Enhancing the Efficiency of Cooling Tower

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Certificate

This is to certify that work in this thesis has been carried out by **Mr. Muhammad Usman, Mr. Muhammad Hamza Ashraf and Mr. Usama Bin Zahid** and completed under my supervision, at School of Chemical and Materials Engineering, National University of Sciences and Technology, H-12, Islamabad, Pakistan.

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Dedication
To

OUR PARENTS

Without whom none of this would have been possible and for their support throughout our lives

AND TEACHERS

For inspiring us and supporting us throughout the entirety of this project.

Acknowledgement

First of all, we bow before Allah Almighty to thank for His countless blessings and rewards who gave us the strength and ability to complete the thesis.

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We are also thankful to our parents, without their assistance and encouragement; it was not possible to complete the project successfully.

ABSTRACT

ICI Soda Ash began its commercial production in 1944. Through various expansion projects plant's original capacity of 18,000 tons/year has increased to 350,000 tons/year and by the end of 2018 it is expected to become a half million ton site. ICI soda ash plant caters to about 70% of the country's total demand for this commodity.

The purpose of this project is to design an optimized cooling tower to increase its efficiency. After literature review, consideration of current industrial practices and consultation with both supervisors, we calculated the performance of the Cooling tower on the existing parameters and provided an improved design of Cooling tower.

The improved design of the cooling tower will help not only help in increasing the efficiency, but also reduces the cost of operation.

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Nomenclature

ΔG: Gibbs free energy

A: Area

C: Cost

°C: Degree centigrade

D: Dia

F: Flow Rate

g: Acceleration due to gravity

H: Height

J: Joule

L: *Length*

Mol: Mole

P: Pressure

Q: Energy Flow rate

t: time

V: Volume

W: *Width*

C_P: Specific Heat Capacity at Constant Pressure

T: Temperature

$\dot{V}$: Volumetric Flow Rate

Chapter-1
Introduction

1.1 About ICI Soda Ash

ICI Soda Ash plant was established in 1929 and began its commercial production in 1944. This plant was gone through many expansion projects, objective of which was to increase production capacity. Initially, ICI was producing 18,000 TPA (tons per annum) of soda ash and after various expansion projects its capacity has been increased to 350000 TPA. By the end of 2018, it expected to become a half million ton site.

Main product of ICI Soda Ash is Sodium Carbonate (Soda Ash), other products are dense soda ash and refined sodium carbonate. ICI Soda Ash is meeting 70% of country requirement. Most customers from Pakistan are relying on ICI Soda Ash as trusted supplier. Soda Ash has varied application which includes soap, detergents and glass industry

Figure 1 ICI Soda Ash Plant

1.1 Soda Ash Production

Soda Ash is widely used in Glass, Steel, Detergent and the vast Chemicals based industries. Earnest Solvay in 19th Century developed the most modern process of producing Soda Ash called Solvay's process or Ammonia Soda process. The process is efficient in terms of easily available and inexpensive raw materials available for the production of Soda Ash (Sodium Carbonate, Na_2CO_3) that include brine solution and limestone (Calcium Carbonate, $CaCO_3$). The demand of Soda Ash can be clearly estimate from the recent production of Soda Ash worldwide which is around 42 Million tons per year. Following statistics with the year of 2000 as reference indicates the worldwide production of soda Ash.

1.2 History of Soda Ash

Worldwide Soda Ash was obtained through natural sources when industrial processes had not developed enough. These natural resources included mineral and vegetable sources. Sodium carbonate is termed as Soda Ash because historically it was obtained from ashes of plant growing in sodium rich soil. When Soda Ash production was not enough as needed by the Glass and Detergents industries, it became necessary to develop a new practical production process and French Academy of Science urged scientists to develop an industrially applicable Soda Ash manufacturing process. A French physician, Nicholas Leblanc in 1791 came up with the idea of using common salt, Sulfuric Acid and Limestone as raw material for Soda Ash production. This process was called 'Leblanc Process' or 'Black Ash' process. Leblanc process dominated the early 19th Century Soda Ash industry but this process was not environmentally stable. It involved the emission of massive quantities of Hydrogen Chloride Gas (HCl) in to the atmosphere. It also required the discharge of Calcium Sulfide as solid waste which not only produced hazardous gases but also lost large amount of an important chemical like Sulfur. This led Earnest Solvay to modify Leblanc's process using Brine, Limestone and Ammonia as major raw materials. While the two processes were considered for long time by industrialists for the sake of comparison, Solvay's process had to dominate because of simpler and cleaner process of Soda Ash production. When Soda Ash's price took a downward steep in 1861, Leblanc's process began to rule as well and by the end of World War one, this process was completely rejected by industrialists and Solvay's process has ruled since then as the Soda Ash production major process. Although Soda Ash can be mined where large amount of deposits is found, less consideration has been given to it because of the risk of impurity of ores and the subsequent process of refining the ores through expensive and energy intensive methods.

1.3 Solvay's Process

Solvay's or Ammonia Soda process utilizes easily available raw materials (Salt and Limestone with recycling of Ammonia) in a cleaner way. Soda Ash produced by this process can be sold in two forms depending on the customer industry. Light Soda Ash with density of around 500 kg/m^3 is majorly in demand by Detergent and Chemicals industries. Light Soda Ash can be converted in to Dense Soda Ash (with a density of around 1000 kg/m^3) by the process of recrystallization, dehydration and compaction. Glass industry mainly requires compacted Light Soda or Dense Soda Ash.

1.4 Problem Statement

In ICI Soda Ash plant, we have variety of process stream which are cooled by using cooling water. The cooling water is supplied by cooling tower. The reason to use cooling tower is that they are efficient and cheap.

The problem is to enhance the efficiency of cooling tower and reduce water losses so that less make up water required and more transfer or exchange of heat to cool water.

1.5 Background

As the whole soda ash production process involve so many process streams. At some stages we also need to cool them by mean of cooling water. Cooling water they use is mainly obtain from ground water source or Jhelum. The water contains high amount of impurities including bicarbonates, carbonates, chlorides, and sulphate of calcium and magnesium.

This water is treated in various ways. Temporary hardness is remove by clarifier to decrease blowdown losses but few amount of dissolve calcium carbonate left behind. It varies from 500 to 1500 ppm.

1.6 Issue

ICI Soda ash plant is increasing its production to 500,000 TPA and because of that higher temperature stream are generated therefore we have to increase the efficiency of cooling tower so that more energy is absorbed and condition remain at optimal level.

High temperature is not suitable for absorber and Solvay tower because reactions are not feasible at higher temperature therefore we are using cooling tubes inside Solvay and absorber tower to decrease the temperature and to stable the product form because of that we have to increase cooling tower efficiency so that more energy is absorbed.

1.7 Mechanical Draft Cooling Tower

A large number of industries are using mechanical draft cooling tower. Mechanical draft cooling tower are famous due to their compactness and brilliant performance in transferring heat. Mechanical draft is famous due to their high effectiveness, light weight and reasonable price.

Although they are used by industries for many years but this technology and its manufacturing is limited to few companies in some of most develop nations.

Mechanical draft tower use fan, driven by electric motors to produce the flow of air. The tower is called induce draft if fan is installed in air exit at the top of the tower. The tower is called force draft if fan is installed in air entry at the bottom of tower. The flow is counter flow hot water enter from the top and air from the bottom in between there is a packing where there is a direct contact between two fluid and they exchange heat. Cold water leaves from the bottom and hot air from the top.

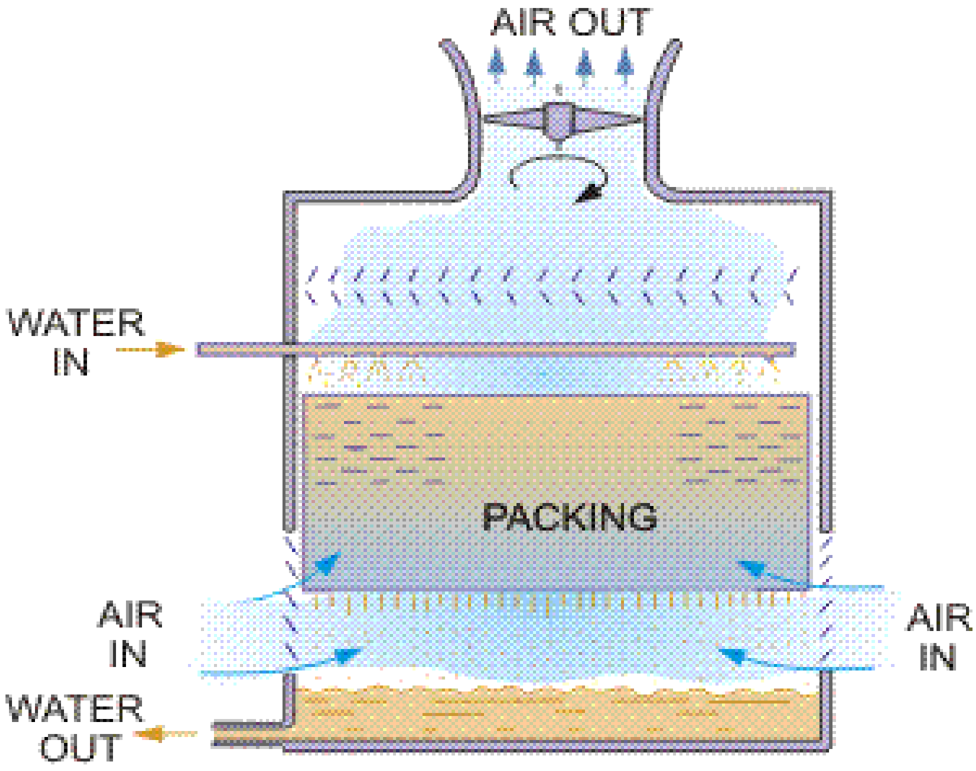


Figure 2 Mechanical Draft Cooling Tower

1.7.1 Why Mechanical draft Tower

- For the same capacity the mechanical draft cooling tower are much smaller in size than natural draft cooling tower because of increase in cooling capacity due to increase in volume of air being forced out by fan.
- Capacity control is possible by regulating the speed of fan which control the volume of air which in turn control capacity.
- Natural draft cooling tower are only suitable for outside area whereas mechanical draft cooling tower can be located even inside the building.

1.7.2 How Things Work

The working principle of cooling tower is very similar to evaporative type condensers, in which hot water is cooled by evaporation. Water evaporates when `warm water came in contact with cold air the evaporating water also absorbs the latent heat form water surrounding it. By losing latent heat, the water is cooled down.

1.8 Type of Mechanical Draft Cooling Tower

Following are the types of mechanical draft cooling tower

- Induced draft

- Forced draft

1.8.1 Induced Draft

In induced type cooling tower, the fan is located at the top of the tower where it creates low pressure inside the tower. Axial fan is used for this type of tower. The advantage of using induced draft is that it uses 50% less energy as compare to forced draft. It is easy to install and maintain. Low noise level is another advantage of cooling tower.

1.8.2 Forced Draft

In this system the fan is located at the bottom of the tower which causes over pressure, both axial and centrifugal fan can be use. The advantages of using forced draft is that it has low absorbed capacity, dry air stream drive and easy maintenance.

Chapter-2

Literature Review

2.1 Process Description:

The Solvay process is the major industrial process for the production of Sodium Carbonate (Soda Ash).

Overall Reaction: $2NaCl + CaCO_3 \xrightarrow{yields} Na_2CO_3 + CaCl_2$

However, the reaction cannot occur directly as the reaction is endothermic and Gibbs free energy change is greater than zero$(\Delta G > 0)$. Thus, the reaction comprises of multiple steps containing different reactions being taken place.

2.2 Cooling Tower:

Cooling tower is one of the major component of many industries, its basic purpose is to reject waste heat to the atmosphere with the help of air to decrease the temperate of the water to the required value. Water that has been heated in by any industrial process is then sent to the cooling tower via pipes. Water is sprayed on to the banks called "fill", it slows the water flow in the cooling tower, which helps in the increased air-water contact time. In the cooling tower, water is then subjected to incoming air, which is being entered in to the tower with the help of fans.

Basic principle

Cooling tower utilizes both mass and heat transfer to cool down the water. Cooling of water is due to the evaporation of small amount of water. Heat transfer process includes the latent heat transfer from water to air and a sensible heat transfer for the evaporation of water.

About 80% of this heat transfer per kg of air flowed inside the cooling tower relies upon the temperature and dampness substance of air. Wet bulb temperature of air demonstrates the water content of air in short wet bulb temperature of air is the most minimal temperature to which the water can be cooled. Essentially, the water temperature approaches to the wet the bulb temperature, however practically it will not reach the wet bulb temperature of air in a cooling tower, as it is difficult to contact all the water with outside air as the water drops through the wetted fill surface to the basin.

Factors affecting the operation of cooling tower

- Dry-bulb and wet-bulb temperature of air
- Temperature of hot water entering the tower
- Contact time between air and water
- Uniformity of distribution of the air and water inside the tower
- Air pressure drop
- Required temperature of cooled water

2.3 Types of Cooling Tower:

Cooling towers are manufactured in many types based on the requirement, having various size and shapes.

2.3.1 Atmospheric Cooling Towers:

Atmospheric cooling tower doesn't require any mechanical fan for the air to enter the tower, air flows into the tower naturally. Although these types of cooling tower and very inexpensive, they are mostly used on small scale, and can only in used in areas where wind flow is high.

2.3.2 Hyperbolic Natural Draft:

In hyperbolic natural draft cooling tower air is transferred due to the density difference between the hot air inside and the cold air outside. Hyperbolic natural draft is divided in to the following types.

2.3.3 Counter Flow Natural Draft:

Counter flow towers are designed in a way that air flows upward vertically, and the water falls from top to bottom, as the name suggests, air and water are flowing in opposite direction to each other. Counter flow towers use pressurized spray type systems which sprays water on the top of the fill.

2.3.4 Cross Flow Natural Draft:

In cross flow natural draft, the water flows horizontally while air flows vertically in the chamber. Air doesn't pass through the distribution chamber in cross flow towers.

2.3.5 Mechanical Draft Cooling Towers:

Mechanical draft cooling tower consists of either single fan or multiple fans which are used to suck in the air that is required for the heat exchange. Efficiency of mechanical draft cooling tower is much higher, and mechanical draft cooling towers can be used anywhere. They are not affected by the outside atmosphere. Mechanical draft cooling towers are further divided in to two types based on the position of the fan in the tower.

2.3.6 Forced Draft:

In forced draft cooling tower fan is placed at the bottom of the tower from where air enters the tower.

Advantages:

- A part of the velocity head of air thrown by the blower is converted to pressure head on entering into the tower. It makes energy efficient than induced draft.
- As Fans are installed near the ground it leads to a less vibrations in Cooling Tower.

Disadvantages:

- Air flow through packing may not be uniform.
- Recirculation rate decreases if the wind velocity becomes high.

2.3.7 Induced Draft:

In induced draft cooling tower fan is placed at the top of the cooling tower where air exists the tower, in induced draft cooling tower pressure difference is created which results in better performance as compared to forced draft cooling tower.

Advantages:

- More contact of dry air at bottom of the tower with the coldest water.
- As more humid air is in contact with the warm water is leads to maximum average driving force for both mass and heat transfer

Disadvantages:

- Power consumption is high.
- Power consumption of cross flow induced tower is lower than counter current flow induced draft tower.

2.4 Important Terms:

Wet Bulb Temperature: The temperature of the entering air that enters in to the cooling tower being measured by wet bulb thermometer.

Factors affecting the wet bulb temperature:

- Dry bulb temperature of air
- Humidity of air
- Velocity of air

Dry Bulb temperature: The temperature of the entering air that enters in to the cooling tower being measured by dry bulb thermometer.

Approach: The difference between the wet bulb temperature of the ambient air and the water leaving the cooling tower is known as the tower's approach. The approach is a function of cooling tower capability to cool down the water. For example a large cooling tower will produce a closer approach for a given heat load, flow rate and entering conditions of the air.
Approach depends on tower design and the following factors affect approach:

- Air to water contact time
- Amount of fill surface
- Size of water droplets

Blowdown: Water that is discharged from the system to control the concentrations of impurities and salts from the system. The loss of water through blowdown is termed as Blowdown losses

Drift losses: Lost water during the circulation when water droplets are being carried by the air stream in to the atmosphere.

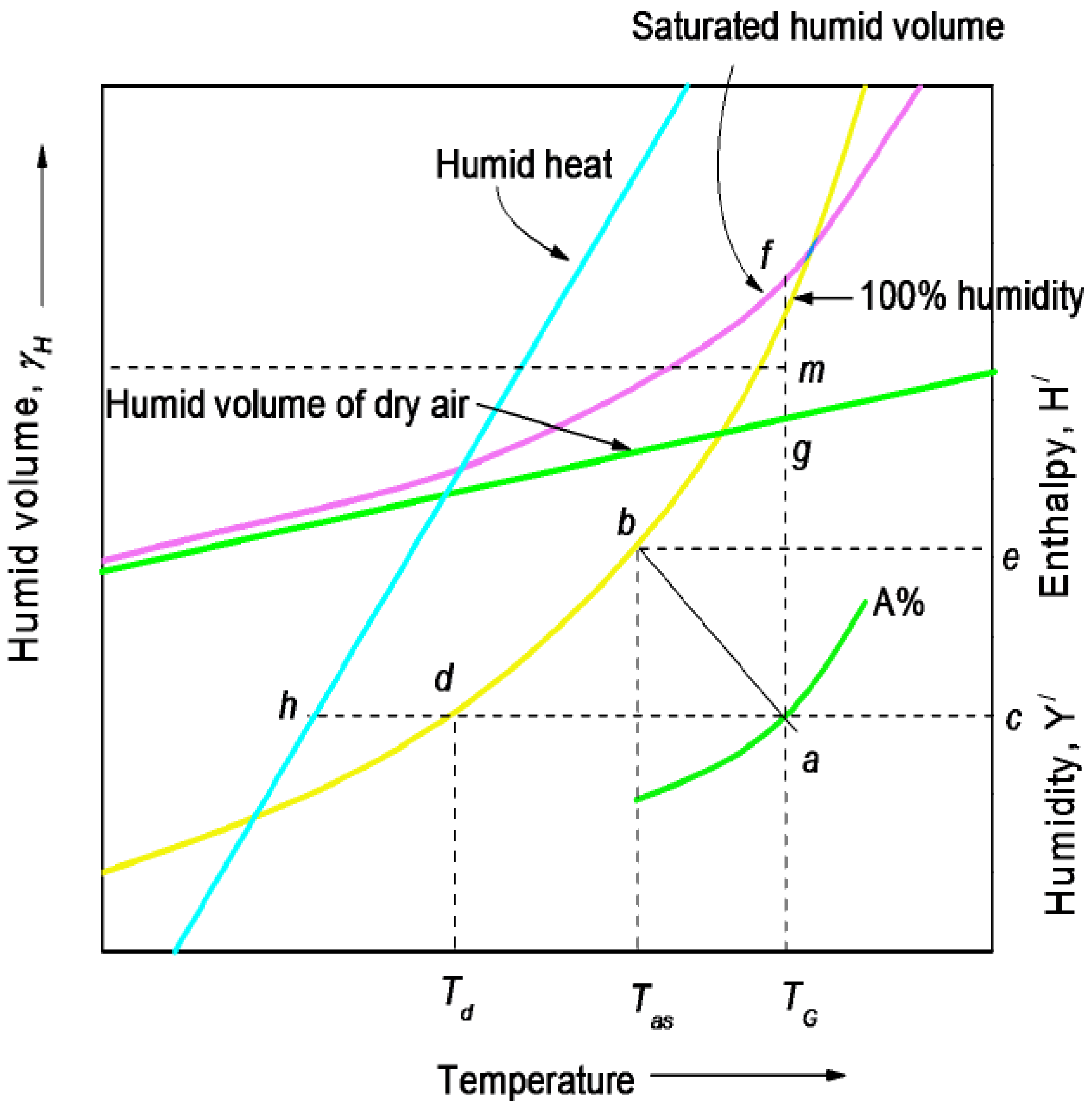
Relative Humidity: Relative Humidity is the ratio of water vapors partial pressure to the equilibrium pressure of water at any temperature. It depends upon pressure and the temperature of the system. At low temperatures, it requires less water vapor to achieve high value of relative humidity; more water vapor is required to achieve high relative humidity in warm or hot air.

Range: Difference between the hot water temperate and the cold-water temperature is called range

$$R = Hot\ water\ inlet\ temperature - Cold\ Water\ outlet\ Temperature$$

2.5 The Psychometric chart construction and its use

Some thermodynamics properties of air like dry-bulb temperature, wet-bulb temperature, relative humidity, absolute humidity, dew point, enthalpy and specific volume are all inter-related. The psychometric chart shows how these interdependencies are related. It also helps to calculate them for example if value of any two of these properties are known other 5 properties can be easily obtained through psychometric chart.



2.6 Why water is used for Cooling?

These factors makes the water an excellent Cooling medium:

- Its cost and availability.
- Easy handling
- Amount of heat per unit volume carried by water is high
- Insignificant compression and expansion with normal temperature ranges.
- It does not decompose

Chapter-3
Cooling Tower Design Methodology

Designing is an action meant at giving complete explanation of a manufacturing system or part of a system. For successive engineering and utilization these explanations characterize an explicit specification of size, performance and other characteristics are important. Cooling tower design methodology is rather complex process due to some qualitative judgement and quantitative calculation must be done.

The production of soda ash is not a straight process and require several steps for its production as the change in Gibbs free energy is greater than zero. The methodology used for the design of cooling tower is to apply material and energy balance on whole soda ash plant for finding out the hot water flow rate and temperature entering the tower and the temperature of cooled water that is required for the Absorption and Solvay tower.

3.1 Process Flow Diagram

To apply the material and energy balance for the calculation of water flow rate and temperature first we have to develop a process flow diagram in which there is all the steps that is required for the production of soda ash/sodium carbonate.

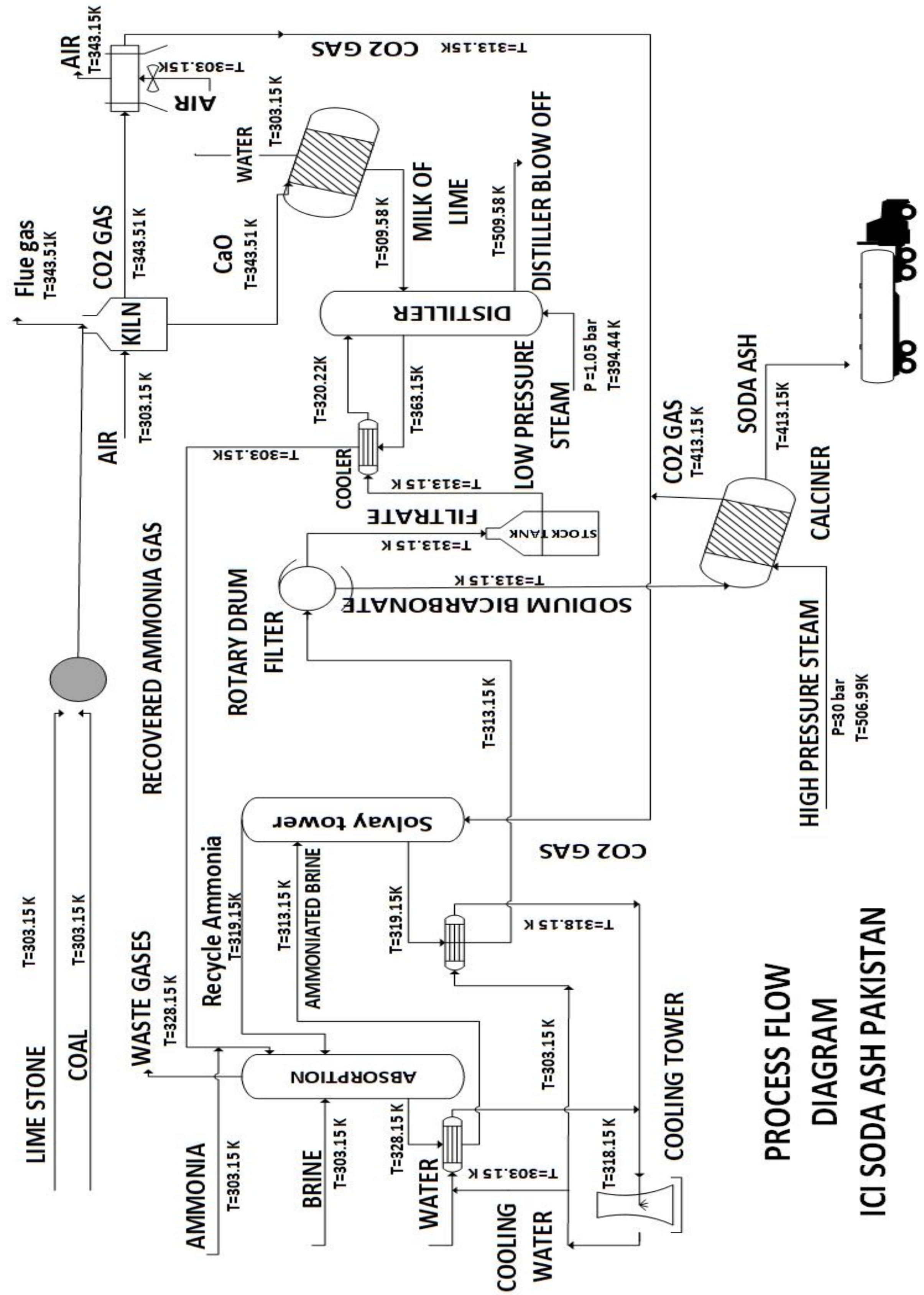


Figure 3 Process Flow Diagram

3.2 Material Balance and Energy Balance

Material balance is applied on the whole plant to calculate the water flow rate entering the tower.

3.2.1 Feed Specification

The production of ICI Soda Ash plant is 1000 ton per day since the efficiency we are considering is 90% therefore the production is 900 ton per day or 8490.56 kmol. For the production of 900 ton per day the amount of feed required is shown in following table

Brine solution	30%
Sodium chloride	18,868 kmol
Water	204,400 kmol
Ammonia	86,570 kmol
Coal	467,477 kmol
Oxygen	31,165 kmol

Table 1: Feed specification

3.2.2 Absorption Tower

The brine and ammonia are introduced in absorption tower in counter flow direction at 30℃ temperature where ammonia get absorbed in water to form ammoniated brine. The absorption is exothermic and cooling tubes are used inside the absorption tower to maintain the temperature. The amount of ammonia absorbed in water depend on the temperature of water lower the temperature more the ammonia will absorb in water. The relationship between ammonia absorption and water temperature is shown in the figure below

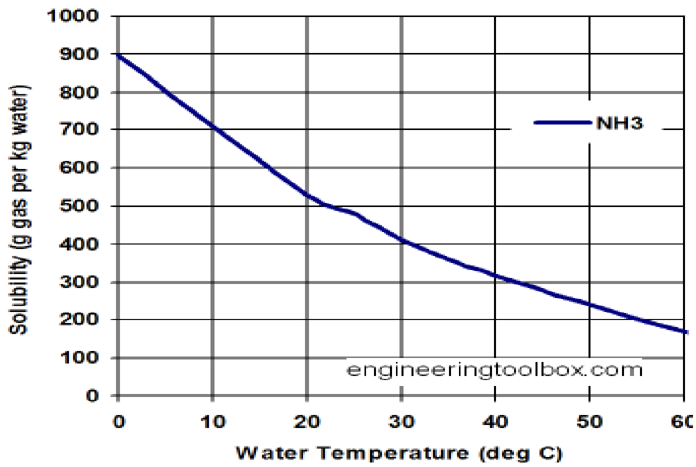


Figure 4 Ammonia Absorption

The general equation of material balance is:

$$Inflow - Outflow + Generation - Consumption = Accumulation$$

The feed entering the absorption tower are:

Sodium chloride = 18,868 kmol

Ammonia = 204,400 kmol

Water = 86,570 kmol

Since we are considering 90% efficiency the amount of ammonia remain unabsorbed is 10 of the total amount entering.

The outlet stream from absorption tower consist of

Ammonia hydroxide = 77,913 kmol

Water = 126,487 kmol

Sodium chloride = 18,868 kmol

Ammonia (unreacted) = 8,657 kmol

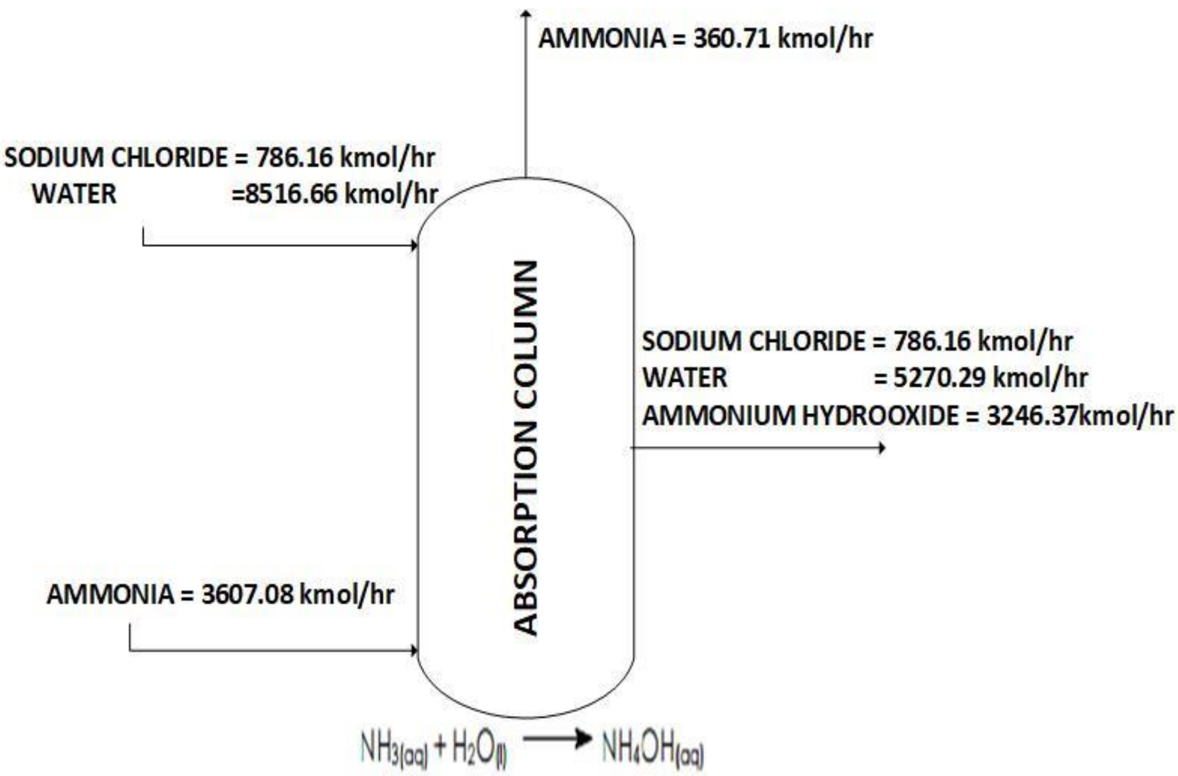


Figure 5 Absorption Tower Material Balance

Overall energy balance is

$$Energy\ in + Generated = Energy\ out$$

The energy entering and leaving the absorption tower is calculated by the formula

$$Energy = mCp\Delta T$$

Since we know the mass flow rate of inlet and outlet stream we calculated the amount of energy in and amount of energy out from there we calculate the heat generated during the absorption.

Energy in = 408.40*10^4 kJ/hr

Energy out = 1906.14*10^4 kJ/hr

Energy generated = 1497.73*10^4 kJ/hr

The amount of heat generated is absorbed by water in cooling tubes to maintain the optimal conditions. Therefore, the flow rate of water inside the tube is calculated by using formula

$$Energy = mCp\Delta T$$

Flow rate of water = 8376.26 kmol/hr

3.2.3 Kiln

In kiln calcium carbonate is decomposed into carbon dioxide and calcium oxide by heating at high temperature. The amount of heat required is generated by burning coal in the presence of air. The carbon dioxide produce from kiln is entered in air cooler to reduce its temperature to 30 °C. The coal entering the kiln have following composition

Carbon = 80%

Ash = 17%

Moisture = 1%

Volatile matter = 2%

The feed entering the kiln is

Carbon = 31,165 kmol

Calcium carbonate = 46,749 kmol

Oxygen = 31,165 kmol

Nitrogen = 117,240 kmol

The outlet stream of kiln contains

Carbon dioxide = 77,914 kmol

Calcium oxide = 46,749 kmol

Nitrogen = 117,240 kmol

The amount of ash and flue gas produce in kiln by burning of coal is

Ash =79,471 kg

Flue gas = 14,024 kg

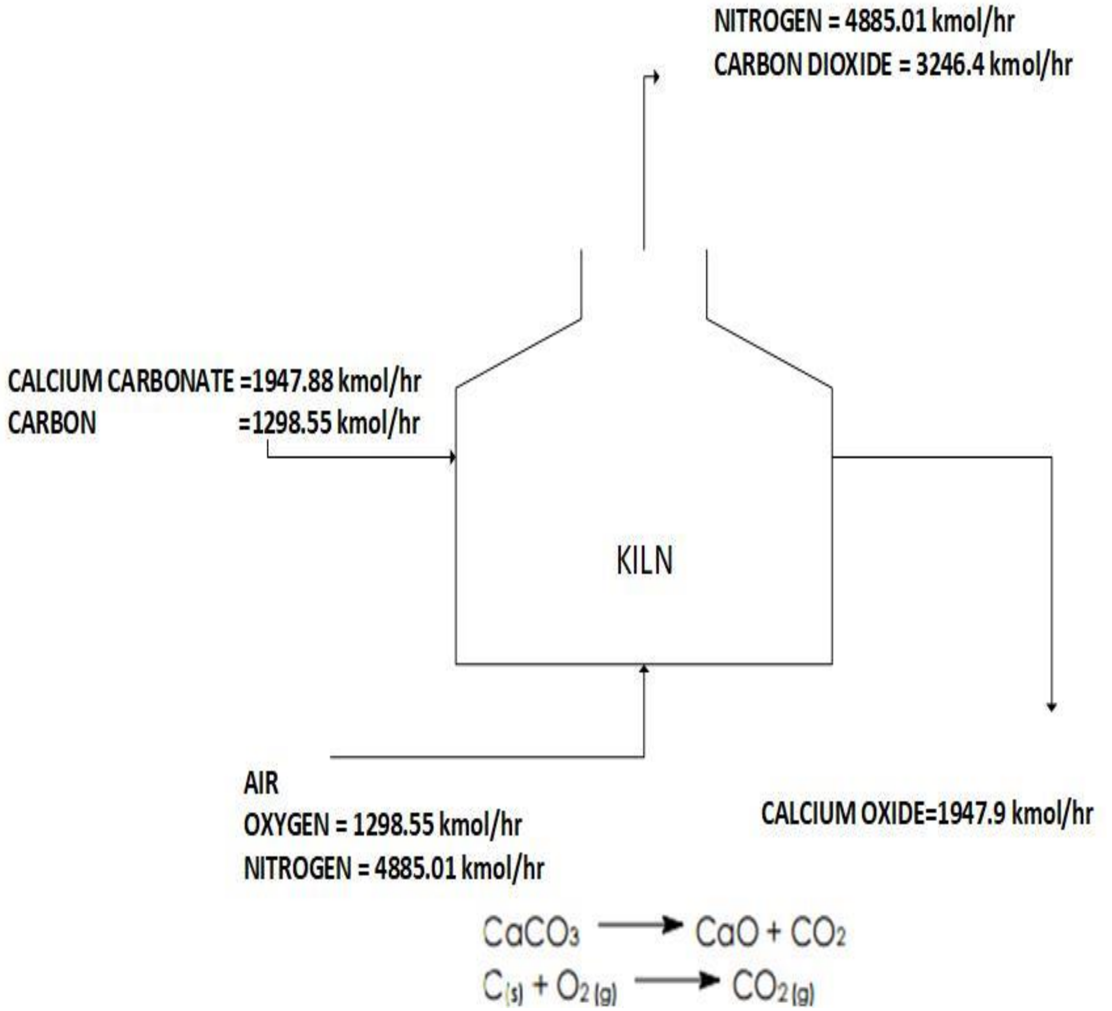


Figure 6 Material Balance Kiln

Now for the energy balance the amount of energy that is entering in the kiln is calculated by

$$Energy = mCp\Delta T$$

Energy in = 172.24*10^4 kJ/hr

The amount of energy generated by burning coal is calculated by the product of mass of coal and its calorific value

Calorific value of coal = 6500kcal/kg

Heat generated = 52972.9*10^4 kJ/hr

The amount of heat absorbed by calcium carbonate is calculated by dissociation heat of calcium carbonate.

Dissociation heat of calcium carbonate = 182 kJ/mol

Heat absorbed = 35451.32*10^4 kJ/hr

Net heat generated by the kiln is the difference between heat generated by combustion and heat absorbed.

Total heat generated = 17521.6*10^4 kJ/hr

The outlet enthalpy is calculated and from there we calculated the temperature of outlet stream

Energy out =17627.6*10^4 kJ/hr

Outlet stream temperature = 70℃

The amount of heat consumed by moisture in coal to convert into vapors is

Heat consumed = 66.2*10^4 kJ/hr

The carbon dioxide produce is cooled by air cooler to 30 °C and introduce in Solvay tower.

The flow rate of air in air cooler is 774.46 kmol/hr

3.2.4 Solvay Tower

The ammoniated brine and carbon dioxide are introduced in Solvay tower in counter flow direction the carbon dioxide react with ammoniated brine to produce ammonia bicarbonate and sodium bicarbonate. The reaction is highly exothermic and cooling tubes are used inside Solvay tower to maintain the optimal condition, water circulate inside cooling tube which absorbed heat. The amount of carbon dioxide that remain unreacted is 10% of total carbon dioxide entering.

The composition of entering stream is

Ammonia hydroxide = 77,913 kmol

Water = 126,487 kmol

Sodium chloride = 18,868 kmol

Carbon dioxide = 77,914 kmol

Since we are considering 90% efficiency the output stream contains

Ammonia bicarbonate = 51,253.7 kmol

Water = 134,278.3 kmol

Sodium bicarbonate = 18,868 kmol

Carbon dioxide = 7791.4 kmol

Ammonia = 7791.4 kmol

Ammonia chloride =18,868 kmol

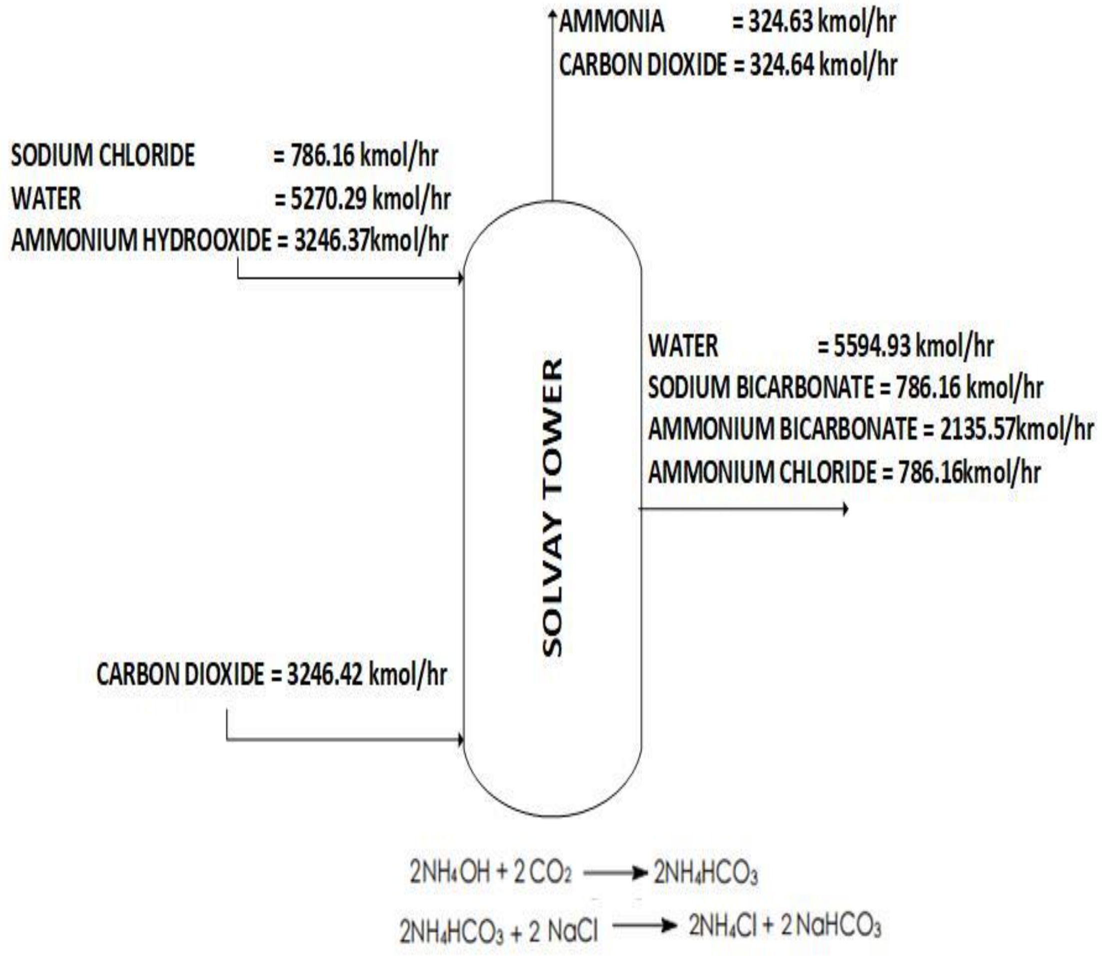


Figure 7 Material balance Solvay Tower

Overall energy balance is

$$Energy\ in + Generated = Energy\ out$$

The energy entering and leaving the Solvay tower is calculated by the formula

$$Energy = mCp\Delta T$$

The amount of heat generated is calculated by the difference between energy in and energy out.

Energy in = 1121.24*10^4 kJ/hr

Energy out = 2770.26*10^4 kJ/hr

Energy generated = 1.64*10^4 kJ/hr

The amount of heat generated is absorbed by water in cooling tubes to maintain the optimal conditions. Therefore, the flow rate of water inside the tube is calculated by using formula

$$Energy = mCp\Delta T$$

Flow rate of water = 8456.9 kmol/hr

3.2.5 Rotary Drum Filter

The sodium bicarbonate that is produce in Solvay tower is separated from the stream by rotary drum filter around 90% of sodium bicarbonate is separated as filtrate.

The inlet stream is

Ammonia bicarbonate = 51,253.7 kmol

Water = 134,278.3 kmol

Sodium bicarbonate = 18,868 kmol

Ammonia chloride =18,868 kmol

Filtrate composition:

Water = 2685.5 kmol

Sodium bicarbonate = 16,981.2 kmol

Residue composition:

Ammonia bicarbonate = 51,253.7 kmol

Water = 131,592.7 kmol

Sodium bicarbonate = 1886.8 kmol

Ammonia chloride =18,868 kmol

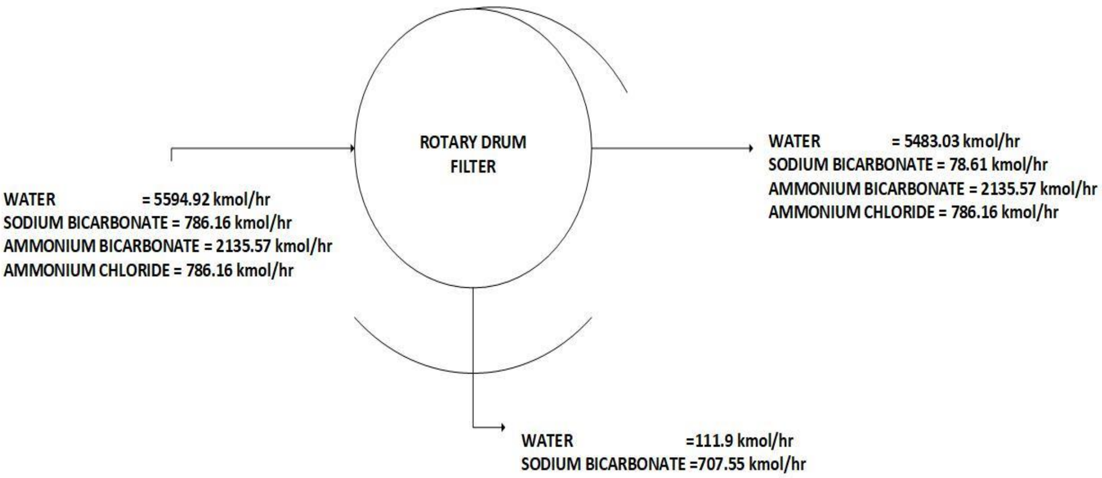


Figure 8 Material Balance Rotary Drum Filter

3.2.6 Lime Slaker

The calcium oxide that is produce in kiln is introduce in lime slaker where it reacts with water to form calcium hydroxide. Since we are considering 90% efficiency the amount of calcium hydroxide produce is 42,074 kmol.

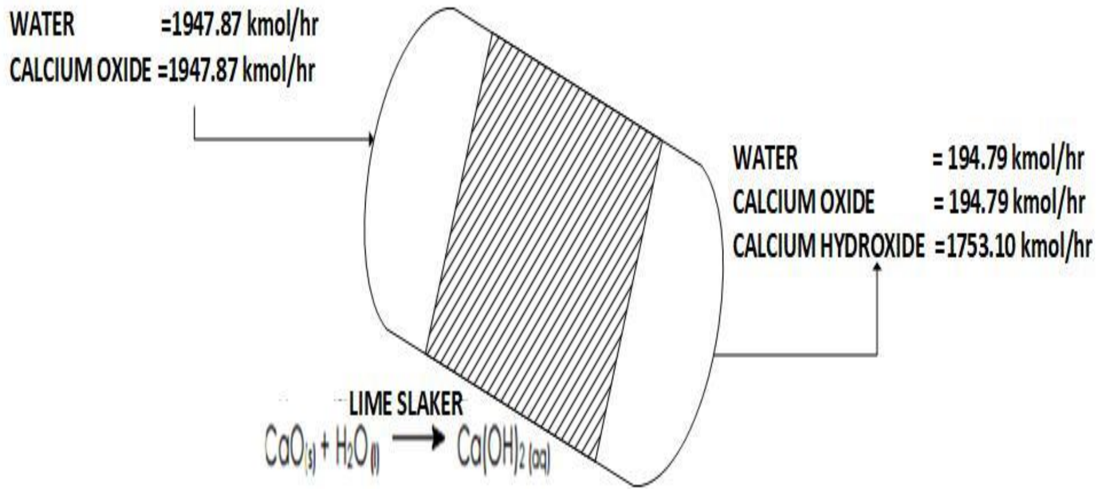


Figure 9 Material Balance Lime Slaker

The reaction involve in production of calcium hydroxide is exothermic and the temperature of outlet stream is increased.

Energy in = 108.16*10^4 kJ/hr

Energy out = 1040.67*10^4 kJ/hr

Energy generated = 59.86*10^4 kJ/hr

Energy consume = 58930.9*10^4 kJ/hr

So, from there we calculate the temperature of outlet stream that is **236.4** °C.

3.2.7 Distiller

The calcium hydroxide that is produce form lime slaker is enter in distiller where it reacts with the ammonia chloride in residue to produce ammonia which is recycle back to absorption tower and calcium chloride which is the side product. The ammonia produce is at high temperature therefore it exchanges it heat in the cooler with the coming feed. Low pressure steam is also introduced in the distiller to enhance the production of ammonia.

The efficiency of distiller is 90% therefore 10% of calcium hydroxide remain un reacted

Inlet stream composition.

Ammonia bicarbonate = 51,253.7kmol

Water = 136,267.6 kmol

Sodium bicarbonate = 1886.8 kmol

Ammonia chloride =18,868 kmol

Calcium hydroxide = 42,074 kmol

Calcium oxide = 4674.9 kmol

The outlet stream composition

Ammonia = 63,110 kmol

Carbon dioxide = 46,128 kmol

Calcium chloride = 8490.6 kmol

Ammonia bicarbonate = 5125.4kmol

Water = 199,377 kmol

Sodium bicarbonate = 1886.8 kmol

Ammonia chloride =1886.8 kmol

Calcium hydroxide = 33,584 kmol

Calcium oxide = 4674.9 kmol

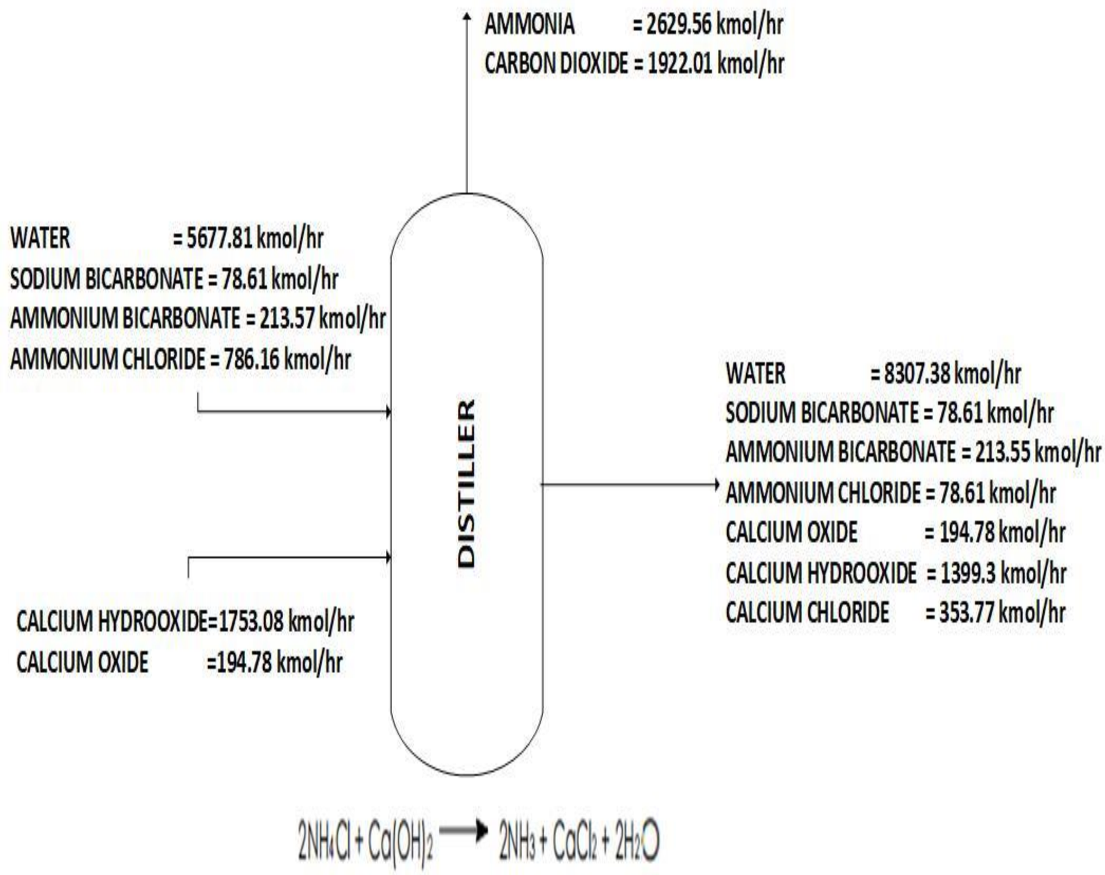


Figure 10 Material Balance Distiller

The energy entering and leaving the distiller is calculated by the formula

$$Energy = mCp\Delta T$$

The amount of heat supplied by LPS is calculated by following formula

$$Energy\ supplied\ = (Energy\ in + Energy\ Absorbed) - Energy\ out$$

Energy in = 534.3*10^4 kJ/hr

Energy out = 4041.1*10^4 kJ/hr

Energy absorbed = 12,206.8*10^4 kJ/hr

The amount of heat supplied by LPS is

Heat supplied = 11,722.9*10^4 kJ/hr

So, we calculate the flow rate of LPS that is 109.4 kmol/hr.

Ammonia produce is at high temperature it exchanges it heat with the residue of rotary drum filter inside a cooler. The temperature of ammonia is decreases to 47 °C.

3.2.8 Calciner

The filtrate from rotary drum filter is enter in calciner where high pressure steam is introduced to decompose sodium bicarbonate into sodium carbonate.

The efficiency of calcine is 90% therefore 10% remain unconverted

Inlet stream composition

Water = 2685.5 kmol

Sodium bicarbonate = 16,981.2 kmol

Outlet composition

Water = 11,176 kmol

Sodium bicarbonate = 8490.6 kmol

Carbon dioxide = 8490.6 kmol

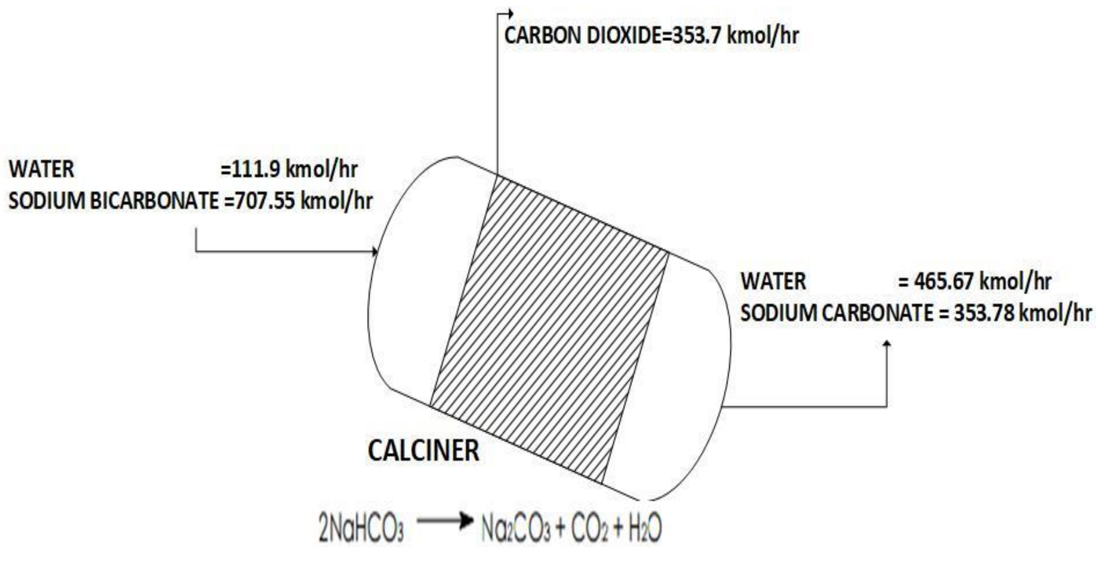


Figure 11 Material Balance Calciner

The amount of heat supplied by LPS is calculated by following formula

$$Energy\ supplied\ = (Energy\ in + Energy\ Absorbed) - Energy\ out$$

Energy in = 108.16*10^4 kJ/hr

Energy out = 1040.6*10^4 kJ/hr

Energy absorbed = 58,930.9*10^4 kJ/hr

The amount of heat supplied by LPS is

Heat supplied = 5986.3*10^4 kJ/hr

So, we calculate the flow rate of HPS that is 82.25 kmol/hr.

Components	Absorption column		Kiln		Solvay Tower		Rotary Drum Filter			Lime Slaker		Distiller		Calciner	
	IN(kmol)	OUT(kmol)	IN(kmol)	OUT(kmol)	IN(kmol)	OUT(kmol)	IN(kmol)	Residue (kmol)	Permeate (kmol)	IN(kmol)	OUT(kmol)	IN(kmol)	OUT(kmol)	In(kmol)	OUT(kmol)
Nacl	18868	18868			18868										
H20	204400	126487			126487	134278.3	134278.3	131592.73	2685.56	46749	4674.9	136267.63	199377.16	2685.56	11176.16
NH3	86570	8657				7791.3							63109.53		
NH4OH		77913			77913										
CO2				77914.13	77914.13	7791.41							46128.33		8490.6
CaCO3			46749												
Carbon			31165.13												
O2			31165.13												
N2			117240.26	117240.26											
CaO				46749						46749	4674.9	4674.9	4674.9		
NaHCO3						18868	18868	1886.8	16981.2			1886.8	1886.8	16981.2	
NH4HCO3						51253.7	51253.7	51253.7				51253.7	5125.37		
NH4Cl						18868	18868	18868				18868	1886.8		
Ca(OH)2											42074.1	42074.1	33583.5		
CaCl2													8490.6		
Na2CO3															8490.6

Table 2: Overall Material Balance Summary

Unit	Energy In (KJ/hr) (10^4)	Heat Generated/(KJ/hr) (10^4)	Heat Consumed(KJ/hr) (10^4)	Energy Out (KJ/hr) (10^4)
Absorption Column	408.40	1497.73	0	1906.14
Kiln	172.24	17.52	66.22	17627.63
Solvay Tower	1121.24	1.64	0	2770.26
Lime Slaker	108.16	59.86	58930.97	1040.67
Distiller	534.34	11.42	7918.11	4041.10
Calciner	7654.96	11.72	12206.80	7171.11

Heat Transfer Equipment	Flowrates (kmol/hr)	Energy lost by hot fluid (KJ/hr) (10^4)	Energy gained by cold fluid (KJ/hr) (10^4)
Cooling tubes for Absorption Tower	8376.26	956.15	956.15
Cooling tubes for Solvay Tower	8456.90	965.35	965.35
Air Cooler	774.46	396.23	396.238
Cooler	4551.60	1070.16	1070.16

Table 3: Overall Energy Balance Summary

Chapter-4

Cooling Tower Design Calculations

The hot water flowrate and temperature is found by applying material and energy balance across Soda ash plant. The amount of water that is treated by cooling tower is 8456.9 kmol/hr and the temperature of the inlet hot water is 45 °C.

The problem we have to solve is to enhance the efficiency of cooling tower because ICI is increasing its production to 500,000 ton per year as more heat will be absorbed by cooling tubes used in absorption and Solvay tower. Therefore, enhancing the efficiency of cooling means more heat is absorbed by cooling water in cooling tubes which will keep the optimum conditions inside the tower and keeps the production process economical.

Methods for enhancing the efficiency of cooling tower

- Splashing of water droplet on air
- Improve the water quality
- Heat integration of hot water with in the plant

4.1 Splashing of water droplet on air

The temperature of incoming air is decreased by splashing fine droplet of water on incoming air. The fine droplet of water is generated by atomizer and air is pass through it sit ha when air is forced through the fan these fine droplets evaporates and the temperature of air decreases. The decreased in air temperature means more heat is absorbed by air which increases the efficiency

4.2 Improve water quality

The quality of water that is treated in cooling tower effect its efficiency. The water with more slats content will exchange less heat as compare to the water with less salt content. The more the salt more will be the scaling inside the tower and more will be the blowdown losses hence the amount of makeup water increases. Fouling due to presence of dirt, sand etc. corrosion to the steel part and microbiological growth due to presence of microorganism present in water. By improving the quality all these losses are reduce and efficiency of cooling tower increases.

4.3 Heat integration with in plant

The hot water that is entering to the cooling tower exchanges heat with some other stream inside the plant so that low temperature stream is cooled inside cooling tower this process also increases the efficiency of cooling tower.

4.4 Design calculations

In designing of a cooling tower, we have to calculate the

- Tower cross-section required to take the given load of warm water
- Height of packing require to achieve desire cooling

To calculate the tower cross section and height we have to apply the material and energy balance around the cooling tower

4.4.1 Material balance around cooling tower

The material balance around cooling tower helps in calculating the evaporation losses, blowdown losses and drift losses. The sum of these losses gives the makeup water required.

Flow rate of water = 152,226 kg/hr

Since we are considering no leakage therefore

$$\text{losses} = \text{Evaporation} + \text{Blowdown} + \text{Drift}$$

The evaporation losses are calculated from following formula

$$\text{Evaporation losses} = \left(\text{Correction factor} * \left(\frac{\text{Range}}{5.56}\right) * 1\%\right) * \text{inlet flow}$$

Correction factor = 0.85

Evaporation losses = 3491 kg/hr

The calculation of blow down losses depend on the solids balance present in water therefor

$$\text{Blowdown losses} = \frac{\text{Evaporation losses}}{\text{COC} - 1}$$

The COC is cycle of concentration and it is calculated by applying chloride balance on entering and leaving water from cooling tower.

COC = 4

Blowdown losses = 1162.8 kg/hr

Drift losses is usually 0.5% of the total flow of water from cooling tower

$$\text{Drift losses} = 0.5\% * \text{inlet flow}$$

Drift losses = 7.6 kg/hr

Therefore, the amount of makeup water required after every hour is

Makeup = 4660.60 kg/hr

4.4.2 Energy balance around cooling tower

The energy balance around cooling tower is complex because of simultaneously heat and mass transfer and due to this some assumption are made before applying energy balance.

- The rate of vaporization of water is less than the rate of water input to the tower i.e. 1% of the total input flow rate.
- Adiabatic and evaporative cooling of water occur in tower.

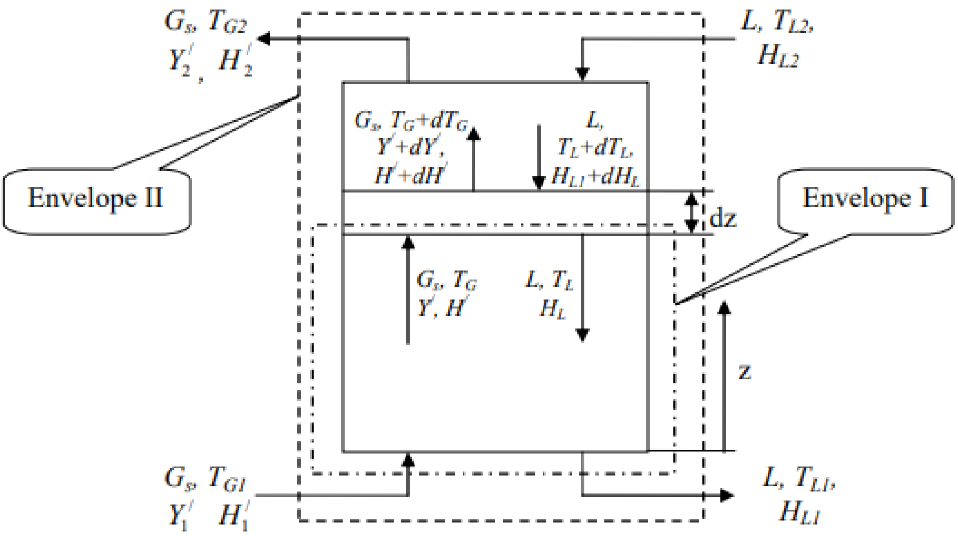


Figure 12 Enthalpy balance diagram of water cooling tower

Let L is the water flow rate and Gs is the air flow rate both in kg/m^2*sec across the differential thickness dZ the temperature of water is decreases by dT_1 and enthalpy of air is increased by dH`.

Hence the change in enthalpy of water is

$$L * Cwl * dTl$$

And change in enthalpy of air is

$$Gs * dH`$$

Enthalpy balance over differential area dZ is

Over envelop 1

$$L * Cwl * (Tl - Tl1) = Gs * (H` - H1`)$$

Enthalpy balance over whole tower

Envelop 2

$$L * Cwl * (Tl2 - Tl1) = Gs * (H2` - H1`)$$

The equilibrium curve of air water system is the plot of enthalpy od saturated air versus liquid temperature at equilibrium.

Rate of transfer of water vapor to air over differential volume is

$$Gs * dY` = k\gamma` * a * (Yi` - Y`)$$

The decrease in the temperature of air for sensible heat transfer to water is

$$-Gs * c_H * dT_G = h_G * a * dZ * (T_G - T_i)$$

Differential of equation will give

$$Gs * dH` = k\gamma` * a * dZ * (Hi` - H`)$$

The packing height (Z) of cooling tower is obtain by rearranging the above equation

$$\int_{H1`}^{H2`} dH`/(Hi` - H`) = k\gamma` \frac{a}{Gs} * Z$$

Number of transfer unit is

$$N_{tG} = \int_{H1`}^{H2`} dH`/(Hi` - H`)$$

Height of transfer unit is

$$H_{tG} = \frac{Gs}{(k\gamma * a)}$$

Hence the height of cooling tower packing section is the product of number of transfer unit and height of transfer unit.

There is not direct relationship between Hi` and enthalpy of bulk gas H` therefore the integral cannot be solved analytically.

Let hl*a is the volumetric heat transfer coefficient on the water side.

$$\frac{(Hi` - H`)}{Tli - Tl} = -\frac{hl}{k\gamma`}$$

Substituting

$$Gs * dH` = L * Cwl * dTl$$

And rearranging

$$\int_{Tli}^{Tlo} dTl/(Hi` - H`) = k\gamma` \frac{a}{L * Cwl} * Z$$

This equation is called Markel Equation.

4.2.3 Thermodynamic of Air

The thermodynamic properties of air are found by the help of psychometric chart. Psychometric chart is a graphical representation of property of air which includes physical and thermodynamic properties such as dry bulb temperature, wet bulb temperature, humidity, enthalpy and air density.

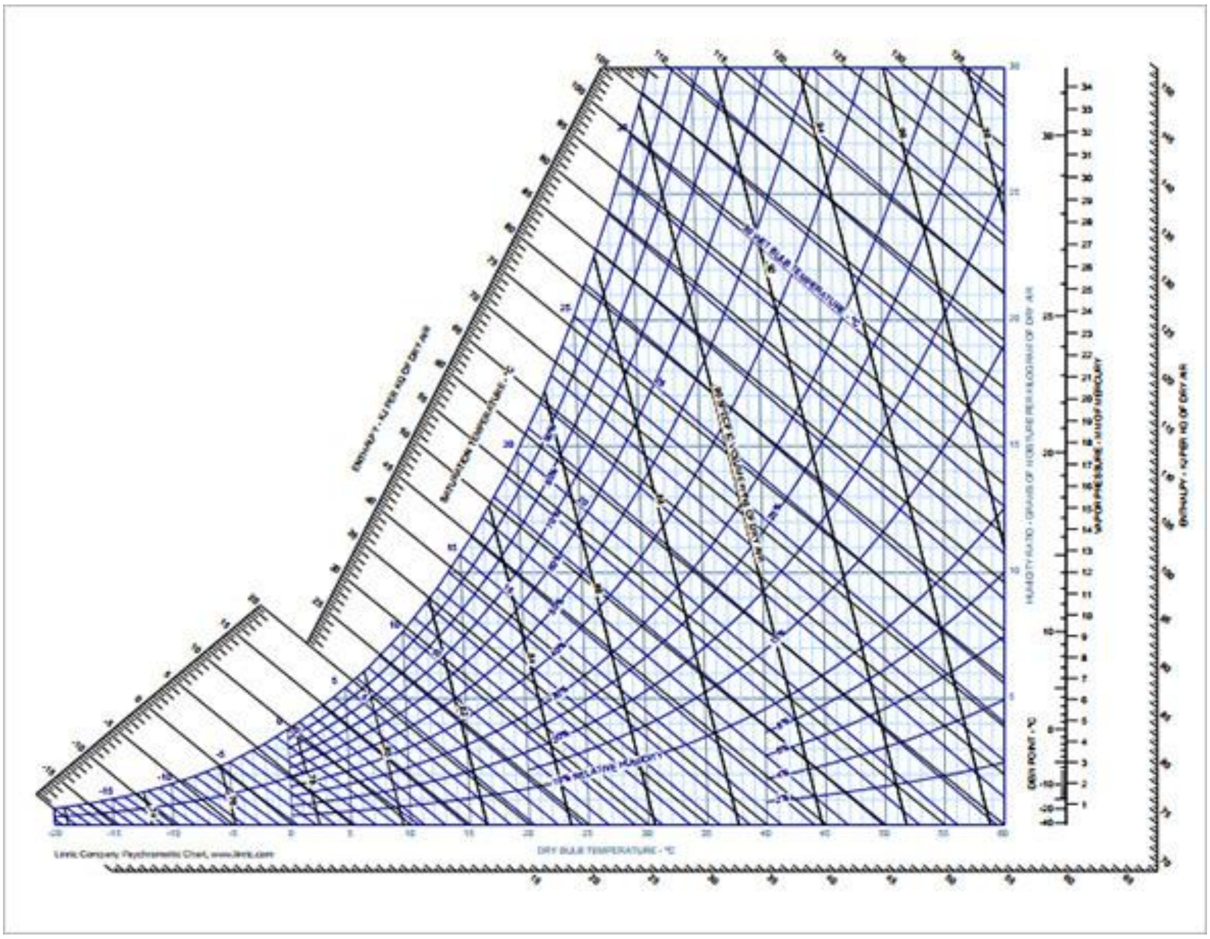


Figure 13 Psychometric Chart

4.2.4 Energy balance calculations

Merkel equation is used to calculate the tower characteristic

$$\int_{\mathrm{Tli}}^{\mathrm{Tlo}} \mathrm{dTl}/(\mathrm{Hi`} - \mathrm{H`}) \; = \mathrm{k\gamma`}\frac{\mathrm{a}}{\mathrm{L} * \mathrm{Cwl}} * \mathrm{Z}$$

The tower characteristic is normally determined used the Chebyshev rule

$$kaV/L \; = ((Ti - To)/4) * (1/\Delta h1) + (1/\Delta h2) + (1/\Delta h3) + (1/\Delta h4))$$

$$\Delta h1 = value\ of\ hw - ha\ \ at\ (T2 + 0.1(T2 - T1))$$

$$\Delta h2 = value\ of\ hw - ha\ \ at\ (T2 + 0.4(T2 - T1))$$

$$\Delta h3 = value\ of\ hw - ha\ \ at\ (T1 - 0.4(T2 - T1))$$

$$\Delta h4 = value\ of\ hw - ha\ \ at\ (T1 - 0.1(T2 - T1))$$

T_i = 45 °C

To = 30 °C

Δh1

T = 31.5 °C

h_w = 135.02 kJ/kg

h_a = 104 kJ/kg

Δh1 = 31.02 kJ/kg

Δh2

T = 36 °C

h_w = 150.82 kJ/kg

h_a = 113 kJ/kg

Δh2 = 37.82 kJ/kg

Δh3

T = 39 °C

h_w = 163.36 kJ/kg

h_a = 117 kJ/kg

Δh3 = 46.36 kJ/kg

Δh4

T = 43.5 °C

h_w = 180.07 kJ/kg

h_a = 122 kJ/kg

Δh3 = 58.07 kJ/kg

$$\frac{kVa}{L} = 0.365$$

Height of transfer unit = 17.99 ft

Height of packing = 6.57 ft

Range of cooling tower is the difference between hot water temperature and cold-water temperature of cooling tower.

Hot water temperature = 45 °C

Cold water temperature = 30 °C

Range of cooling tower = 15 °C

The approach of cooling tower is the difference between cold water temperature and wet bulb temperature of air

Wet bulb temperature = 18.52 °C

Approach = 11.5 °C

The heat lost by water is equal to the heat gain by air

Heat lost by water = $m * Cp * \Delta T$

m = 152,226 kg/hr

Cp water = 4.18 kJ/kg

ΔT = 15 °C

Heat lost = 954.45 kJ/hr

This amount of heat is absorbed by air and from there we can calculate the mass of air required

Inlet wet bulb temperature of air = 18.52 °C

Enthalpy of air at inlet temperature = 72.11 kJ/kg

Outlet wet bulb temperature of air = 30 °C

Enthalpy of air at outlet temperature = 118.62 kJ/kg

Specific volume of air at inlet temperature = 0.845 m^3/kg

Mass of air required = 205,215.4 kg/hr

4.2.5 Cooling tower design calculation

Cooling tower design calculation are used to calculate the ground area, tower height, air loading, length of water distribution pipes etc.

Ground area of cooling tower is calculated by the ratio of water flow rate to water loading

$$\text{Ground area} = \text{ water flowrate/water loading}$$

Water loading = 2000 kg/hr*ft^2

Water flow rate = 152,226 kg/hr

Ground area = 76.11 ft^2

Air loading is the flow of air on the specific area. Air loading is very important for the transfer of heat the more the air loading the more will be the transfer of heat. Air loading depend on the fan capacity, tower area and density of air and water.

$$\text{Air Loading} = (\text{Fan capacity/Tower area }) * \text{density (air} + \text{water)}$$

Fan capacity = 1000m^3/hr

Density of (water + air) = 1001.25 kg/m^3

Air loading = 13,154.78 kg/hr*ft^2

Velocity of water is calculated by the ratio of volume of water to the area of pipe

Volume of water = 152.226 m^3/hr

Diameter of pipe = 0.3 m

Area of pipe = 0.07m^2

Velocity of water = 0.6 m/sec

Length of the pipe required for the water distribution in cooling tower is calculated by the following formula

Q= $2 * 3.14 * K * L * (T2 - T1)/\log(d0/di)$

The material used for piping is stainless steel

K = 40 w/m-°C

d_o = 0.302 m

d_i = 0.300 m

Log (d_o /d_i) = 0.002

Length of pipe = 7.3 m

Number of turns required depend upon the distance between 2 pipes

Pitch = 0.4 m

Height of tower = 2 m

Number of turns = 5

The efficiency of cooling tower is calculated by following formula

$$\text{Efficiency} = \frac{Range}{\text{Range} + \text{Approch}}$$

Hence the efficiency is **56%**

Chapter-5

Cost Analysis

5.1 Direct Cost

Direct cost is the cost that is directly attributed to the production of specific goods or services. This includes equipment cost, piping cost, instrumentation cost, construction cost etc.

Equipment cost:

1. Cost of Sensor = $70
2. Cost of control valves = 2*$50=$100
3. Cost of metering pump = $300
4. Check valve Cost = $60
5. Fan Cost = 300$

Total Equipment Cost = $830

Instrumentation Cost = $200

Piping Cost = $180

Electrical cost = $140

Total direct cost = $1350

5.2 Operating Cost

Operating cost are the expense which are related to the operation of the equipment. These are the cost paid by industries to operate and run the equipment operations.

Volume of fill is the product of area of tower and height of packing

Volume of fill = 48.72 m^3

Cost of PVC per unit volume = $18

The cost of fills is = $877

The volume of the concrete in the tower shell can be calculated by the product of tower area and total height of tower.

Volume of concrete = 92.4 m^3

Cost of concrete per unit volume = $90

Cost of concrete used is $8316.

The cost of pump is calculated by the graph which show the relationship between pump capacity and cost

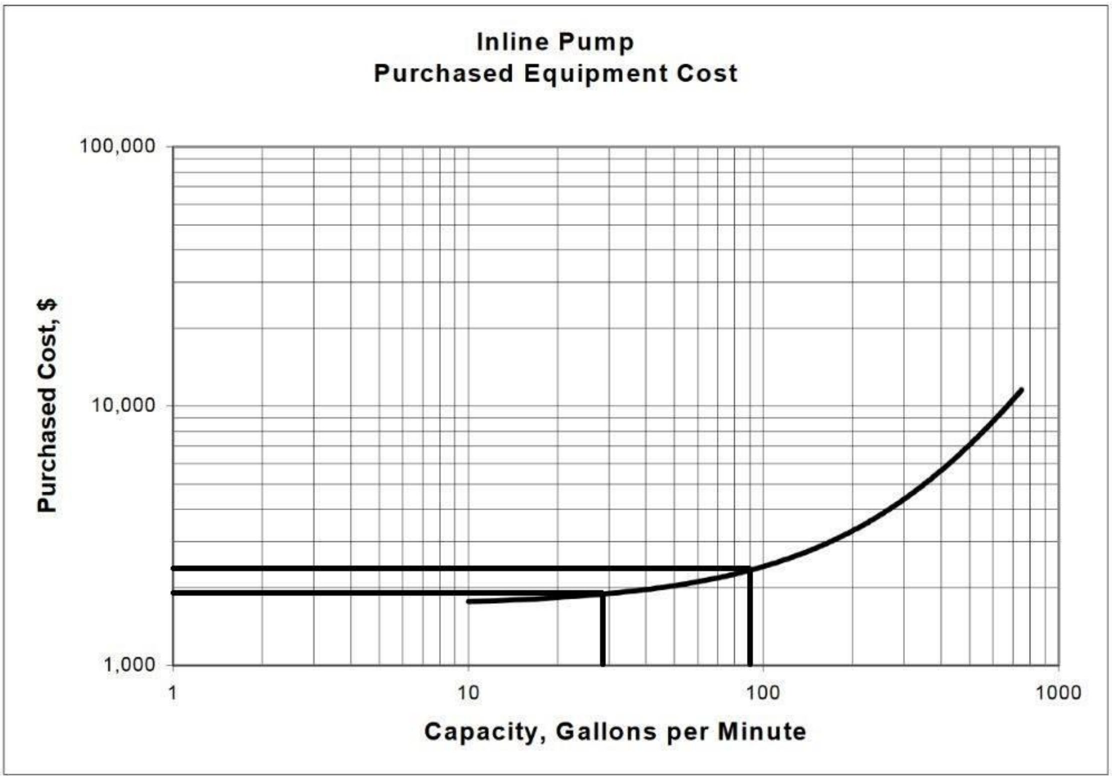


Figure 14 Pump Cost

Pump capacity = 670 gpm

Pump cost = $9000

Total operating cost = $18,193.

5.3 Indirect Cost

Indirect cost is cost that are either fixed or variable cost. Indirect cost includes administration, personnel and security costs.

Engineering design and supervision cost: $400

Contractor fee = $200

Construction expenses = $200

Total indirect cost = $800

Total Capital Cost = Direct + Indirect = 1350+800 = $2150

Total cost is the sum of total capital cost and operating cost

Total cost = $20,343

The payback period is calculated by the total amount of saving per year

Cost of washing = $250

Since we are reducing the number of washing from 40 to 23 the amount of saving is calculated as

Cost of saving = $4250

Payback Period = $\frac{Total\ cost}{Total\ Saving}$

Payback Period = 4.7 years

Chapter-6

HAZOP Analysis

The term "HAZOP Analysis" stands for hazard and operability analysis. It is systematic and structured method of examining an already operating system or a system which is planned for operation in future. It is a qualitative analysis of the system which is done by a team of qualified experts to find the locations in system which have high risk potential towards equipment and labour. It is also used to avert the possible adverse effects to process efficiency, which may occur due to the risks at the certain locations. The study is qualitative and also identifies deviations which may potentially result in process inefficiencies. So, this is operability study not to be confused with "Hazard Analysis" which quantitatively measures the risk associated with the process.

Procedure:

Certain words are used in identification of steps used for carrying out the hazard and operability analysis (HAZOP). These words along with their brief definitions are given below:

Intention:

This defines how a particular part of the process was intended to operate i.e. the intention of the designer.

Deviations:

These are departures from the designer's intention. These deviations are detected by the systematic application of the guide words.

Causes:

Here possible reasons for the deviation are considered answers to the questions like how and why are determined. Only the deviation resulting from a realistic cause is treated as meaningful.

Consequences:

The results of a meaningful deviation (now meaningful can be large deviations for some processes and small for processing requiring critical control).

Hazards: Consequences that can potentially cause damage (loss) or injury.

Case 1

Intention: Keeping the cooling water inlet temperature at 45°C.

Deviation: The temperature rises to about 60°C.

Causes: The increase in the inlet temperature of cooling tower causes the decrease in the efficiency of cooling tower. The outlet temperature of water from cooling tower is much higher than before therefore less amount of heat is absorbed from absorption tower hence it decreases the absorption of ammonia in water which results in overall decrease in production of soda ash.

Hazard: This can potentially decrease the efficiency of cooling tower and absorption tower which can decrease the production of soda ash.

Case 2

Intention: Maintaining the air flow rate at 205,215.4 kg/hr

Deviation: Decrease in flow rate of air

Causes: The decrease in the flow rate of air causes less heat to remove from water hence the decrease in water temperature is not according to the process requirement therefore the efficiency of overall process decreases.

Consequences: The decrease in flow rate of air means that the fan is not working properly or its propeller are damage.

Case 3

Intention: Wet bulb temperature of air maintain at 18.5°C.

Deviation: The wet bulb temperature increases than the design/ operation requirements.

Causes: The increase in the wet bulb temperature of air means that air is already saturated with water vapours and the mass transfer of water vapour is minimum inside the cooling tower hence less transfer of heat.

Consequences: The increase in wet bulb temperature results decrease in efficiency of cooling tower.

Chapter-7

Recommendations

To enhance the efficiency of cooling tower we have recommended following changes:

7.1 Honey comb packing structure

To enhance the efficiency of cooling tower we have recommended to use the honey comb structure packing because of following reasons:

- They provide a maximum contact area for mass and heat transfer.
- Crossing of air and water streams is in close proximity.
- It creates a diffused turbulence which is conductive to evaporation, causing an efficient heat transfer.
- Light weight of packing
- Cheap

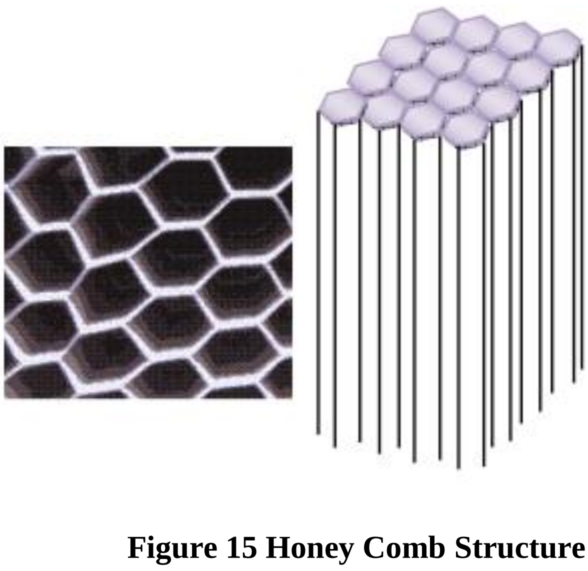


Figure 15 Honey Comb Structure

7.2 Splashing of fine water droplet on air

The air entering the tower passes through an atomizer where fine droplets of water is splashed on it. When air is forced through the fan these water droplets evaporates and the temperature of air decreases, hence it can absorbed more energy from hot water which results in the increased efficiency of cooling tower.

7.3 Heat integration of hot water

The hot water that is entering the cooling tower exchanges heat with some stream within the system, so that low temperature water stream enters the cooling tower, thereby increasing the efficiency.

Chapter-8

Conclusion

By discerning the hot water temperature and flowrate entering the cooling tower, the efficiency of cooling tower operating in ICI's Soda Ash plant at Kalar Kahar is calculated, which is 48%. Our proposed design of cooling tower have efficiency of 56% at wet bulb temperature of 18.5 °C. We proposed induced draft type cooling tower, considering the cost of project and thermodynamic properties of the region, the efficiency is increased to 56%. This design of cooling tower will maintain the optimum conditions inside the Absorption column and Solvay/Carbonating tower during the increase in overall production of Soda ash. Secondly, we proposed honey comb structured packing because, it will maximize contact time and contact area between water-air system, it is light weight and cheap both in terms of installation and maintenance.

Taking into account the concrete structure of tower, honey comb packing, PVC piping, and CIP of cooling tower, the total cost of cooling tower comes out to be $20,343.

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