain fluid of specific mass flow rate and temperature.

By using heat transfer equation,

This equation gives the idea about the requirement of heat exchanger before having any idea of heat exchanger itself.

There are several factors for the selection of the heat exchanger such as Heat transfer rate required, Cost, Size and Weight, Material, Type and Pumping power.

***Cost***- It plays very important role in selection of the heat exchanger. The operation and maintenance cost of heat exchanger are important consideration in assessing the overall cost.

***Pumping power****-* Both the fluids are forced through heat exchanger with the help of pump. Annual cost of electricity associated with the operation of the pump

Minimizing the pressurization will reduce the cost of pumping but will maximize the size of heat exchanger and hence the initial cost.

***Size and weight***- Mostly the smaller and lighter the heat exchanger, the better it is. In aerospace and automotive industries the size and weight of heat exchanger required is small and light weight.

As the size increases the price of heat exchanger increases. Size of heat exchanger can be limited by the space available to install heat exchanger.

***Heat Transfer rate***- It is most important factor in the selection and designing of heat exchanger. Heat exchanger should be capable of transferring desired amount of heat to achieve the desired temperature range for given mass flow rate.

**Q4.**

Demonstration and analysis of the air conditioning process using Air Conditioning Trainer EC1501.

The data given below in Table Q4 is collected in a model that is used to demonstrate the air cooling and dehumidifying process using a psychrometric chart.

The video for the experimental set-up of the Air Conditioning Trainer EC1501 is given in the link below.

<https://www.youtube.com/watch?v=e3zxGMG-cI8>

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Parameter** | **Symbol** | **Experiment case** | | | |
| **Compressor OFF** | | **Compressor ON** | |
| **Inlet(1)** | **Outlet(2)** | **Inlet(1)** | **Outlet(2)** |
| Dry bulb temp | TA(1or2) | 22.5 | 22.5 | 22.6 | 15.5 |
| Relative humidity | *Φ(1 or 2)* | 34.7 | 34.8 | 33.8 | 53.9 |
| Wet bulb temp | TW |  |  |  |  |
| Dew-point temp | TD |  |  |  |  |
| Humidity ratio | *ω* |  |  |  |  |
| Enthalpy | hA |  |  |  |  |

|  |  |  |  |
| --- | --- | --- | --- |
| **Difference Between Inlet and Outlet** | **Symbol** | **Compressor OFF** | **Compressor ON** |
| Dry bulb temperature | ΔTA (°C) |  |  |
| Relative humidity | Δφ (%) |  |  |
| Humidity ratio | Δω (kg/kg) |  |  |
| Enthalpy | ΔhA (kJ/kg) |  |  |

**Results Analysis**

**(a)** Complete Table Q4a & Q4b and compare the changes of all the properties of the moist air both with the compressor on and off using the psychrometric chart and formulas (16), (17), (18) and (19) given in the Appendix 1. **(5 marks)**

**(b)** Discuss the changes in relative humidity and absolute humidity of the air when the compressor is on. If significant variation is observed between the relative humidity and absolute humidity changes, discuss the reason. **(10 marks)**

(c) Create a line that connects the inlet air (point 1) and the outlet air (point 2) state points on the psychrometric chart and suggest why there are differences. **(5 marks)**

(d) Verify if a dehumidifying process is occurring simultaneously with a cooling process using formula (19) if Tsat-evaporating =10°C. **(10 marks)**

(e) Discuss your results of dry-bulb temperature, relative humidity, wet-bulb temperature, dew-point temperature, humidity ratio and enthalpy you obtained when the compressor is off and on. **(10 marks)**  **Total: (40 marks)**

***Solution:***

**A)** Following are the values taken from psychometric chart and formulae for the given data

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Parameter** | **Symbol** | **Experiment case** | | | |
| **Compressor OFF** | | **Compressor ON** | |
| **Inlet(1)** | **Outlet(2)** | **Inlet(1)** | **Outlet(2)** |
| Dry bulb temp | TA(1or2) | 22.5 | 22.5 | 22.6 | 15.5 |
| Relative humidity | *Φ(1 or 2)* | 34.7 | 34.8 | 33.8 | 53.9 |
| Wet bulb temp | TW | 13.5 | 13.7 | 13.2 | 10.5 |
| Dew-point temp | TD | 6.5 | 6.6 | 4.5 | 5.5 |
| Humidity ratio | *ω* | 0.006 | 0.007 | 0.0028 | 0.0075 |
| Enthalpy | hA | 37 | 36 | 37.5 | 29 |

|  |  |  |  |
| --- | --- | --- | --- |
| **Difference Between Inlet and Outlet** | **Symbol** | **Compressor OFF** | **Compressor ON** |
| Dry bulb temperature | ΔTA (°C) | 0 | 7.1 |
| Relative humidity | Δφ (%) | 0.1 | 20.1 |
| Humidity ratio | Δω (kg/kg) | 0.001 | 0.0047 |
| Enthalpy | ΔhA (kJ/kg) | 1 | 8.5 |

**B)** From the experimental data:-

For compressor ‘ON’ condition-

**Inlet (1) Outlet (2)**

Relative humidity - 33.8 53.9

Absolute humidity - 0.0028 0.0075

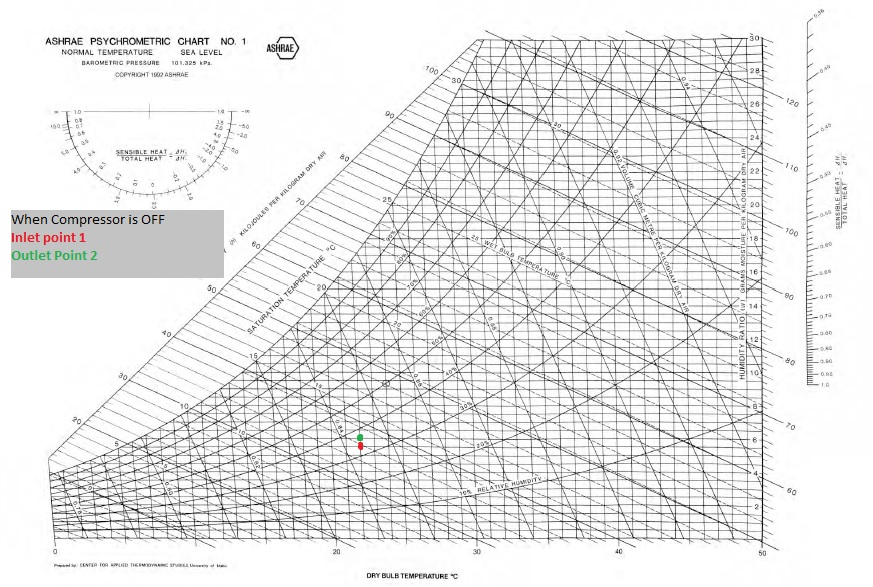
Relative humidity represents amount of water in air in %.

Both relative humidity and absolute humidity increased when we carried out compressor ON setup, the amount of water vapour increased in the air from inlet to outlet, but temperature also reduced.

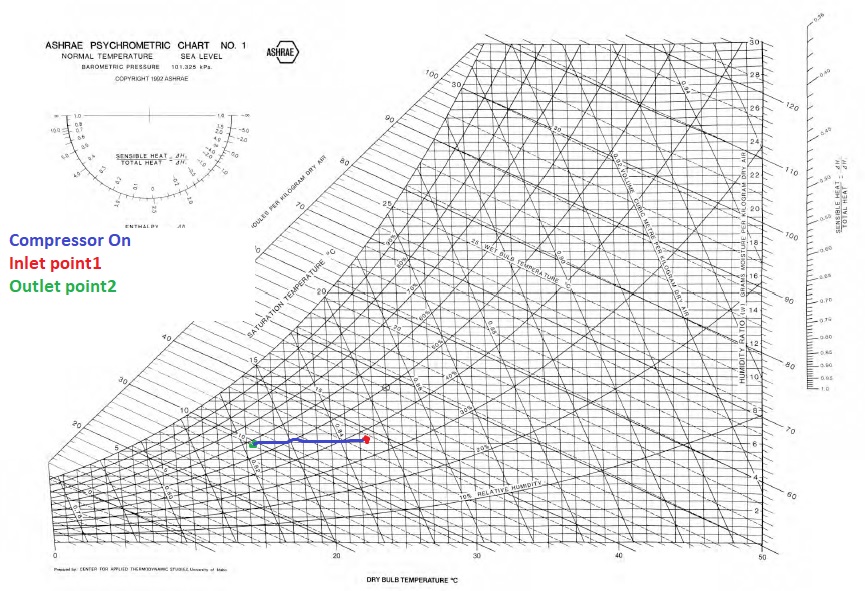
When the compressor automatically shuts OFF that means the desired condition of air is reached.

Absolute humidity of the given system having no considerable change.

**C)**  ***Compressor OFF condition***



***Compressor ON condition***

****

**D)**

****

The above chart representation is for compressor ‘on’ condition.

Point 1 – inlet point

Point 2- outlet point

We can see from the chart that, there is sensible cooling process taking place from point 1 to point 2.

Since the temperature of the air is decreasing and relative humidity is increasing and there is no change in moisture content. Hence no humidification process is taking place.

And also, if the condition reaches to the 100% saturations than, the dry bulb temperature and dew point temperature will be same.

Hence there is new can see dry bulb temperature is not decreasing less than 15.5’c hence no humidification.

**E)** From the table we can conclude about the results as follows:-

**Condition -1:-** When compressor is “OFF”.

In the given experimental set up, if the compressor is off here we can see that,

* There is no change in dry bulb temperature at inlet and outlet
* The relative humidity also not changed as a considerable value to focus on.
* Wet bulb temperature also remains same approx.
* No considerable change in dew point temperature
* Also no change in the enthalpy and the humidity ratio.

Hence while compressor is not working, there are no changes seen (considerable) on the air properties.



**Condition -2** :- When compressor is ON



This is the psychometric chart representation of the case 2 when the compressor is “ON”

From the above chart and table of the experiment data we can conclude that:-

* There is decrease in the dry bulb temperature, hence air get cooled.
* Relative humidity also increase from inlet to the outlet point.
* Wet bulb temperature of the air is also decreased at the considerable amount.
* Dew point temperature reduced by 1’ degree only.
* There is no considerable change in the absolute humidity. Here we can see that sensible heat graph.
* There is also loss of enthalpy from inlet to outlet.

***References:***

1. Yunus A. Çengel, 1998: Heat and Mass transfer, ‘https://easyengineering.net/heat-transfer-a-practical-approach-by-cengel.pdf’
2. F.\_P. Incropera, D.\_P. DeWitt, (Ebook) Fundamentals of Heat\_and Mass Transfer Solution Manual
3. F. P. Incropera, D.P. DeWitt: A Heat transfer textbook, third edition.
4. ASHRAE PSYCHROMETRIC CHART: ASHRAE Psychrometric Chart #1 (SI), https://www.ashrae.org › Bookstore
5. Incropera, De Witt, Bergman, Lavine: Fundamentals of Heat and Mass Transfer (Sixth Edition)