

# Design of a sulfuric acid production plant engineering essay



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This project is prepared according to the requirements of chemical engineering department, and it's also a preliminary study of sulfuric acid production plant.

The project begins with chapter one which includes introduction, definition of sulfuric acid and shows the main uses of sulfuric acid which have made it an important chemical in the world, followed by chapter two which talks about literature, market survey and the history and current processes for production the sulfuric acid also it gives small glimpse of the prices trends of the raw material and product.

That is followed by description for various processes to produce sulfuric acid in chapter three, which ends with the selection of the best process which is the double contact process; the description and flow sheet of the selected process are discussed in chapter four.

Material and energy balance results are listed in chapter five and the location of the plant is selected in chapter six by comparing different locations, and the best location for the plant (as its set in this report) is Aqaba city. .

Finally, material and energy balance details are discussed in the appendix, that includes the used charts and references.

## CHAPTER ONE

### INTRODUCTION

#### 1. 1 Definition

Sulfuric acid is a strong mineral acid with the molecular formula  $H_2SO_4$ . It is a clear, colorless, odorless, viscous liquid that is very corrosive. It is soluble in water at all concentrations. Sulfuric acid has many applications, and is one of the top products of the chemical industry.

There are another names for sulfuric acid, it is sometimes called oil of vitriol.

1

Its chemical formula is

Figure (1. 1. 1): Sulfuric Acid Formula1

1. 2 Physical and Chemical properties

This table shows the main chemical and physical properties of sulfuric acid

## **Sulfuric acid**

### **IUPAC**

### **Oil of vitriol**

### **Other name**

### **H<sub>2</sub>O<sub>4</sub>S**

### **Molecular formula**

**98. 08 g mol<sup>-1</sup>**

### **Molar mass**

**Clear, colorless, odorless liquid**

### **Appearances**

**1. 84 g/cm<sup>3</sup>, liquid**

### **Density**

**10 °C, 283 K, 50 °F**

### **Melting point**

**337 °C, 610 K, 639 °F**

### **Boiling point**

### **Miscible**

### **Solubility in water**

**∞<sup>3</sup>**

### **Acidity(pka)**

**pungent odor**

### **Odor**

**Non-flammable****Flash point****26.7 cP (20 °C)****Viscosity****0.3****Ph**

Table (1. 2. 1): physical properties1

**1.3 Application and Uses**

Sulfuric acid is a very important chemical commodity, and indeed, a nation's sulfuric acid production is a good indicator of its industrial strength.

It is used as electrolyte in lead-acid batteries (accumulators) .

It is important in the production of fertilizers such as ammonium sulfate (sulfate of ammonia),  $(\text{NH}_4)_2\text{SO}_4$ , and superphosphate,  $\text{Ca}(\text{H}_2\text{PO}_4)_2$ , which is formed when rock phosphate is treated with sulfuric acid.

It is used to remove oxides from iron and steel before galvanising or electroplating .

Concentrated sulfuric acid is used as a dehydrating agent, that is, to remove water, since it has a tendency to form hydrates such as  $\text{H}_2\text{SO}_4 \cdot \text{H}_2\text{O}$ ,  $\text{H}_2\text{SO}_4 \cdot 2\text{H}_2\text{O}$ .

Sulfuric acid is used in the production of nitroglycerine, an inorganic ester & organic nitrate, which is used as an explosive.

It is used in petroleum refining to wash impurities out of gasoline and other refinery products.

It is used in manufacturing of hydrochloric acid, nitric acid, phosphoric acid, ether, plastics, metal sulfates, cellophane, dyes, drugs, perfumes, disinfectants and even glue. 1

This chart shows the distribution of using sulfuric acid

Figure (1. 3. 1): Sulfuric Acid Distribution. 1

Specification of raw materials

sulfur, S, 16

Name, symbol, number

32. 065g·mol<sup>-1</sup>

Standard atomic weight

Yellow colored lumps, crystals, powder, or formed shape

Appearances

Lumps 75-115 lbs./ft<sup>3</sup> Powder 33-80 lbs./ft<sup>3</sup>

Bulk Density

388. 36 K, 115. 21 °C, 239. 38 °F

Melting point

717. 8 K, 444. 6 °C, 832. 3 °F

Boiling point

Insoluble

Solubility In Water

Solid

Physical State

1. 819 g·cm<sup>3</sup>

Liquid density at maps.

Table (1. 3. 1): Physical & Chemical Properties of Sulfur. 1

## CHAPTER TWO

### LITERATURE AND

### MARKET SURVEY

#### 2. 1 History and Current processes

The discovery of sulfuric acid is credited to the 8th century chemist and alchemist, Jabir ibn Hayyan (Geber). The acid was later studied by 9th century Persian physician and alchemist Ibn Zakariya al-Razi (Rhazes), who obtained the substance by dry distillation of minerals including iron(II) sulfate heptahydrate,  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ , and copper(II) sulfate pentahydrate,  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ . When heated, these compounds decompose to iron(II) oxide

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and copper(II) oxide, respectively, giving off water and sulfur trioxide, which combine to produce a dilute solution of sulfuric acid. 1

This method was popularized in Europe through translations of Arabic and Persian treatises, as well as books by European alchemists, such as the 13th-century German Albertus Magnus. 1

There are two major processes (lead chamber and contact) for production of sulfuric acid and it is available commercially in a number of grades and concentrations. The lead chamber process, the older of the two processes, is used to produce much of the acid used to make fertilizers; it produces a relatively dilute acid (62%-78% H<sub>2</sub>SO<sub>4</sub>). The contact process produces a purer, more concentrated acid but requires purer raw materials and the use of expensive catalysts. In both processes sulfur dioxide is oxidized and dissolved in water. The sulfur dioxide is obtained by burning sulfur, by burning pyrites (iron sulfides), by roasting nonferrous sulfide ores preparatory to smelting, or by burning hydrogen sulfide gas. Some sulfuric acid is also made from ferrous sulfate waste solutions from pickling iron and steel and from waste acid sludge from oil refineries. 1

## 2. 2 Supply and Demand

This table shows the production rates of sulfuric acid (in metric tones) in some countries at different years.

Production of sulfuric acid in metric tones

Year



country

1994

1997

2000

2006

France

2227

2242

2269

1755

Germany

3380

3496

4898

4595

Greece

360

675

688

815

Italy

1228

1590

1043

1616

Spain

2348

2810

2418

3500

United kingdom

1225

1205

1058

447

Sweden

518

630

629

1010

Table (2. 2. 1): Production Rates of Sulfuric Acid. 3

This table shows the production and sales amounts of sulfuric acid and the consumption rate of sulfur in Jordan from 2000 to 2005, these amounts in (ton/year).

Sulfur consumption

(ton/year)

U]Sulfuric acid

Year

Sales

(ton/year)

Production

(ton/year)

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370925

43824

1108605

2000

309816

46614

919548

2001

351011

43307

1055208

2002

265865

51445

961208

2003

364301

49661

1102899

2004

346345

48323

1046540

2005

Table (2. 2. 2) Jordan Production, Sales and Raw Material Consumption. 5

### 2. 3 Prices trends of the raw material and product

The global sulfuric acid market experienced an unprecedented rise and fall in pricing between fall 2007 and spring 2009. Consumption of sulfuric acid for fertilizers fell steeply in the second half of 2008 due to the collapse in the global economy. The second half of 2009 is expected to experience almost flat to slightly positive growth, anticipating the improvement in market conditions in 2010. Trade is expected to fall globally, except for Southeast Asia, which would continue to depend on imports. As of early spring 2009, the market is continuing to deteriorate as the supply shortage situation has been replaced by product oversupply in almost all regions.

And the world sulfuric acid supply trends are shown in the following chart.

Figure (2. 3. 1): World Sulfuric Acid Supply. 2

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## CHAPTER THREE

### PROCESS SELECTION

#### Process Selection

Sulfuric acid is an important raw material used in many industrial processes, such as phosphate fertilizer production and to a much lesser extent for nitrogen and potassium fertilizers, sulfuric acid is produced by catalytic oxidation of sulfur dioxide to sulfur trioxide, which is subsequently absorbed in water to form sulfuric acid.

There are no major variations of commercial interests on this mentioned chemistry. There are alternatives as to source of Sulfur dioxide and method of conversion to sulfur trioxide. The two most common methods for the conversion of sulfur dioxide to sulfuric

acid are:

1. Lead Chamber Process.
2. Contact Process
3. 1 Lead Chamber Process

This is an old process and was introduced in Europe in near the middle of 18th century, it's used to produce much of the acid used to make fertilizers; it produces a- relatively dilute acid (62%-78% H<sub>2</sub>SO<sub>4</sub>). The classic lead chamber process consists of three stages: Glover tower, lead chambers and Guy-Lussac Tower.

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In this method hot sulfuric dioxide gas enters the bottom of the reactor called a Glover tower where it is washed with nitrous vitriol (sulfuric acid with nitric oxide, NO, and nitrogen dioxide, NO<sub>2</sub>, dissolved in it) and mixed with nitric oxide and nitrogen dioxide gases.

The Glover tower serves two functions: concentration of the chamber acid and stripping of nitrogen oxides from the liquid to the gas. Concentration of the chamber acid (62% to 68% H<sub>2</sub>SO<sub>4</sub>) is achieved by the hot gases entering the tower which evaporate water from the acid.

Some of the sulfur dioxide is oxidized to sulfur trioxide and dissolved in the acid wash to form tower acid or Glover acid (about 78% H<sub>2</sub>SO<sub>4</sub>). The dissolved nitrogen oxides are stripped from the acid and carried with the gas out of the Glover tower into the lead chambers.

From the acid tower a mixture of gases (including sulfur dioxide and trioxide, nitrogen oxides, nitrogen, oxygen, and steam) is transferred to a lead-lined chamber where it is reacted with more water.

Sulfuric acid is formed by a complex series of reactions; it condenses on the walls and collects on the floor of the chamber. There may be from three to twelve chambers in a series. The acid produced in the chambers, often called chamber acid or fertilizer acid, contains 62% to 68% H<sub>2</sub>SO<sub>4</sub>.

After the gases have passed through the chambers they are passed into a reactor called the Gay-Lussac tower where they are washed with cooled concentrated acid (from the acid tower); the nitrogen oxides and unreacted

sulfur dioxide dissolve in the acid to form the nitrous vitriol used in the acid tower. Remaining waste gases are usually discharged into the atmosphere.

Product acid at a concentration of 78% H<sub>2</sub>SO<sub>4</sub> is drawn from the cooled acid stream that is circulated from the Glover tower to the Guy-Lussac tower. Nitrogen losses are made up with nitric acid which is added to the Glover tower.

The major disadvantage includes the limitations in throughput, quality and concentration of the acid produced, also the environmental pollution.

Figure (3. 1. 1): Typical process flow sheet for the lead Chamber.

### 3. 2 Contact Process

Because of economic reasons Contact plants are widely used compared to the lead plants, they are classified according to the raw materials charged to them: elemental Sulfur burning, spent sulfuric acid and hydrogen sulfide burning, and metal sulfide ores and smelter gas burning. The contributions from these plants to the total acid production are 81, 8, and 11 percent, respectively.

The contact process incorporates three basic operations (stages), each of which corresponds to a distinct chemical reaction.

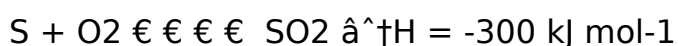
First, elemental sulfur is received in a solid form containing various impurities. The sulfur is melted in the sulfur melter in the presence of hydrated lime which neutralizes any acidity present in the sulfur. This



neutralization prevents problems of acid corrosion which would otherwise be encountered.

Heat for the melting of the sulfur is supplied from steam coils. The molten sulfur is kept agitated to improve heat transfer, to prevent solids settling on the bottom of the sulfur pits and to prevent a crust forming on top. The “dirty sulfur” is filtered to remove impurities present and after filtering is transferred to the “clean sulfur” pit where it is kept molten until it is pumped to the burner.

Molten sulfur at a temperature of 130°C is sprayed into the burner in the presence of warm, dry air. The sulfur burns, forming sulfur dioxide



The resulting sulfur dioxide is fed to a process unit called a converter, where it is catalytically oxidized to sulfur trioxide (SO<sub>3</sub>):



It's apparent that the equation gives a decrease in volume; this reaction would be aided by pressure. High conversions are however, obtainable with catalysts at 400 to 500°C with a small excess of oxygen and the use of pressure.

The available methods to maximize the formation of SO<sub>3</sub>:

As this is an exothermic process, a decrease in temperature by removal of the heat will favour the formation of SO<sub>3</sub>.

Increased oxygen concentration.

SO<sub>3</sub> removal (as in the case of the double absorption process).

Increased pressure.

Catalyst selection, to reduce the working temperature (equilibrium).

Longer reaction time.

In the contact processes, the sulfur dioxide is converted to sulfur trioxide by the use of metal oxide catalyst, the characteristics of the used catalyst are:

Porous carrier having large surface area, controlled pore size and resistance to process gases at high temperature; in pellet form if used in fixed bed and powdered form if used for fluidized bed. Ex- Alumina, silica gel, zeolites.

Active catalytic agent:

Preparations are generally kept secret for the competitive reasons but they usually

consist of adding water soluble compounds to gels or porous substrates and firing

at temperature below the sintering point.

Promoter:

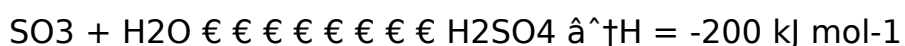
Alkali and/or metallic compounds added in trace amounts to enhance the activity

of the catalytic agent.

A catalyst, vanadium pentoxide (V<sub>2</sub>O<sub>5</sub>) is used to increase the reaction rate because it's relatively immune to poisons, also because of its low initial investment and only 5% replacement per year. It is only effective above its melting point of 400 °C. The greatest conversion of SO<sub>2</sub> to SO<sub>3</sub> is reached by passing the gas over several catalyst beds, cooling the gas between each pass so that the reaction temperature remains between 400 and 500 °C. As can be seen the figure.

The disadvantages of using the V<sub>2</sub>O<sub>5</sub> catalyst are that it must use dilute SO<sub>2</sub> input (7-10%), as a catalyst it is less active and requires high oxygen or sulfur dioxide to give economic conversions also it requires larger converters and thus higher initial investment.

Finally, the sulfur trioxide is absorbed in to very concentrated sulfuric acid (a 98-99 percent solution of H<sub>2</sub>SO<sub>4</sub> in water), This operation takes place in the absorbing tower where the gas travels up through the tower, counter-current to the acid falling from the top of the tower producing a thick fuming liquid called oleum, the oleum is mixed carefully with water to avoid producing fine mist of sulfuric acid that is difficult to condense and could escape to pollute the air, the sulfur trioxide in the oleum reacts with the water as follows:



It is clear that the reaction is exothermic and the absorbing sulfuric acid has to be cooled continuously; the heat is available at a relatively low temperature and is not worth recovering.

The efficiency of the absorption step is related to :

The H<sub>2</sub>SO<sub>4</sub> concentration of the absorbing liquid. (98.5 – 99.5%).

The temperature range of the liquid (normally 70 -120 °C).

The technique of the acid distribution.

The raw gas humidity (mist passes the absorption equipment).

The mist filter.

The temperature of incoming gas.

The co-current or countercurrent character of the gas stream in the absorbing liquid.

Main disadvantages of the contact process are that concentrated acid (98%) of high purity can be produced directly and that compact plants of quite high capacity have now become rather common place.

The contact process can be applied in different techniques; three of those techniques are described in the following sections

### 3. 2. 1 Single contact / single absorption process

After purification and drying, the SO<sub>2</sub> is converted to SO<sub>3</sub> using a series of four catalyst beds, containing alkali and V<sub>2</sub>O<sub>5</sub>. Afterwards, the SO<sub>3</sub> is absorbed in concentrated sulfuric acid and, if necessary, an oleum absorber is installed upstream. SO<sub>3</sub> reacts with the water contained in the absorber

acid to yield H<sub>2</sub>SO<sub>4</sub>. The absorber acid is kept at the desired concentration of approximately 99% w/w by addition of water or dilute H<sub>2</sub>SO<sub>4</sub>.

The single contact/single absorption process is generally used for gases with an SO<sub>2</sub> Content from 3 – 6 %. New single contact plants are built only for inlet gases with substantial fluctuation of the SO<sub>2</sub> content.

The investment cost of this technique is low compared to the investment cost of double contact plants.

Figure (3. 2. 1. 1): Typical process flow sheet for a single catalysis plant.

### 3. 2. 2 Double Contact/ Double Absorption Process

The double contact process was implemented to develop the single contact/single absorption process. In this process a primary SO<sub>2</sub> conversion of 85 – 95 % is achieved in the first catalysis stage of the converter before entry into an intermediate absorber, depending on the arrangement of the converter beds and the contact time.

What makes the double contact/double absorption process more advantageous is that its ability to feed gases with higher SO<sub>2</sub> concentrations than would be possible with the single catalysis process. Which leads to smaller gas volumes and therefore smaller equipment with comparable production capacities.

This results in a considerably higher conversion rate, if the residual gas is passed through the following converter beds (usually one or two). The SO<sub>3</sub>

which is formed in the second catalysis stage is absorbed in the final absorber.

In general the process uses gases with an SO<sub>2</sub> content of 10 to 11 %. The inlet gas temperature is about 400°C. Gases with lower temperatures require reheating from 50 to 400°C. This is usually carried out with recovered heats from the conversion process.

Operating the double contact process at an elevated pressure of 5 bar increases the conversion rate by shifting the conversion equilibrium and favouring the formation of SO<sub>3</sub>.

The disadvantages are higher electricity consumption and, at the same time, less steam production. Higher NO<sub>x</sub> emissions are caused by higher sulfur combustion temperatures (1800°C), but savings of 10 -17 % on investment costs are gained.

Figure 3. 2. 2. 1: Typical process flow sheet for a sulfur burning double catalysis

plant.

### 3. 2. 3 Wet catalysis process

The wet catalysis process is applicable to wet SO<sub>2</sub> gases. The potential for the formation of sulfuric acid mist might require tail gas treatment.

Wet SO<sub>2</sub> gases (eg. from the burning of H<sub>2</sub>S gases or from the catalytic conversion of H<sub>2</sub>S gases) are directly supplied into the contact tower without

previous drying. SO<sub>3</sub> formed by the catalytic conversion immediately reacts with the moisture of the gases, thereby forming the acetic acid. The sulfuric acid is condensed in a condenser installed after the contact tower.

Factors

Sulfuric Acid Production By Lead Chamber process

Sulfuric Acid Production By single contact/single absorption process

Sulfuric Acid Production By double contact/double absorption process

Sulfuric Acid Production By Wet Catalysis process

Health and safety hazards involved

Less safe, waste gases are discharged to the atmosphere

Less amount of SO<sub>3</sub> is absorbed so the rest is discharged to the atmosphere

A larger amount of SO<sub>3</sub> is absorbed

A larger amount of SO<sub>3</sub> is absorbed

Operating cost

High operating cost

Less operating

The least operating cost

Less operating cost

## Raw material

SO<sub>2</sub>, NO, NO<sub>2</sub>, O<sub>2</sub>, H<sub>2</sub>O.

Melted sulfur, O<sub>2</sub>, SO<sub>2</sub>, SO<sub>3</sub>.

Melted sulfur, H<sub>2</sub>O, O<sub>2</sub>, SO<sub>2</sub>, SO<sub>3</sub>.

Wet SO<sub>2</sub> gases, H<sub>2</sub>S, O<sub>2</sub>, SO<sub>3</sub>.

## Waste products and by products

Exhaust gases are discharged to the atmosphere

Large amounts of SO<sub>2</sub> gas are discharged to the atmosphere

Less amounts of SO<sub>2</sub> gas are discharged to the atmosphere, less heat released after each successive catalyst bed.

A larger amount of SO<sub>3</sub> is absorbed

## Equipment

Acid Tower (Glover Tower), Lead Chambers, Reactor (Gay-lussac Tower)

Air dryer, burner, waste heat boiler, converter, single absorption column.

Air dryer, burner, waste heat boiler, converter, intermediate and external absorption column.

Burner, convertor, acid tower.

## Yield

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Yields 78% H<sub>2</sub>SO<sub>4</sub>

New plants achieve 98 to 99 % conversion rates

Yields about 98%

Yields 70 to 80 % H<sub>2</sub>SO<sub>4</sub>

Environmental pollution

More gases are discharged to the atmosphere

More gases discharged to the atmosphere

Less gases discharged to the atmosphere

More gases are discharged to the atmosphere

Purity of products

Low purity

Low purity

High purity

Low purity

Table (3. 2. 1): Process selection

Factors

Sulfuric Acid Production By Lead Chamber process

Sulfuric Acid Production By single contact/single absorption process

Sulfuric Acid Production By double contact/double absorption process

Sulfuric Acid Production By Wet Catalysis process

Health and safety hazards involved

5

5

5

3

Operating cost

6

4

7

5

Raw material

6

5

7

5

Waste products and by products

6

6

7

5

Equipment

7

5

8

6

Yield

5

6

7

9

Environmental pollution

5

5

6

4

Purity of products

6

5

7

9

Total (80)

46

41

54

46

Table (3. 2. 2): Process Selection

According to the discussion and the data presented above we choose the Double Contact/Double Absorption process.

## CHAPTER FOUR

## PROCESS DISCRPTION

4. 1 Production of H<sub>2</sub>SO<sub>4</sub> by double contact process

The process begins in the burner, in which the melt sulfur is pumped to the burner where it is burnt in an excess of dry air. The gas exiting the burner is maintained at (8 – 9%v/v) sulfur dioxide and approximately 830°C due to the heat produced by the exothermic reaction.

Sulfurs on burning gives about one third of heat combustion of coal , and this heat raises the temperature of combustion gases roughly in accordance with the figure (4. 1. 1) as shown.

Figure (4. 1. 1): Theoretical Flame Temperature. 8

This heat is high in temperature and there is plenty of it, consequently it is worth utilizing and the hot gases are led across pipes through which the water passes. The water is heated, steam is raised and the gases are cooled.

The sulfur dioxide/air gas mixture is then passed through the stream to converter. The sulfur dioxide is converted to sulfur trioxide by reacting with oxygen over a catalyst.

This reaction is described by the equation:



This reaction occurs in the converter, a four-stage reaction vessel with each stage consisting of a solid catalyst bed through which the gas is passed. The catalyst used is vanadium pentoxide ( $V_2O_5$ ), and potassium sulphate dispersed on a silica base which forms a porous support, giving a large surface area for reaction.

This reaction is exothermic and its equilibrium constant decreases with increasing temperature (Le Chatelier's Principle).

Figure (4. 1. 2) shows the percentage conversion of  $SO_2$  to  $SO_3$  that would be reached at an  $SO_2$  concentration of 8% v/v and a range of gas temperatures.

However, the reaction rate is also temperature dependent, so that if the temperature becomes too low the equilibrium point will not be reached.

In practice, the gas temperature must be maintained between (400 – 500°C) to maintain a high reaction rate and also high conversion equilibrium.

As the reaction is exothermic, heat is generated across each of the catalyst beds. This heat must be removed between each stage to maintain the optimum reaction temperature into the following stage. The temperature rise through each catalyst bed and the inter-stage cooling is shown in Figure (4. 1. 2).

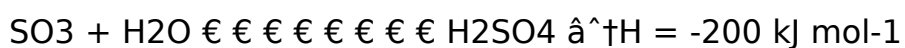
Figure (4. 1. 2): The Temperature Rise Through Beds. 7

The gas after passing through three catalyst bed goes to the first absorption tower where the Sulfur trioxide is removed. The gas is then reheated to

about 420 C, passed through the fourth catalyst bed, then cooled and sent to a second absorption tower.

The gas mixture goes to the first and second absorption tower, a packed tower where SO<sub>3</sub> is absorbed into a counter-current flow of 98 – 99% sulfuric acid.

The overall reaction can be described by the following equation, where sulfur trioxide reacts with the free water to produce sulfuric acid:



The circulating sulfuric acid must be maintained at about 98% concentration and temperature is controlled in the desired range of (70°C\_90°C) to maximize the absorption efficiency.

The acid strength is important because the vapor pressure of sulfur trioxide above sulfuric acid is at a minimum at an acid strength of 98% (see Figure (4. 1. 3)).

At higher concentrations the increased vapor pressure is caused by SO<sub>3</sub> and at lower concentrations the water vapor pressure increases sharply and the resultant acid mist is not readily re-absorbed and escapes to the atmosphere. A stream of sulfuric acid is continuously bled off and cooled through a plate heat exchanger before being passed into the storage tanks.

Figure (4. 1. 3): Relation Between Vapor Pressure and Concentration. 7

Figure (4. 1. 4) : Flow Sheet

## CHAPTER FIVE

### ENERGY AND MASS BALANCE

#### 5. 1 MASS BALANCE

\*Drier:

Components

Amount

**%**

H<sub>2</sub>O

1. 27

1. 3

O<sub>2</sub>

21. 12

23

N<sub>2</sub>

69. 4

75. 7

Temperature



25C

pressure

1 atm

M1

M2

Components

Amount

%

H<sub>2</sub>SO<sub>4</sub>

39.4

98

H<sub>2</sub>O

0.8

2

Temperature

150C

pressure

1 atm

M3

Components

Amount

%

O2

21. 12

23. 3

N2

69. 4

76. 7

Temperature

25C

pressure

1 atm

M4

Components

Amount

%

H<sub>2</sub>SO<sub>4</sub>

39.42

95

H<sub>2</sub>O

2.1

5

Temperature

150C

pressure

1 atm

\*Burner:

M3

Components

Amount

%

O<sub>2</sub>

21. 12

23. 3

N2

69. 4

76. 7

Temperature

26C

pressure

1 atm

M5

Components

Amount

%

S

3. 76

100

Components

Amount

%

SO<sub>2</sub>

28.16

29

O<sub>2</sub>

7.04

7

N<sub>2</sub>

69.4

64

Temperature

830C

pressure

1 atm

M6

\*Converter:

M6

Components

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Amount

%

SO<sub>2</sub>

28.16

29

O<sub>2</sub>

7.04

7

N<sub>2</sub>

69.4

64

Temperature

400C

pressure

1 atm

M7

Components

Amount

**%**

O<sub>2</sub>

2. 11

2

N<sub>2</sub>

69. 44

66

SO<sub>2</sub>

8. 45

8

SO<sub>3</sub>

24. 64

24

Temperature

450

pressure

1 atm

M8

Components

Amount

%

SO<sub>2</sub>

26.72

26

O<sub>2</sub>

1.69

1.6

N<sub>2</sub>

69.44

66.4

SO<sub>3</sub>

26.72

26



Temperature

450

pressure

1 atm

M9

Components

Amount

%

SO<sub>2</sub>

0.314

6

O<sub>2</sub>

0.0768

1.5

N<sub>2</sub>

3.47

66.5

SO<sub>3</sub>

1. 36

26

Temperature

450

pressure

1 atm

M10

Components

Amount

%

SO<sub>2</sub>

0. 314

6

O<sub>2</sub>

0. 0768

1. 5

N<sub>2</sub>

3. 47

66. 5

SO<sub>3</sub>

1. 36

26

Temperature

450

pressure

1 atm

M11

Components

Amount

%

SO<sub>2</sub>

6. 08

6

O<sub>2</sub>

1. 54

6

N<sub>2</sub>

65. 97

66. 5

SO<sub>3</sub>

25. 84

26

Temperature