SEBHA UNIVERSITY
Faculty of Energy and Mining Engineering
DEPARTMENT of Chemical Engineering

GRADUATION PROJECT SUBMITTED FOR B.SC DEGREE ENTITLED:-

PRODUCTION OF ACETONE FROM ISO-PROPAANOL

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UNDER THE SUPERVISION OF :-

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Acknowledgment

We are indebted to many former teachers, colleagues, and students who directly or indirectly helped in preparing this project. We want to extend our special thanks to: (Dr. Mousa Al_Tall). For his patience and dedication throughout this project. And we would like to say thanks to our parents for their care, encouragement and support through all these years.
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Abstract

The aim of the project is to design a chemical process to produce Acetone from Iso-propyl-alcohol (IPA) with a conversion of 90% and a capacity of 33,000 metric tons per year at the given conditions.

A comprehensive material and energy balance together with detailed design calculations for a reactor were carried out.

Physical and chemical properties, manufacturing processes of Acetone, and instrumentation flow sheet were also included.
Introduction

Acetone is the simplest ketone and one of the most abundant volatile organic compounds (VOCs) in the atmosphere, with typical mixing ratios ranging from a few hundred parts per trillion (pptv) to several parts per billion (ppbv) or more \(^1\). Formulation and production of other chemicals can account for up to 75 percent of all uses of acetone. Acetone is a volatile organic compound (VOC) that is considered to have low toxicity, though improper use of it can cause serious problems. There are a number of uses for acetone, including in chemicals, solvents and nail polish remover. The most common use of acetone is to formulate other chemicals. Beyond chemicals and solvents, other uses for acetone exist in the production of cosmetics and household and personal care products.

Acetone is classified as a low-toxicity VOC. It easily evaporates in the air, dissolves in water and is highly flammable. Chemical manufacturers can produce acetone, although it also can be found in the environment as a naturally occurring substance. However, by the late 1950s, routes to produce solvents from petroleum were made cost-competitive with fermentation4. In addition, the major feedstock at the time was molasses, which spiked in price because of animal feed demand.

Acetone is typically produced in commercial quantities as a by-product during the formation of phenol. However, acetone manufactured thus generally contains small amounts of the reactant benzene and the desired product phenol \(^2\). In the past, these impurities were deemed to be within allowable limits. However, recent downward revisions of these limits by the US Food and Drug Administration has made alternative processes (which do not involve benzene) more attractive. We wish to begin the design of one such alternative process to produce 33,000 metric tons of acetone per year, using isopropyl alcohol as the reactant.
Chapter One

Literature Review
1.1. Definition of acetone

Acetone is a colourless liquid with a distinctive taste and ‘fruity’ odour.

- Formula: \( \text{CH}_3\text{COCH}_3 \)
- Molecular Weight: 58.079 g/mol.
- Chemical structure:

```
  H3C
 /   \\  \
\  \\  \\
O   C
 \  /  \
  \   \
CH3
```

Acetone is the simplest and most important of the ketones. It is a colourless, mobile flammable liquid with a mildly pungent and somewhat aromatic odor \(^3\).

It is miscible in all proportions with water and with organic solvents such as diethyl ether, methanol, ethyl alcohol, and esters. It is used as solvent for cellulose acetate and nitro cellulose, as a carrier for acetylene, and as a raw material for the chemical synthesis of a wide range of products, e.g. ketone bis-phenol, di-acetone alcohol, mesityl oxide, methyl isobutyl Ketone, hexylene glycol (2-methyl-2, 4-pentanediol), and isophorone.
1.2 Historical Background

Until World War I, acetone was manufactured by the dry distillation of calcium acetate, which was obtained by neutralizing pyroligneous acid (wood distillate) with lime and evaporating to dryness. When World War I began, new methods of manufacture were explored. Calcium acetate could be made from acetic acid which had been produced by fermentation of alcohol or from acetylene. However, this method could not compete with the fermentation process developed by Weizmann and Hamlyn for the conversion of carbohydrate (cornstarch or molasses) to acetone and butyl and ethyl alcohol by use of a special bacillus. Publicker Industries, Commercial Solvents, and National Distillers, at one time, had combined bio-fermentation process acetone capacity of 22,700 metric tons per year.

This method, in turn, became non-competitive in the late 1950s and early 1960s owing to the economics of scale of the cumene hydro-peroxide-to-phenol and the isopropyl alcohol dehydrogenation processes. Production of acetone by dehydrogenation of isopropyl alcohol actually began in the early 1920s.

It remained the dominant production method through the sixties, in 1976, 60% of United States acetone capacity was based on cumene hydro-peroxide. In 1974, about 65% of the acetone produced was via the cumene hydro-peroxide process.

The process for direct oxidation of propylene to acetone was developed in the early to middle 1960s by Waker Chemie. However, this technology is not known to be in use in the United States. In the middle 1960s, virtually all United States acetone was produced from propylene. The two important routes in the United States to acetone are cumene hydro-peroxide cleavage and dehydrogenation of isopropyl alcohol. An undefined minor portion of the acetone from isopropyl alcohol is produced by catalytic oxidation.

1.3 Acetone properties

It is colourless, mobile, flammable liquid with a mildly pungent and somewhat aromatic odor. It is miscible in all proportions with water and with organic solvents such as ether, methanol, ethyl alcohol, and esters. Acetone is used as a solvent for cellulose acetate and nitrocellulose, as a such ketone, hexylene glycol(2-methyl-2,4-pentanediol), and isophorone carrier for acetylene and as raw material for the chemical synthesis of a wide range of
products as ketene, methyl methacrylate, bisphenol A, diacetone alcohol, mesityl oxide, methyl isobutyl

### 1.3.1 Physical properties

**Table (1.1)**: Properties of acetone as a function of Temperature

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Viscosity, mPa.s</th>
<th>Specific gravity, t/20°C</th>
<th>Vapour pressure, Kpa</th>
<th>Surface tension, Dyn/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.4</td>
<td>0.807</td>
<td>9.3</td>
<td>26.2</td>
</tr>
<tr>
<td>20</td>
<td>0.32</td>
<td>0.783</td>
<td>24.7</td>
<td>28.7</td>
</tr>
<tr>
<td>40</td>
<td>0.27</td>
<td>0.759</td>
<td>54.6</td>
<td>21.2</td>
</tr>
<tr>
<td>60</td>
<td>_</td>
<td>_</td>
<td>112</td>
<td>18.7</td>
</tr>
<tr>
<td>80</td>
<td>_</td>
<td>_</td>
<td>226.6</td>
<td>16.2</td>
</tr>
<tr>
<td>100</td>
<td>_</td>
<td>_</td>
<td>386.5</td>
<td>_</td>
</tr>
</tbody>
</table>

**Table (1.2)**: physical properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula</td>
<td>$C_3H_6O$</td>
</tr>
<tr>
<td>Melting point, °C</td>
<td>-94.6</td>
</tr>
<tr>
<td>Appearance</td>
<td>Colorless liquid</td>
</tr>
<tr>
<td>Molar mass, g mol$^{-1}$</td>
<td>58.08</td>
</tr>
<tr>
<td>Density, g cm$^{-3}$</td>
<td>0.791</td>
</tr>
<tr>
<td>Viscosity at 10°C, mPa.s</td>
<td>0.36</td>
</tr>
<tr>
<td>Flash point</td>
<td>-20°C(-4°F;738K)</td>
</tr>
<tr>
<td>Boiling point at 1 atm,°C</td>
<td>56.1</td>
</tr>
<tr>
<td>Specific heat of liquid, J/g.k</td>
<td>2.6</td>
</tr>
<tr>
<td>Electrical conductivity at 25°C, S/Cm</td>
<td>5.5*10^{-8}</td>
</tr>
<tr>
<td>Heat of Vaporization, kJ/mol</td>
<td>29.1</td>
</tr>
</tbody>
</table>
1.3.2 Chemical Properties

Acetone has closed-cup flash point of -18°C and an autoignition temperature of 538°C. The explosive limits of acetone-air mixtures lie between 2.15 and 13.0 vol % acetone in air at 25°C. Acetone shows the typical reactions of saturated aliphatic ketones. It forms crystalline compounds with alkali bisulfites; e.g. with sodium bisulphate, the compound (CH₃)₂C(OH)₅SO₃Na is obtained. Reducing agents converts convert acetone to isopropyl alcohol and pinacol. Propane is the product of the Clemmensen reduction:

\[
(CH_3)_2C=O+4HCl+2Zn(Hg) \rightarrow CH_3CH_2CH_3+2ZnCl_2+2Hg+H_2O
\]

Isopropyl amine is produced by reductive ammonolysis of acetone:

\[
(CH_3)_2C=O+NH_3+H_2 \xrightarrow{\text{catalyst}} (CH_3)_2CHNH_2 + H_2O
\]

Acetone undergoes much condensation reaction. For example, condensation with amines will yield Schiff bases. Orthoformic esters condense with acetone to form acetalts. With hydrogen sulfide, acetone reacts to form thioketone; with mercaptans, it yields thio ketals. In the

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific heat of vapor, J/(mol.k)</td>
<td>92.1</td>
</tr>
<tr>
<td>Heat of combustion of liquid, kJ/mol</td>
<td>1787</td>
</tr>
<tr>
<td>Heat of formation gas at 25°C, kJ/mol</td>
<td>-216.5</td>
</tr>
<tr>
<td>Heat of formation liquid at 25°C, kJ/mol</td>
<td>-248</td>
</tr>
<tr>
<td>Entropy of liquid at 298.15k, J/k</td>
<td>200.1</td>
</tr>
<tr>
<td>Acidity</td>
<td>19.2</td>
</tr>
<tr>
<td>Basicity</td>
<td>-5.2</td>
</tr>
<tr>
<td>Explosive limits</td>
<td>2.6-12.8%</td>
</tr>
<tr>
<td>Molar entropy, j/mol.K</td>
<td>200.4</td>
</tr>
<tr>
<td>Refractive index</td>
<td>1.359</td>
</tr>
<tr>
<td>Dipole moment</td>
<td>2.91D</td>
</tr>
</tbody>
</table>

Specific heat of vapor, J/(mol.k) | 92.1
Heat of combustion of liquid, kJ/mol | 1787
Heat of formation gas at 25°C, kJ/mol | -216.5
Heat of formation liquid at 25°C, kJ/mol | -248
Entropy of liquid at 298.15k, J/k | 200.1
Acidity | 19.2
Basicity | -5.2
Explosive limits | 2.6-12.8%
Molar entropy, j/mol.K | 200.4
Refractive index | 1.359
Dipole moment | 2.91D
presence of an amine, or ammonia, various esters condense readily with acetone. In the presence of sodium alkoxides and sodium amide, β-diketones are formed. It is also possible to produce β-diketones by reaction of acetone with carboxylic anhydrides in the presence of boron tri-fluoride \[^4\].

Acetone is stable to many of the usual oxidants, such as Fehling’s solution, silver nitrate, cold nitric acid, and neutral potassium permanganate, but it can be oxidized with some of the stronger oxidants such as alkaline potassium permanganate, chromic acid, hot nitric acid. Acetone can also be oxidized by an alkali metal hypohalite or by halogen in the presence of a base, to a halo-form and alkali metal acetate.

**1.4 Uses of acetone**

**1.4.1 Feed stock**

The important industrial use for acetone involves its reaction with phenol for the manufacture of bisphenol A.

![Uses for Acetone](image)

**Figure (1.2) Uses of Acetone**

Bisphenol A is an important component of many polymers such as polycarbonates, polyurethanes and epoxy resins. Acetone has also been used in the manufacture of cordite.

**1.4.2 Cleaning fluid**

Acetone is after the primary (or only) component in nail polish remover. Ethyl acetate, another organic solvent, is sometimes used as will. Acetone is also used as a superglue remover. It can be used for thinning and cleaning fibre glass resins and epoxies. It is a strong solvent for most plastics and synthetic fibre. It is ideal for thinning fibre glass
resin, cleaning fibre glass tools and dissolving two-part epoxies and superglue before hardening. A heavy-duty degreases, it is useful in the preparation of metal prior to painting; it also thins polyester resins, vinyl and adhesives. It easily removes residues from glass and porcelain. In biological research contexts, buffers that contain acetone (such as citrate-buffered formalin) use the acetone to lyses cells for further experimentation.

1.4.3 Solvent
Acetone can also dissolve many plastic, including those used in Nalgene bottles made of polystyrene, polycarbonate and some types of polypropylene. In the laboratory, acetone is used as a polar aprotic solvent in a variety of organic reactions. Acetone is also used extensively for the safe transporting and storing of acetylene in the mining industry. Vessels containing a porous material are first filled with acetone followed by acetylene, which dissolves in to the acetone. One litre of acetone can dissolve around 250 litres of acetylene.[5]

1.4.4 Medical uses
Acetone is used in a variety of general medial and cosmetic applications and is also listed as a component in food additives and food packaging. Dermatologists use acetone with alcohol for acne treatments to peel dry skin. Acetone is commonly used in chemical peeling. Common agents used today for chemical peels are salicylic acid, glycolic acid, 30% salicylic acid in ethanol, and trichoroacetic acid (TCA). Prior to chemefoliation, the skin is cleaned and excess fat removed in a process called defatting. Acetone, Septisol, or a combination of these agents is commonly used in this process.

1.4.5 Other uses
Acetone is also used as drying agent, due to the readiness with which it mixes with water. It can be used as an artistic agent; when tubed on the back of a laser print or photocopy placed face-down on another surface and burnished firmly, the toner of the image is allowed to the destination surface.

1.5 Analysis and storage
Acetone can be determined by treating with hydroxylamine hydrochloride and titrating the liberated hydrochloric acid. The formation of iodo form from the reaction of acetone with
iodine (hypoiodate) is the basis of another useful method of analysis. The excess iodine is titrated, and the amount which has reacted with the acetone is thus determined by difference. In current industrial practice, gas chromatography is also widely used, especially for quality control purposes. The chief impurity in acetone is usually few tenths of one percent of water. Acetone contains no oxidizable impurities, and the colour of a few drops of permanganate is retained for several hours. Other test methods were covered in the previous section.
Since acetone, as commercially produced today, is virtually a pure product, common practice is to store the product in steel tanks. Acetone is also transported in steel drums, tank trucks, and rail cars.

1.6 Metabolism of acetone

1.6.1 Biosynthesis

Small amounts of acetone are produced in the body by the decarboylation of ketone bodies. Certain dietary patterns, including prolonged fasting and high-fat low-carbohydrate dieting, can produce ketosis, in which acetone is formed in body tissue. Certain health conditions, such as alcoholism and diabetes, can produce ketoacidosis, uncontrollable ketosis that leads to a sharp, and potentially fatal, increase in the acidity of the blood. Since it is a by-product of fermentation, acetone is a by-product of the distillery industry.

1.6.2 Metabolic use

Although some biochemistry textbooks and current research publications indicate that acetone cannot be metabolized, there is evidence to the contrary some dating back thirty years. Acetone can be produced from the oxidation of ingested isopropanol, or from the spontaneous/enzymatic breakdown of acetoacetate (a ketone body) in ketonic individuals. It can then be metabolized either by CYP2E1 via methyl-glyoxal to D-Lactate and pyruvate, and ultimately glucose/energy, or by a different pathway via propylene glycol to pyruvate, lactate, acetate (usable of energy) and propionaldehyde.

1.7 Acetone Manufacturing Process

1.7.1 Wacket-Hechst direct oxidation of propene

The most elegant method for manufacturing acetone is the Wacket-Hechst process, which has been practiced commercially since 1964. In this liquid phase process, propene is
oxidized to acetone with air at 110-120°C and 10-14 bar in the presence of catalyst system contain(PdCl₂):

\[ CH_3CH = CH_2 + 1/2O_2 \xrightarrow{catalyst} CH_3COCH_3 \]

The selectivity to acetone the main product is 92%, The conversion of propene is more than 99% as in the oxidation of ethylene to a cetaldehyde (PdCl₂) is reduced to (Pd) in a stoichiometric reaction then re oxidized to divalent palladium with the redox system

\[ CUCl_2 \rightarrow CUCl \]

### 1.7.2 Co-production in Hock Phenol process

Benzene is alkylated to cumene is oxidized to cumene Hydro peroxide which in turn is cleaved to phenol and acetone

\[ C_6H_5CH(CH_3)_2 \xrightarrow{\alpha} C_6H_5C(CH_3)_2OOH \xrightarrow{acid} C_6H_5OH + CH_3COCH_3 \]

Over 90% of phenol product in the USA is via the cumene per oxidation one kg of phenol production will result in 0.6 kg of acetone.

The process steps are: oxidation of cumene to a concentrated hydro peroxide cleavage of the hydro peroxide neutralization of the cleaved and distillation to recover acetone. The temperature is generally between 80°C and 130°C. A typical process involves the use of three or four cumene oxidation reaction in series. The temperature from a high of 115°C in the first reactor to 90°C for the last reactor. This procedure may result in concentration of cumene hydro peroxide of 9-12% in reactor No1, 15-20% in reactor No3 and 32-39% in reactor No. yields of cumene hydro peroxide may be in range of 90-95%. The total residence time in each reactor is likely to be in range of 3-6hr. The product is then concentrated by evaporation to 75-85% cumene hydro peroxide. The cleavage reaction occurs under acid conditions in agitated vessel at 60°C-100°C, a large number of non-oxidizing in organic acids are useful for this reaction. At this point, the reaction mass is a mix of phenols acetone, and a wide variety of other products such as cumylphenols, a cetophenone dimethylphenol carbinol, and x.methylstyrene. It may be neutralized with a sodium phenoxide solution. Process water be added to facilitate removed of any inorganic salts; the product may then go through a separation and a wash stage or go directly to a distillation tower.
1.7.3 Old method

Previously, acetone was produced by the dry distillation of acetone, for example calcium acetate in ketonic decarboylation.

\[ \text{Ca(CHCOO)}_2 \rightarrow \text{CaO} + \text{CO}_2 + (\text{CH}_3)_2 \text{CO} \]

1.7.4 Dehydrogenation of isopropanol

The other process of commercial importance in the production of acetone is the catalytic dehydrogenation of isopropanol. The reactions endothermic.

\[ \text{CH}_3 - \text{CHOH} - \text{CH}_3 \rightarrow \text{CH}_3 - \text{CO} - \text{CH}_3 + \text{H}_2 \] (1)

\[ 2\text{CH}_3 - \text{CHOH} - \text{CH}_3 \rightarrow (\text{CH}_3)_2 \text{CH} - \text{O} - \text{CH(\text{CH}_3)}_2 + \text{H}_2\text{O} \] (2)

\[ \text{CH}_3 - \text{CHOH} - \text{CH}_3 \rightarrow \text{CH}_2 = \text{CH} - \text{CH}_3 + \text{H}_2\text{O} \] (3)

The equilibrium of the dehydrogenation reaction is shifted to acetone by increasing temperature.

At 325°C (97%) conversion is theoretically possible. A large number of catalysts for the reaction have been investigated these include: copper, silver, platinum, and palladium metal as well as sulfides of transition metals of the groups IV, V, and VI of the periodic table. These catalysts are made with inert supports and are used at 400°C-600°C lower temperature reactions (315°C – 482°C) have been successfully conducted using zinc oxide –zirconium oxide combinations, copper. Chromium oxide combinations and combinations of copper and silicon dioxide. In one commercial version the catalyst is zinc oxide (7-8%) on pumice carried.

The isopropanol feed may contain up to 12% water without seriously affecting dehydrogenation to the ketone. Isopropgyal is feed to the catalyst beds with an equimolar
ratio of hydrogen to decrease catalyst fouling in this process at an operating temperature of 380°C conversion started at 98% per pass with fresh catalyst but drops to point where catalyst regeneration is necessary after 10 days. At this point organic material on the catalyst is burned using a mixture of 2% \( O_2 \) and 98% \( N_2 \).

Each batch catalyst has a life of about 6 months it is usual practice to raise the temperature of the reactor of the reactor as time proceeds to compensate for the loss of catalyst activity. When brass spelter is used as a catalyst it has been found necessary to remove the catalyst at intervals of 500-1000 hr. and to treat it with a minerals acid to regenerate catalytically active surface.

When 6-12% Zirconium oxide is added to a zinc oxide catalyst life is a said to be minimum of 3 months.

The dehydrogenation is carried out in a tubular reactor. Conversions are in the range of 75%-95% A process described by shell international research is a useful two stage reaction to attain high conversion with lower energy cost and lower capital costs.

The first stage uses a tubular reactor at 420°-550°C to convert up to 70% of the alcohol to acetone. The second stage employs a unheated fixed bed reactor with the same catalyst used in the tube reactor to complete the conversion at about 85%.

The selectivity of isopropyl alcohol to acetone vapour phase dehydrogenation is high, there are a number of by products that must be removed from the acetone. The hot reactor effluent contains a converted isopropyl alcohol and hydrogen, and is also may contain propylene, polypropylene, mesityl oxide, [di.isopropylether], acetaldehyde, propinoaldehyde, and many other hydrocarbons and carbon oxides.

The mixture is cooled and the non-condensable gases are scrubbed with water if desired, because the resultant gas stream is mainly hydrogen part of it can be recycled to control catalyst fouling. The liquid are fractionally distilled taking acetone overhead and mixture of Isopropyl alcohol and water as bottoms.

A caustic treatment may be used to remove minor aldehyde contaminants prior to this distillation. Additional acetone purification columns may be employed. In another fraction acting column, the aqueous isopropyl alcohol is concentrated up to about 88% for to the reactor.
1.8 Description of the process

At the beginning of the process, feed including i-propyl alcohol and water, and recycle stream are mixed in feed drum. From here, this mixture is send to vaporizer to change stream’s phase as vapour. After vaporizer, mixture is heated to reaction temperature in the heater. Reactor used is a tubular flow reactor. Acetone, hydrogen gas (H2) are produced and water and i-propyl-alcohol are discharged. The mixture which are acetone, hydrogen, water, i-propyl-alcohol are sent to cooler and then to condenser. After condenser the mixture is sent to flash unit. Hydrogen, acetone, i-propyl-alcohol and water are obtained as top product. This top product is sent to scrubber to remove hydrogen. The bottom product of flash unit which is consist of acetone, water, i-propyl-alcohol are mixed with the bottom product of scrubber before acetone column. In acetone column, acetone is obtained from top product with 99 wt%. Í-propyl alcohol and water and also 0,1% of acetone is sent to i-propyl-alcohol column from bottom product. The top product of this column is sent to feed drum and bottom product is thrown away as waste water.

A process flow sheet for acetone production is as given in Figure (1.3).
Chapter Two

Material Balance Calculations
2. MASS BALANCES

Operating days/year = 330

Production Rate: 100 ton/day = 4167 kg/h = 33000 ton/year of acetone (99% purity)

The feed consist of 67% of I-propyl-alcohol and 33% water

2.1 REACTOR

I-Propylalcohol=100 kmol/h
H₂O = 49.25 kmol/h

conversion = 90% and the side reactions are neglected

\[ \text{CH}_3\text{CHOHCH}_3 \rightarrow \text{CH}_3\text{COCH}_3 + \text{H}_2 \]

\[ n_{\text{acetone}5} = 100 \times 0.9 = 90 \text{ kmol/h} \]
\[ n_{\text{H}_25} = 100 \times 0.9 = 90 \text{ kmol/h} \]
\[ n_{\text{H}_2\text{O}5} = 49.25 \text{ kmol/h} \]
\[ n_{\text{I-propyl-alcohol}5} = 100 \times 0.1 = 10 \text{ kmol/h} \]

\[ n_{\text{Total}5} = n_{\text{acetone}5} + n_{\text{H}_25} + n_{\text{H}_2\text{O}5} + n_{\text{I-propyl-alcohol}5} = 239.25 \text{ kmol/h} \]

the concentration of stream 5 is given in table below

\[ y_i = \frac{n_i}{n_T} \]

Table (2.1) the concentration of stream 5

<table>
<thead>
<tr>
<th>Components</th>
<th>(n) kmol/h</th>
<th>Concentration (y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>90</td>
<td>0.376</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>90</td>
<td>0.376</td>
</tr>
<tr>
<td>water</td>
<td>49.25</td>
<td>0.206</td>
</tr>
<tr>
<td>I-propyl-alcohol</td>
<td>10</td>
<td>0.042</td>
</tr>
</tbody>
</table>
2.2 FLASH UNIT

- It is assumed that there is no change at temperature and pressure.

\[
k_i = \frac{y_i}{x_i} = \frac{p_i}{p_t} = \frac{p_i^*}{p_t^*}
\]

Where \( p_i^* \) = vapor pressure of component \( i \)

The vapor pressure can be calculated by using Antoine equation

\[
\log p^* = A - \frac{B}{T + C}
\]

\( p^* \) = vapor pressure, mmHg

A,B,C = the Antoine coefficients

T = temperature, C

Table (2.2) the Antoine coefficients for the components

<table>
<thead>
<tr>
<th>components</th>
<th>Antoine coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>acetone</td>
<td>7.02447</td>
</tr>
<tr>
<td>I-propyl-alcohol</td>
<td>8.37895</td>
</tr>
</tbody>
</table>
At the bubble point (T = 81°C)

\[ \text{For acetone} \]
\[ \log p_i^* = 7.02447 - \frac{1161}{224 + 81} = 3.2179 \]
\[ p_i^* = 1651.58 \text{ mmHg} \]
\[ k_{acetone} = \frac{1651.58}{\left( \frac{1.5}{1.013} \right) \times 760} = 1.4676 \]

\[ \text{For I-propyl-alcohol} \]
\[ \log p_i^* = 8.37895 - \frac{1788.02}{227.438 + 81} = 2.5819 \]
\[ p_i^* = 381.856 \text{ mmHg} \]
\[ k_{IPA} = \frac{381.856}{\left( \frac{1.5}{1.013} \right) \times 760} = 0.3393 \]

\[ \text{For water} \]
\[ \ln p_i^* = 7.96681 - \frac{1668.21}{228 + 81} = 2.5681 \]
\[ p_i^* = 369.913 \text{ mmHg} \]
\[ k_{H_2O} = \frac{369.913}{\left( \frac{1.5}{1.013} \right) \times 760} = 0.3287 \]

From literature; \((V/F) = 0.2\)
The presence of \(H_2\) does not affect the process, so we neglect \(n_{H_2}\)
\[ F = n_{acetone} + n_{H_2O} + n_{IPA} = 149.25 \text{ kmol/h} \]
\[
\begin{align*}
\text{F} &= \text{V} + \text{L} \quad \text{V} = 29.85 \text{ kmol/h} \\
0.2 &= \frac{\text{V}}{\text{F}} \quad \text{L} = 119.4 \text{ kmol/h} \\
\frac{\text{F}}{\text{F}} &= \frac{\text{V}}{\text{F}} + \frac{\text{L}}{\text{F}} \\
1 &= 0.2 + \frac{\text{L}}{\text{F}} \\
\text{L} &= 0.8 \text{ F} = 0.8 \times 149.25 = 119.4 \text{ kmol/h} \\
\text{V} &= 29.85 \text{ kmol/h} \\
\text{y}_v &= k_i \times x_L \\
\text{F} \ x_f &= \text{V} \ y_v + L \ x_L
\end{align*}
\]

\begin{itemize}
\item For acetone

\[y_v = 1.468 \times x_L\]
\[90 = 29.85 \times y_v + 119.4 \times x_L\]
\[90 = 29.85 \times y_v + 119.4 \times \frac{y_v}{1.468}\]
\[90 = (29.85 + 119.4) \times y_v\]
\[x_L = 0.551\]
\[y_v = 0.809\]

\item For i-propyl-alcohol

\[y_v = 0.339 \times x_L\]
\[10 = 29.85 \times y_v + 119.4 \times x_L\]
\[x_L = 0.077\]
\[y_v = 0.026\]

\item For water

\[y_v = 0.329 \times x_L\]
\[49.25 = 29.85 \times y_v + 119.4 \times x_L\]
\[x_L = 0.381\]
\end{itemize}
\[ y_v = 0.125 \]

➢ At stream 8:

\[ V = 29.85 \text{ kmol/h} \]

\[ y_{\text{acetone}} = 0.809 \Rightarrow n_{\text{acetone} 8} = (0.809) \times (29.85) = 24.148 \text{ kmol/h} \]

\[ y_{\text{i-propyl-alcohol}} = 0.026 \Rightarrow n_{\text{i-propyl-alcohol} 8} = (0.026) \times (29.85) = 0.766 \text{ kmol/h} \]

\[ y_{\text{water}} = 0.125 \Rightarrow n_{\text{water} 8} = (0.125) \times (29.85) = 3.731 \text{ kmol/h} \]

➢ At stream 9:

\[ L = 119.4 \text{ kmol/h} \]

\[ x_{\text{acetone}} = 0.551 \Rightarrow n_{\text{acetone} 9} = (0.551) \times (119.4) = 65.789 \text{ kmol/h} \]

\[ x_{\text{i-propyl-alcohol}} = 0.077 \Rightarrow n_{\text{i-propyl-alcohol} 9} = (0.077) \times (119.4) = 9.194 \text{ kmol/h} \]

\[ x_{\text{water}} = 0.381 \Rightarrow n_{\text{water} 9} = (0.381) \times (119.4) = 45.491 \text{ kmol/h} \]
2.3 SCRUBBER

\[
\begin{align*}
H_2 &= 90 \text{ kmol/h} \\
H_2O &= 3.731 \text{ kmol/h} \\
\text{Acetone} &= 24.184 \text{ kmol/h} \\
i\text{-propyl-alcohol} &= 0.766 \text{ kmol/h}
\end{align*}
\]

T = 81\(^0\)C (354.15 K); P = 1.5 bar (1.48 atm)

Assume 1/1000 of inlet acetone is in off-gas.

➢ At stream 12;

\[
n_{H_2} = 90 \text{ kmol/h}
\]

\[
= \frac{1}{1000} \times 24.148 = 0.024148 \text{ kmol/h}
\]

\[
n_{T12} = n_{H_2} + n_{\text{acetone12}} = 90 + 0.024148 = 90.0242 \text{ kmol/h}
\]

\[
y_{\text{acetone12}} = \frac{0.024148}{90.0242} = 2.68 \times 10^{-4}
\]

\[
y_{H_2} = \frac{90}{90.0242} = 0.99973
\]

➢ At stream 10;

\[
n_{\text{acetone10}} = 24.148 - 0.024148 = 24.124 \text{ kmol/h}
\]

\[
n_{T8} = 24.148 + 90 + 3.731 + 0.776 = 118.655 \text{ kmol/h}
\]
\[ n_{IPA_{10}} = 0.766 \text{ kmol/h} \]

\[ n_{H_2O_{10}} = 3.371 + n_{stream_{11}} \]

\[ \frac{y_{acetone_{8}}}{y_{acetone_{8}}} = \frac{24.148}{118.655} = 0.203 \]

\[ \frac{y_{acetone_{12}}}{y_{acetone_{8}}} = \frac{1 - A}{1 - A^6} \]

Where \( A = \frac{n_{T_{11}}}{m n_{T_8}} \)

\[ m = \frac{e^{10.92-\frac{3598}{T}}}{P} = \frac{e^{10.92-\frac{3598}{354.15}}}{1.84} = \frac{2.13614}{1.48} = 1.443 \]

\[ \frac{y_{acetone_{12}}}{y_{acetone_{8}}} = \frac{2.68 \times 10^{-4}}{0.203} = 1.32 \times 10^{-3} = \frac{1 - A}{1 - A^6} \]

Assume \( A = 3.523 \)

\[ \frac{1 - 3.523}{1 - 3.523^6} = \frac{2.523}{1910.95} = 1.32 \times 10^{-3} \]

\( A = 3.523 \)

\[ n_{T_{11}} = m A n_{T_8} = 1.443 \times 3.523 \times 118.655 = 603.21 \text{ kmol/h} \]

\[ n_{T_{10}} = n_{acetone} + n_{H_2O} + n_{IPA} \]

\[ n_{T_{10}} = 24.124 + (603.21 + 3.731) + 0.776 = 631.84 \text{ kmol/h} \]
2.4 ACETONE COLUMN

 acetone = 89.913 kmol/h  
i-propyl-alcohol = 9.96 kmol/h  
water = 652.43 kmol/h

➢ At stream 13;

\[
\begin{align*}
n_{\text{acetone}13} &= n_{\text{acetone}9} + n_{\text{acetone}10} = 65.789 + 24.124 = 89.913 \text{ kmol/h} \\
n_{\text{i-IPA13}} &= n_{\text{i-IPA9}} + n_{\text{i-IPA10}} = 9.194 + 0.766 = 9.96 \text{ kmol/h} \\
n_{\text{H}_2\text{O13}} &= n_{\text{H}_2\text{O9}} + n_{\text{H}_2\text{O10}} = 45.491 + 606.941 = 652.43 \text{ kmol/h} \\
n_{\text{T13}} &= n_{\text{acetone13}} + n_{\text{H}_2\text{O13}} + n_{\text{i-IPA13}} \\
n_{\text{T13}} &= 89.913 + 652.43 + 9.96 = 752.303 \text{ kmol/h}
\end{align*}
\]

Assume that 1/1000 of acetone is in bottom product

\[
\begin{align*}
n_{\text{acetone15}} &= \frac{1}{1000} \times 89.913 = 0.0899 \text{ kmol/h} \\
n_{\text{acetone14}} &= 89.913 - 0.089 = 89.824 \text{ kmol/h}
\end{align*}
\]

Since acetone purity is 99%
$n_{T14} = \frac{89.823 \times 100}{99} = 90.73 \text{ kmol/h}$

$n_{IPA14} = 90.73 - 89.823 = 0.907 \text{ kmol/h}$

➤ At stream 15;

$n_{IPA15} = n_{IPA13} - n_{IPA14} = 9.96 - 0.9074 = 9.053 \text{ kmol/h}$

$n_{H2O15} = n_{H2O13} = 652.43 \text{ kmol/h}$

$n_{acetone15} = 0.0899 \text{ kmol/h}$
2.5 IPA COLUMN

acetone = 0.0899 kmol/h
i-propyl-alcohol = 9.053 kmol/h
water = 652.43 kmol/h

since all the i-propyl-alcohol is at the top product

\[ n_{IPA17} = n_{IPA15} = 9.053 \text{ kmol/h} \]
\[ n_{acetone17} = n_{acetone15} = 0.0899 \text{ kmol/h} \]

By neglecting \( n_{acetone} \) in \( S_{17} \) and assuming the composition of the recycle stream is as feed stream so that:

\[ y_{H2O} = 0.33 \]
\[ y_{IPA} = 0.67 = \frac{n_{IPA17}}{n_{T17}} = \frac{9.053}{n_{T17}} \]
\[ n_{T17} = \frac{n_{IPA17}}{y_{IPA}} = \frac{9.053}{0.67} = 13.512 \text{ kmol/h} \]
\[ n_{H2O17} = n_{T17} - n_{IPA17} = 13.512 - 9.053 = 4.459 \text{ kmol/h} \]
\[ n_{H2O16} = n_{H2O15} - n_{H2O17} = 652.43 - 4.459 = 647.97 \text{ kmol/h} \]
2.6 FEED DRUM

\[
\begin{align*}
\text{i-propyl-alcohol} & = 9.053 \text{ kmol/h} \\
\text{water} & = 4.459 \text{ kmol/h}
\end{align*}
\]

\[
\begin{align*}
\text{i-propyl-alcohol} & = 100 \text{ kmol/h} \\
\text{water} & = 49.25 \text{ kmol/h}
\end{align*}
\]

Input = Output

\[
\begin{align*}
n_{IPA2} & = n_{IPA1} + n_{IPA17} \\
n_{IPA1} & = 100 - 9.053 = 90.947 \text{ kmol/h} \\
n_{H_2O2} & = n_{H_2O1} + n_{H_2O17} \\
n_{H_2O1} & = 49.25 - 4.459 = 44.791 \text{ kmol/h} \\
n_{H_2O1} & = 49.25 - 4.459 = 44.791 \text{ kmol/h}
\end{align*}
\]

Acetone product

\[
\begin{align*}
n_{acetone14} & = 89.823 \frac{kmol}{hr} \times 58.08 \frac{kg}{kmol} \times \frac{1ton}{10^3 kg} \times \frac{7920hr}{1year} = 41318.005 \text{ ton/year}
\end{align*}
\]

since 33000 tons/year acetone is wanted to produce, all of these calculations should be correlated as this amount. These new values are shown in Table (3.3).

scale factor \(\frac{33000}{41318.005} = 0.7987\)

to allow for loses round off to 0.8

The calculated material balances are given in Tables (2.3) & (2.4).
Table (2.3) calculated mol and mass values of substances

<table>
<thead>
<tr>
<th>Component line stream no.</th>
<th>Acetone</th>
<th>i-propyl-alcohol</th>
<th>Water</th>
<th>Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kmole/hr</td>
<td>Kg/hr</td>
<td>Kmole/hr</td>
<td>Kg/hr</td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
<td>90.947</td>
<td>5456.82</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td>-</td>
<td>100</td>
<td>6000</td>
</tr>
<tr>
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<td>-</td>
<td>-</td>
<td>100</td>
<td>6000</td>
</tr>
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<td>-</td>
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<td>6000</td>
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<tr>
<td>16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>17</td>
<td>0.0899</td>
<td>5.2142</td>
<td>9.053</td>
<td>543.18</td>
</tr>
</tbody>
</table>
Chapter Two: Material Balance Calculations

<table>
<thead>
<tr>
<th>Component line stream no.</th>
<th>Acetone</th>
<th>Water</th>
<th>Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Kg/hr</td>
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<td>1</td>
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</table>
Chapter Three

Energy Balance Calculations
3. ENERGY BALANCES

3.1 FEED DRUM

T = 25°C
m_{i-\text{propyl-alcohol}} = 4366.5 \text{ kg/hr}  
m_{\text{water}} = 645 \text{ kg/hr}

T = 32.2°C
m_{i-\text{propyl-alcohol}} = 4800 \text{ kg/hr}  
m_{\text{water}} = 709.2 \text{ kg/hr}

T = 100.3°C
m_{i-\text{propyl-alcohol}} = 434.52 \text{ kg/hr}  
m_{\text{water}} = 64.21 \text{ kg/hr}

Table (3.1) heat capacity for organic and inorganic materials

<table>
<thead>
<tr>
<th>components</th>
<th>(a)</th>
<th>(b \times 10^{-2})</th>
<th>(c \times 10^{-5})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone(_g)</td>
<td>71.96</td>
<td>20.10</td>
<td>-12.78</td>
</tr>
<tr>
<td>(H_2g)</td>
<td>28.84</td>
<td>0.00765</td>
<td>0.3288</td>
</tr>
<tr>
<td>(H_2O_g)</td>
<td>33.46</td>
<td>0.6880</td>
<td>0.6704</td>
</tr>
<tr>
<td>(H_2O_L)</td>
<td>18.2964</td>
<td>47.212</td>
<td>-133.88</td>
</tr>
<tr>
<td>IPA(_L)</td>
<td>23.247</td>
<td>1.886</td>
<td>6.405</td>
</tr>
</tbody>
</table>

\[ C_p = a + b \left( \frac{T_1 + T_2}{2} \right) + c \left( \frac{T_1^2 + T_1 T_2 + T_2^2}{3} \right) \]

\(T_{\text{ref}} = 25°C\)

\(C_{p,IPA1} = 1.715 \text{ kJ/kg.K} \quad C_{p,H_2O17} = 2.034 \text{ kJ/kg.K} \)

\(C_{p,IPA2} = 1.585 \text{ kJ/kg.K} \quad C_{p,H_2O2} = 2.161 \text{ kJ/kg.K} \)

\[ \sum H_R - \Delta H_R^\circ + q = \sum H_P \]

no reaction \(\Delta H_R^\circ = 0\)
adiabatic system \( q = 0 \)

\[
\sum H_R = \sum H_P
\]

\[
\sum H_R = H_{s1} + H_{s17}
\]

\( H_{s1} = 0 \) at \( T = ref = 25^\circ C \)

\[
\sum H_R = H_{s17} = (m_{\text{IPA}17} C_{\text{IPA}17} + m_{\text{H}_2\text{O}17} C_{\text{P,}H_2\text{O}17}) \times (373.3 - 298)
\]

\[
\sum H_P = (m_{\text{IPA}2} C_{\text{IPA}2} + m_{\text{H}_2\text{O}2} C_{\text{P,}H_2\text{O}2}) \times (T - 298)
\]

\[
\sum H_R = \sum H_P\]

\[
(434.52 \times 1.715 + 64.21 \times 2.034) \times (373.3 - 298) = (4800 \times 1.585 + 709.2 \times 2.161) \times (T - 298)
\]

\( T = 305.2 \, K = 32.2^\circ C \)
3.2 VAPORIZER

T = 32.2 °C  
\( m_{\text{propyl-alcohol}} = 4800 \text{ kg/hr} \)  
\( m_{\text{water}} = 709.2 \text{ kg/hr} \)

Calculation the bubble point for stream 3, the pressure is 2.0 bar

test T = 118°C

\[ \log p^* = A - \frac{B}{T + C} \]

For IPA

\[ \log p^* = 8.37895 - \frac{1788.02}{118 + 227.438} \]
\[ p^* = 1595.345398 \text{ mmHg} \]

\[ k_{IPA} = \frac{1595.345398}{\left( \frac{2}{1.013} \right) \times 760} = 1.06321 \]

For Water

\[ \log p^* = 7.96681 - \frac{1668.21}{118 + 228} \]
\[ p^* = 1397.635152 \text{ mmHg} \]

\[ k_{H_2O} = \frac{1397.635152}{\left( \frac{2}{1.013} \right) \times 760} = 0.93145 \]

Table (3.2) Specification of stream (S3)

<table>
<thead>
<tr>
<th>Component</th>
<th>mole fraction</th>
<th>( K_i )</th>
<th>( K_i X_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>IPA</td>
<td>0.67</td>
<td>1.06321</td>
<td>0.71235</td>
</tr>
<tr>
<td>Water</td>
<td>0.33</td>
<td>0.93145</td>
<td>0.30738</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total = 1.019</td>
<td></td>
</tr>
</tbody>
</table>

So the bubble point is 118°C
Calculation $\Delta H_u$

$$\Delta H_{vap} = \Delta H_f \left[ \frac{T_C - T}{T_C - T_b} \right]^{0.38}$$

For Water: $T_C = 647.3$ K

$T_b = 394.399$ K

$\Delta H_f = 39,838$ kJ/kmol

$$\Delta H_{vap \text{ water}} = 39,838 \left[ \frac{647.3 - 391}{647.3 - 394.399} \right]^{0.38} = 40,040.6197 \text{ kJ/kmol} = 2224.47887 \text{ kJ/kg}$$

For IPA: $T_C = 508.3$ K

$T_b = 375$ K

$\Delta H_f = 40,683$ kJ/kmol

$$\Delta H_{vap \text{ IPA}} = 40,683 \left[ \frac{508.3 - 391}{508.3 - 375} \right]^{0.38} = 38,753.48455 \text{ kJ/kmol} = 645.891 \text{ kJ/kg}$$

Energy balance around vaporizer

$$C_{IPA3} = 1.750 \text{ kJ/kgK} \quad C_{H_2O3} = 2.041 \text{ kJ/kgK}$$

$$\sum H_{R2} + q = \sum H_{P3}$$

$$= (m_{IPA2} C_{IPA2} + m_{H_2O2} C_{H_2O2}) \ast (305.2 - 298) + q = (m_{IPA3} C_{IPA3} + m_{H_2O3} C_{H_2O3}) \ast (391 - 298) + (m_{IPA} \Delta H_{IPA} + m_{H_2O} \Delta H_{IPA})$$

$$= (4800 \ast 1.585 + 709.2 \ast 2.161) \ast (305.2 - 298) + q = (4800 \ast 1.750 + 709.2 \ast 2.041) \ast (391 - 298) + (4800 \ast 645.891 + 709.2 \ast 2224.47887)$$

$$q = 5,527,874.993 \text{ kJ/hr}$$

Molten Salt: We assume $\Delta T = 20$, $C_{salt} = 1.56$ kJ/kg.K

$$q = m_{salt} C_{salt} \Delta T$$

$$m_{salt} = \frac{q}{C_{salt} \Delta T} = \frac{5,527,874.993}{20 \ast 1.56} = 177,175.4805 \text{ kg/hr} = 177.1754805 \text{ ton/hr}$$
### 3.3 PRE-HEATER

\[ T = 118 \, ^\circ \text{C} \]
\[ m_{\text{water}} = 709.2 \, \text{kg/hr} \]
\[ m_{\text{i-propyl-alcohol}} = 4800 \, \text{kg/hr} \]

\[ T = 325 \, ^\circ \text{C} \]
\[ m_{\text{i-propyl-alcohol}} = 4800 \, \text{kg/hr} \]
\[ m_{\text{water}} = 709.2 \, \text{kg/hr} \]

\[ C_{P,IPA4} = 2.170 \, \text{kJ/kg.K} \]
\[ C_{P,H_2O4} = 2.118 \, \text{kJ/kg.K} \]

\[ \sum H_{R3} + q = \sum H_{P4} \]
\[ (m_{IPA3} \, C_{P,IPA3} + m_{H_2O3} \, C_{P,H_2O3}) \times (391 - 298) + q = \]
\[ (m_{IPA4} \, C_{P,IPA4} + m_{H_2O4} \, C_{P,H_2O4}) \times (598 - 298) \]
\[ (4800 \times 1.750 + 709.2 \times 2.041) \times (391 - 298) + q = \]
\[ (4800 \times 2.170 + 709.2 \times 2.118) \times (598 - 298) \]
\[ q = 2,657,908.22 \, \text{kJ/hr} \]

**Molten Salt:** We assume \( \Delta T = 50 \), \( C_{P,salt} = 1.56 \, \text{kJ/kg.K} \)

\[ q = m_{salt} \, C_{P,salt} \, \Delta T \]
\[ m_{salt} = \frac{q}{C_{P,salt} \, \Delta T} = \frac{2,657,908.22}{50 \times 1.56} = 34,075.746 \, \text{kg/hr} = 34.75746 \, \text{ton/hr} \]
3.4 REACTOR

\[
\begin{align*}
T &= 325 \, ^\circ C \\
\text{m}_{\text{i}-\text{propyl-alcohol}} &= 4800 \text{ kg/hr} \\
\text{m}_{\text{water}} &= 709.2 \text{ kg/hr}
\end{align*}
\]

\[
\begin{align*}
T &= 350 \, ^\circ C \\
\text{m}_{\text{i}-\text{propyl-alcohol}} &= 480 \text{ kg/hr} \\
\text{m}_{\text{water}} &= 709.2 \text{ kg/hr} \\
\text{m}_{\text{acetone}} &= 4176 \text{ kg/hr} \\
\text{m}_{\text{H}} &= 144 \text{ kg/hr}
\end{align*}
\]

\[
(\text{CH}_3)_2 \text{CHOH} \rightarrow (\text{CH}_3)_2 \text{CO} + \text{H}_2
\]

\[
\begin{align*}
C_{p,IPA4} &= 2.170 \text{ kJ/kg.K} \; ; \; C_{p,H_2O4} = 2.118 \text{ kJ/kg.K} \\
C_{p,IPA5} &= 2.223 \text{ kJ/kg.K} \; ; \; C_{p,H_2O5} = 2.128 \text{ kJ/kg.K} \\
C_{p,acetone5} &= 2.349 \text{ kJ/kg.K} \; ; \; C_{p,H_2S} = 14.800 \text{ kJ/kg.K}
\end{align*}
\]

\[
\Delta H_R^o = 55.605 \text{ kJ/kg.K}
\]

\[
q = \sum H_P - \sum H_R + n \Delta H_R^o
\]

\[
q = (m_{\text{acetone5}} \cdot C_{p,acetone5} + m_{\text{H}_2S} \cdot C_{p,\text{H}_2S} + m_{\text{H}_2O5} \cdot C_{p,\text{H}_2O5} + m_{IPA5} \cdot C_{p,IPA5})*
\]

\[
(623 - 298) - (m_{IPA4} \cdot C_{p,IPA4} + m_{H}_2O4 \cdot C_{p,H}_2O4) * (598 - 298) + n \Delta H_R^o
\]

\[
q = (4176 * 2.349 + 144 * 14.800 + 709.2 * 2.128 + 480 * 2.223) *
\]

\[
(623 - 298) - (4800 * 2.170 + 709.2 * 2.118) * (598 - 298) + (55.605 * 72)
\]

\[
q = 1,146,551.4 \text{ kJ/hr}
\]

**Molten Salt**: We assume \(\Delta T = 50\), \(C_{p,salt} = 1.56 \text{ kJ/kg.K}\)

\[
q = m_{salt} \cdot C_{p,salt} \cdot \Delta T
\]

\[
m_{salt} = \frac{q}{C_{p,salt} \cdot \Delta T} = \frac{1,146,551.4}{50 \times 1.56} = 14,699.378 \text{ kg/hr} = 14.699378 \text{ ton/hr}
\]
3.5 COOLER

\[ T = 350 \, ^\circ \text{C} \]
\[ m_{\text{propyl-alcohol}} = 480 \, \text{kg/hr} \]
\[ m_{\text{water}} = 709.2 \, \text{kg/hr} \]
\[ m_{\text{acetone}} = 4176 \, \text{kg/hr} \]
\[ m_{H_2} = 144 \, \text{kg/hr} \]

\[ T = 93 \, ^\circ \text{C} \]
\[ m_{\text{propyl-alcohol}} = 480 \, \text{kg/hr} \]
\[ m_{\text{water}} = 709.2 \, \text{kg/hr} \]
\[ m_{\text{acetone}} = 4176 \, \text{kg/hr} \]
\[ m_{H_2} = 144 \, \text{kg/hr} \]

Calculate \( T_{dp} \) for stream 6

\[ T = 93 \, ^\circ \text{C} \]
\[ p_T = 1.5 \, \text{bar} \]
\[ P_T = 1125.37 \, \text{mmHg} \]

\[ \log p_l^* = 7.02447 - \frac{1161}{224 + 93} = 3.3620 \]
\[ p_l^* = 2301.492 \, \text{mmHg} \]
\[ k_{\text{acetone}} = \frac{2301.492}{1125.37} = 2.045 \]

\[ \log p_l^* = 8.37895 - \frac{1788.02}{227.438 + 93} = 2.7990 \]
\[ p_l^* = 629.5425 \, \text{mmHg} \]
\[ k_{\text{IPA}} = \frac{629.5425}{1125.37} = 0.5594 \]

\[ \log p_l^* = 7.96618 - \frac{1668.21}{228 + 93} = 2.7699 \]
\[ p_i^* = 588.7 \text{ mmHg} \]
\[ k_{H_2O} = \frac{588.7}{1125.37} = 0.523 \]

**Table (3.3) Specification of stream \((S_6)\)**

<table>
<thead>
<tr>
<th>Components</th>
<th>Mole fraction</th>
<th>(K_i)</th>
<th>(\sum X_i = \frac{y_i}{K_i})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>0.603</td>
<td>2.045</td>
<td>0.2949</td>
</tr>
<tr>
<td>Water</td>
<td>0.33</td>
<td>0.5231</td>
<td>0.6309</td>
</tr>
<tr>
<td>IPA</td>
<td>0.067</td>
<td>0.5594</td>
<td>0.1198</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>-</td>
<td>(\sum X_i = 1.045 \approx 1)</td>
</tr>
</tbody>
</table>

**Table (3.4) \(C_p\) values \(kJ / kg.K\) for stream \((S_5)\) and \((S_6)\)**

<table>
<thead>
<tr>
<th>Components</th>
<th>(C_p) at 350°C (kJ/kg.K)</th>
<th>(C_p) at 93°C (kJ/kg.K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>2.349</td>
<td>2.147</td>
</tr>
<tr>
<td>Water</td>
<td>2.128</td>
<td>1.497</td>
</tr>
<tr>
<td>IPA</td>
<td>2.223</td>
<td>1.702</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>14.80</td>
<td>14.6145</td>
</tr>
</tbody>
</table>

Energy balance:

\[
q = \sum H_P - \sum H_R
\]

\[
q = (m_{acetone6} C_{P, acetone6} + m_{H_2O} C_{P, H_2O} + m_{H_2O5} C_{P, H_2O5} + m_{IPA6} C_{P, IPA6}) \times (366 - 298) -
\]

\[
\left( m_{acetone5} C_{P, acetone5} + m_{H_2S} C_{P, H_2S} + m_{H_2O5} C_{P, H_2O5} + m_{IPA5} C_{P, IPA5} \right) \times (623 - 298) -
\]

\[
\left( 4176 \times 2.147 + 144 \times 14.6145 + 709.2 \times 1.497 + 480 \times 1.702 \right) \times (366 - 298) -
\]

\[
\left( 4176 \times 2.349 + 144 \times 14.80 + 709.2 \times 2.128 + 480 \times 2.223 \right) \times (623 - 298)
\]

\[
q = -3,837,308.613 \text{ kJ/hr}
\]

**Molten Salt**: We assume \(\Delta T = 20\)

\[
C_{P, H_2O} = 4.179 \text{ kJ/kg.K}
\]

\[
q = m_{salt} C_{p, salt} \Delta T
\]

\[
m_{salt} = \frac{q}{C_{p, salt}} \Delta T = \frac{3,837,308.613}{20 \times 4.179} = 45911.804 \text{ kg/hr} = 45.911804 \text{ ton/hr}
\]
3.6 CONDENSER

\( T=93^\circ C \ (T_{dp}) \)

\[
\begin{align*}
\text{m}_{\text{water}} &= 709.2 \text{ kg/hr} \\
\text{m}_{\text{acetone}} &= 4176 \text{ kg/hr} \\
\text{m}_\text{H}_2 &= 144 \text{ kg/hr} \\
\text{m}_{\text{IPA}} &= 480 \text{ kg/hr}
\end{align*}
\]

\( T=81^\circ C \ (T_{bp}) \)

\[
\begin{align*}
\text{m}_{\text{water}} &= 709.2 \text{ kg/hr} \\
\text{m}_{\text{acetone}} &= 4176 \text{ kg/hr} \\
\text{m}_\text{H}_2 &= 144 \text{ kg/hr} \\
\text{m}_{\text{IPA}} &= 480 \text{ kg/hr}
\end{align*}
\]

calculate the temperature \( T_{bp} \) of stream 7
Assume \( P_T = 1.5 \text{ bar} \)
\( P_T = 1125.37 \text{ mmHg} \)
Test \( T = 81^\circ C \)

- **For acetone**

\[
\log p_i^* = 7.02447 - \frac{1161}{224 + 81} = 3.2179
\]

\( p_i^* = 1651.629468 \text{ mmHg} \)

\( k_{\text{acetone}} = \frac{1651.629468}{1125.37} = 1.467 \)

- **For 1-propyl-alcohol**

\[
\log p_i^* = 8.37895 - \frac{1788.02}{227.438 + 81} = 2.5819
\]

\( p_i^* = 381.856 \text{ mmHg} \)

\( k_{\text{IPA}} = \frac{381.856}{1125.37} = 0.3393 \)

- **For water**

\[
\log p_i^* = 7.96681 - \frac{1668.21}{228 + 81} = 2.5681
\]

\( p_i^* = 381.856 \text{ mmHg} \)
Chapter Three: Energy Balance Calculations

\[
k_{H_2O} = \frac{381.856}{1125.37} = 0.3286
\]

**Table (3.5) Specification of stream \((S_7)\)**

<table>
<thead>
<tr>
<th>Components</th>
<th>Mole fraction</th>
<th>(K_i)</th>
<th>(K_i X_i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>0.603</td>
<td>1.4676</td>
<td>0.8849</td>
</tr>
<tr>
<td>Water</td>
<td>0.33</td>
<td>0.3287</td>
<td>0.1085</td>
</tr>
<tr>
<td>IPA</td>
<td>0.067</td>
<td>0.3393</td>
<td>0.0227</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.016 ≈ 1</td>
</tr>
</tbody>
</table>

So the bubble point for \(S_7 = 81^\circ C\)

\(C_{P,IPA} = 1.678 \text{ kJ/kg.K} \); \(C_{P,H_2O} = 1.643 \text{ kJ/kg.K}\)

\(C_{P,acetone7} = 2.135 \text{ kJ/kg.K} \); \(C_{p,H_2O} = 14.607 \text{ kJ/kg.K}\)

**For Water:** \(T_C = 647.3 \text{ K}\)
\(T_b = 385.186 \text{ K}\)
\(\Delta H_f = 40.683 \text{ kJ/kmol}\)

\[
\Delta H_{vap H_2O} = 40.683 \left[ \frac{647.3 - 354}{647.3 - 385.116} \right]^{0.38} = 42,454.253 \text{ kJ/kmol}
\]
\(= 2358 \text{ kJ/kg}\)

**For IPA:** \(T_C = 508.3 \text{ K}\)
\(T_b = 366.6 \text{ K}\)
\(\Delta H_f = 39,858 \text{ kJ/kmol}\)

\[
\Delta H_{vap IPA} = 39,858 \left[ \frac{508.3 - 354}{508.3 - 366.6} \right]^{0.38} = 41,169.350 \text{ kJ/kmol}
\]
\(= 686.155 \text{ kJ/kg}\)

**For Acetone:** \(T_C = 508.1 \text{ K}\)
\(T_b = 341.5 \text{ K}\)
\(\Delta H_f = 29,140 \text{ kJ/kmol}\)

\[
\Delta H_{vap acetone} = 29,140 \left[ \frac{508.1 - 354}{508.1 - 341.5} \right]^{0.38} = 28,289.029 \text{ kJ/kmol}
\]
\(= 487.741 \text{ kJ/kg}\)
Chapter Three: Energy Balance Calculations

Energy balance around condenser

\[ \sum H_{R6} + q_T = \sum H_{P7} + \sum m_i \Delta H_{vap} \]

\[ q_T = \sum H_{P7} - \sum H_{R6} + \sum m_i \Delta H_{vap} \]

\[ q_T = \left( m_{IPA7} C_{P,IPA7} + m_{H_2O7} C_{P,H_2O7} + m_{acetone7} C_{P,acetone7} + m_{H_27} C_{P,H_27} \right) \times (354 - 298) - \left( m_{IPA6} C_{P,IPA6} + m_{H_2O6} C_{P,H_2O6} + m_{acetones6} C_{P,acetone6} + m_{H_26} C_{P,H_26} \right) \times (366 - 298) + \left( m_{IPA} \Delta H_{v,IPA} + m_{H_2O} \Delta H_{v,H_2O} + m_{acetone} \Delta H_{v,acetone} \right) \]

\[ q_T = (480 \times 1.678 + 709.2 \times 1.643 + 4176 \times 2.135 + 144 \times 14.607) \times (56) - (480 \times 1.702 + 709.2 \times 1.497 + 4176 \times 2.147 + 144 \times 14.6145) \times (68) + (480 \times 686.155 + 709.2 \times 2358.569 + 4176 \times 487.741) \]

\[ q_T = 3,885,761 \text{ kJ/hr} \]

**Water required:** We assume \( \Delta T = 20 \quad C_{p,water} = 4.182 \text{ kJ/kg.K} \)

\[ q = m_{water} C_{p,water} \Delta T \]

\[ m_{water} = \frac{q_T}{C_{p,water} \Delta T} = \frac{38,85,761}{20 \times 4.182} = 46458.172 \text{ kg/hr} = 46.458172 \text{ ton/hr} \]

**FLASH UNIT**

The flash unit is assumed to be isothermal, the temperature of S8 and S9 is equal to temperature of S7 = 81°C
3.7 SCRUBBER

Energy balance

Assumptions :-

- The scrubber is adiabatic
- The temperature of water inlet = 25°C
- The temperature of $S_{12}$ = 50°C
- The pressure of the unit is 1.5 bar and assumed to be constant
Table (3.6) $C_p$ values $kJ / kg.K$ for (S8) and (S10) and (S11) and (S12)

<table>
<thead>
<tr>
<th>Components</th>
<th>S8</th>
<th>S10</th>
<th>S11</th>
<th>S12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>2.135</td>
<td>2.088</td>
<td>_</td>
<td>2.104</td>
</tr>
<tr>
<td>Water</td>
<td>1.643</td>
<td>2.136</td>
<td>0</td>
<td>_</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>14.607</td>
<td>_</td>
<td>_</td>
<td>14.590</td>
</tr>
<tr>
<td>IPA</td>
<td>1.678</td>
<td>1.591</td>
<td>_</td>
<td>_</td>
</tr>
</tbody>
</table>

\[ \sum H_R - \Delta H_R^0 + q = \sum H_P \]

no reaction $\Delta H_R^0 = 0$

adiabatic system $q = 0$

\[ \sum H_R = \sum H_P \]

\[ \sum H_R = H_{s11} + H_{s8} \]

$H_{s11} = 0$ at $T = ref = 25\degree C$

\[ \sum H_R = (m_{IPA8} C_{p,IPA8} + m_{H_2O8} C_{p,H_2O8} + m_{acetone8} C_{p,acetone8} + m_{H_2S8} C_{p,H_2S8}) \]

\[ \times (354 - 298) \]

\[ \sum H_R = (36.768 \times 1.678 + 48.5424 \times 1.643 + 1122.1376 \times 2.135 + 144 \]

\[ \times 14.607) \times (56) \]

\[ \sum H_R = 259925.8148 \text{ kJ/hr} \]

\[ \sum H_P = H_{s12} + H_{s10} \]
$H_{s12} = (m_{acetone12} C_p,acetone12 + m_{H_212} C_{p,H_212}) \cdot (323 - 298)$

$H_{s12} = (1.12213 \cdot 2.104 + 144 \cdot 14.590) \cdot (25) = 52,584.68769 \text{ kJ/hr}$

$H_{s10} = \left(m_{IPA10} C_p,IPA10 + m_{H_2O10} C_{p,H_2O10} + m_{acetone10} C_{p,acetone10}\right) \cdot (T - 298)$

Assume $T = 307.845$ K

$H_{s10} = (36.768 \cdot 1.591 + 8739.9504 \cdot 2.136 + 1119.3536 \cdot 2.088) \cdot (307.845 - 298) = 207,389.4669 \text{ kJ/hr}$

$\sum H_p = 52,584.68769 + 207,389.4669 = 259,974.1546 \text{ kJ/hr}$

Then $T = 307.845 \text{ K} = 34.854^\circ\text{C}$
3.8 MIXING POINT

T = 34.854 °C
m\text{\textsubscript{i-propyl-alcohol}} = 36.768 kg/hr
m\text{\textsubscript{water}} = 8739.9504 kg/hr
m\text{\textsubscript{acetone}} = 1119.3536 kg/hr

T = 81 °C
m\text{\textsubscript{i-propyl-alcohol}} = 441.31 kg/hr
m\text{\textsubscript{water}} = 655.07 kg/hr
m\text{\textsubscript{acetone}} = 3052.61 kg/hr

T = 48.81 °C
m\text{\textsubscript{i-propyl-alcohol}} = 478.08 kg/hr
m\text{\textsubscript{water}} = 9394.992 kg/hr
m\text{\textsubscript{acetone}} = 4171.963 kg/hr

Energy balance around the mixing point

\[ \sum H_9 + \sum H_{10} = \sum H_{13} \]
\[ \sum H_9 = \left( m_{IPA9} \cdot C_{IPA9} + m_{H_2O9} \cdot C_{H_2O9} + m_{acetone9} \cdot C_{acetone9} \right) \times (354 - 298) \]
\[ \sum H_9 = (441.312 \times 1.678 + 655.0704 \times 1.643 + 3052.6096 \times 2.135) \times (56) \]
\[ \sum H_9 = 466,710.9272 \]
\[ \sum H_9 + \sum H_{10} = 674,100.3941 \text{ kJ/hr} \]
\[ C_{P,acetone13} = 2.103 \text{ kJ/kg.K} \quad C_{P,IPA13} = 1.617 \text{ kJ/kg.K} \]
\[ C_{P,H_2O13} = 1.998 \text{ kJ/kg.K} \]
\[ \sum H_{13} = \left( m_{IPA13} \cdot C_{IPA13} + m_{H_2O13} \cdot C_{H_2O13} + m_{acetone13} \cdot C_{acetone13} \right) \times (T - 298) \]

Assuming \( T = 48.81 °C \)
\[ \sum H_{13} = (878.08 \times 1.617 + 9394.992 \times 1.998 + 4171.963 \times 2.103 \times (321.81 - 298) \]
\[ \sum H_{13} = 674,260.9606 \text{ kJ/hr} \]
3.9 ACETONE COLUMN

The pressure is 1.1 bar

We calculate the $T_b$ for each component using the following formula

$$\ln P^* = A - \frac{B}{T}$$

For acetone

$P_c = 47$ bar \hspace{1cm} $T_c = 508.1$ K

$P = 1.0133$ bar \hspace{1cm} $T = 329.2$ K (normal boiling point)

$$\ln 1.0133 = A - \frac{B}{329.2}$$

$$\ln 47 = A - \frac{B}{508.1}$$

Then; $A = 10.91$ and $B = 3587.3$

At 1.1 bar pressure, boiling point is;
\[
\ln 1.1 = 10.91 - \frac{3587.3}{T_b} \\
T_b = 331.7 \text{ K}
\]

\[\checkmark \quad \text{For I-propyl-alcohol}\]

\[\begin{align*}
P_c &= 47.6 \text{ bar} \\
T_c &= 508.3 \text{ K} \\
P &= 1.0133 \text{ bar} \\
T &= 355.35 \text{ K (normal boiling point)}
\end{align*}\]

\[
\ln 1.0133 = A - \frac{B}{355.35}
\]

\[
\ln 47.6 = A - \frac{B}{508.3}
\]

Then; \( A = 12.807 \) and \( B = 4546.375 \)

At 1.1 bar pressure, boiling point is;

\[
\ln 1.1 = 12.807 - \frac{4546.375}{T_b}
\]

\[T_b = 357.65 \text{ K}\]

\[\checkmark \quad \text{For water}\]

\[\begin{align*}
P_c &= 220.5 \text{ bar} \\
T_c &= 647.3 \text{ K} \\
P &= 1.0133 \text{ bar} \\
T &= 373.15 \text{ K (normal boiling point)}
\end{align*}\]

\[
\ln 1.0133 = A - \frac{B}{373.15}
\]

\[
\ln 220.5 = A - \frac{B}{647.3}
\]

Then; \( A = 12.72 \) and \( B = 4743.39 \)

At 1.1 bar pressure, boiling point is;

\[
\ln 1.1 = 12.72 - \frac{4743.39}{T_b}
\]

\[T_b = 375.723 \text{ K}\]
Calculation the bubble point for $S_{14}$
Test $T = 58.7^\circ C$

- **For 1-propyl-alcohol**

  \[
  \log p^\ast = 8.37895 - \frac{1788.02}{58.7 + 227.438} = 2.1301
  \]

  \[
  p^\ast = 134.927 \text{ mmHg}
  \]

  \[
  k_{IPA} = \frac{134.927}{825.27} = 0.16349
  \]

- **For acetone**

  \[
  \log p^\ast = 7.02447 - \frac{1161}{58.7 + 224} = 2.91764
  \]

  \[
  p^\ast = 827.256 \text{ mmHg}
  \]

  \[
  k_{acetone} = \frac{827.256}{825.27} = 1.00241
  \]

**Table (3.7) Specification of stream ($S_{14}$)**

<table>
<thead>
<tr>
<th>Component</th>
<th>Mole fraction</th>
<th>$k_i$</th>
<th>$k_i x_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>0.9899</td>
<td>1.00241</td>
<td>0.99229</td>
</tr>
<tr>
<td>IPA</td>
<td>0.0101</td>
<td>0.16349</td>
<td>0.001651</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>-</td>
<td>$\sum k_i x_i = 0.9939 \approx 1$</td>
</tr>
</tbody>
</table>

So the bubble point is $58.7^\circ C$

Calculation the dew point for stream 14

Take $T_{dp}$ for $S_{14} = T_{bp}$ for $S_{14}$

$T_{dp} = T_{bp} = 58.7^\circ C$

Calculation the bubble point for $S_{15}$
Test $T = 102.5^\circ C$

- **For acetone**
\[ \log p_i^* = 7.02447 - \frac{1161}{224 + 102.5} = 3.4685 \]
\[ p_i^* = 2941.535776 \text{ mmHg} \]
\[ k_{\text{acetone}} = \frac{2941.535776}{825.27} = 3.564 \]

- For 1-propyl-alcohol

\[ \log p_i^* = 8.37895 - \frac{1788.02}{227.438 + 102.5} = 2.959 \]
\[ p_i^* = 911.0831355 \text{ mmHg} \]
\[ k_{IPA} = \frac{911.0831355}{825.27} = 1.1039 \]

- For water

\[ \log p_i^* = 7.96681 - \frac{1668.21}{228 + 102.5} = 2.9192 \]
\[ p_i^* = 830.378 \text{ mmHg} \]
\[ k_{H_2O} = \frac{830.378}{825.27} = 1.006 \]

Table (4.8) Specification of stream (S15)

<table>
<thead>
<tr>
<th>Component</th>
<th>Mole fraction</th>
<th>( k_i )</th>
<th>( k_i x_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>0.0001359</td>
<td>3.564</td>
<td>0.000484</td>
</tr>
<tr>
<td>IPA</td>
<td>0.01368</td>
<td>1.1039</td>
<td>0.0151</td>
</tr>
<tr>
<td>Water</td>
<td>0.9862</td>
<td>1.006</td>
<td>0.992</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>-</td>
<td>( \sum k_i x_i = 1.007 \approx 1 )</td>
</tr>
</tbody>
</table>

So the bubble point is 102.5°C

Calculate the minimum reflux ratio, \( R_m \)\[8\]

Use underwood equation

\[ R_m = \frac{1}{\alpha_{AB} - 1} \left[ \frac{x_{DA}}{x_{FA}} - \alpha_{AB} \frac{x_{DB}}{x_{FB}} \right] \]
\[ \alpha_{AB} = \frac{k_{\text{acetone}}}{k_{IPA}} = \frac{1.00241}{0.16349} = 6.1313 \]
Energy balance around condenser

Since \( T_{dp} = T_{bp} = 58.7^\circ C \)

Calculation \( \Delta H_{v} = \lambda_{mix} \)

At \( T = 58.7^\circ C \) and \( P = 1.1 \text{ bar} \)

**For Acetone:** \( T_C = 508.1 \text{ K} \)

\[
T_b = 331.7 \text{ K}
\]

\[
\Delta H_f = 29,140 \text{ kJ/kmol}
\]

\[
\Delta H_{vap \ acetone} = 29,140 \left[ \frac{508.1 - 331.7}{508.1 - 331.7} \right]^{0.38} = 29,140 \text{ kJ/kmol}
\]

**For IPA:** \( T_C = 508.3 \text{ K} \)

\[
T_b = 357.65 \text{ K}
\]

\[
\Delta H_f = 39,858 \text{ kJ/kmol}
\]

\[
\Delta H_{vap \ IPA} = 39,858 \left[ \frac{508.3 - 331.7}{508.3 - 357.65} \right]^{0.38} = 42,339 \text{ kJ/kmol}
\]

\[
\lambda_{mix} = y_{acetone} \Delta H_{vap \ acetone} + y_{IPA} \Delta H_{vap \ IPA}
\]

\[
\lambda_{mix} = 0.9899 \times 29,140 + 0.0101 \times 42,339 = 29,273.3099 \text{ kJ/kmol}
\]

\[
q_c = V \lambda_{mix}
\]

\[
q_c = 175.508 \times 29,273.3099 = 5,137,700.07393 \text{ kJ/hr}
\]

\[
q_c = m_c C_{p,c} \Delta T
\]
\[ C_{p,c} = 4.18 \text{ kJ/kg.K} \]

Take \( \Delta T = 25^\circ \text{C} \)

\[
m_c = \frac{q_c}{C_{p,c} \Delta T} = \frac{5,137,700.07393}{4.18 \times 25} = 49,164.59401 \text{ kg/hr}
\]

\[ C_{p,IPA14} = 1.636 \text{ kJ/kg.K} ; \quad C_{p,acetone14} = 2.1131 \text{ kJ/kg.K} \]

\[ C_{p,IPA15} = 1.7205 \text{ kJ/kg.K} ; \quad C_{p,acetone15} = 2.1567 \text{ kJ/kg.K} \]

\[ C_{p,water15} = 2.035 \text{ kJ/kg.K} \]

Overall energy balance

\[ F \Delta H_F + q_r = D \Delta H_D + W \Delta H_W + q_c \]
\[ \Delta H_F = C_{p,mix} \Delta T \]

\[ C_{p,mix} = \sum C_{p,i} x_i \]

\[ C_{p,mix} = 0.11951 \times 2.1029 + 0.01323 \times 1.6171 + 0.86724 \times 1.998 \]
\[ = 2.0054 \text{ kJ/kg.K} \]

\[ \Delta H_F = 2.0054 \times (321.81 - 298) = 47.7485 \text{ kJ/kg} \]

\[ \Delta H_D = C_{p,mix} \Delta T \]

\[ C_{p,mix} = 0.9899 \times 2.1131 + 0.0101 \times 1.6360 = 2.1082 \text{ kJ/kg.K} \]

\[ \Delta H_D = 2.1082 \times (331.7 - 298) = 71.0463 \text{ kJ/kg} \]

\[ \Delta H_W = C_{p,mix} \Delta T \]

\[ C_{p,mix} = 2.1567 \times 0.00013 + 0.0136 \times 1.7205 + 0.9861 \times 2.035 = 2.0303 \text{ kJ/kg.K} \]

\[ \Delta H_W = 2.0303 \times (375.5 - 298) = 157.3482 \text{ kJ/kg} \]

\[ q_r = D \Delta H_D + W \Delta H_W + q_c - F \Delta H_F \]

\[ q_r = 4211.35 \times 71.0463 + 9833.7 \times 157.3482 + 5,137,700.07393 - 14,045.05 \times 47.7485 \]

\[ q_r = 6,313,585.83385 \text{ kJ/hr} \]

Steam required

\[ q_r = m_s \lambda_s \]

\[ m_s = \frac{q_r}{\lambda_s} = \frac{6,313,585.83385}{2260} = 2793.6221 \text{ kg/hr} \]
3.10  IPA COLUMN

Calculation the bubble point for $S_{17}$, the pressure is 1.1 bar
Test $T = 100.3^\circ C$

- **For acetone**

  \[
  \log{p_i^*} = 7.02447 - \frac{1161}{224 + 100.3} = 3.4444 \\
  p_i^* = 2782.604 \text{ mmHg} \\
  k_{acetone} = \frac{2782.604}{825.27} = 3.3717
  \]

- **For I-propyl-alcohol**

  \[
  \log{p_i^*} = 8.37895 - \frac{1788.02}{227.438 + 100.3} = 2.9233 \\
  p_i^* = 838.1305 \text{ mmHg}
  \]
$k_{IPA} = \frac{838.1305}{825.27} = 1.0155$

- **For water**

$$\log p_i^* = 7.96681 - \frac{1668.21}{228 + 100.3} = 2.8854$$

$$p_i^* = 768.1596 \text{ mmHg}$$

$$k_{H_2O} = \frac{768.1596}{825.27} = 0.9307$$

**Table (3.9) Specification of stream (S15)**

<table>
<thead>
<tr>
<th>Component</th>
<th>Mole fraction</th>
<th>$k_i$</th>
<th>$k_ix_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>0.006598</td>
<td>3.3717</td>
<td>0.0222</td>
</tr>
<tr>
<td>IPA</td>
<td>0.6655</td>
<td>1.0155</td>
<td>0.6758</td>
</tr>
<tr>
<td>Water</td>
<td>0.3278</td>
<td>0.9307</td>
<td>0.3050</td>
</tr>
<tr>
<td><strong>∑</strong></td>
<td><strong>-</strong></td>
<td><strong>-</strong></td>
<td><strong>-</strong></td>
</tr>
</tbody>
</table>

$$\Sigma k_ix_i = 1.003 \cong 1$$

The bubble point is 100.3°C

Calculation the dew point for S17

Test $T = 100.5°C$

- **For acetone**

$$\log p_i^* = 7.02447 - \frac{1161}{224 + 100.5} = 3.4466$$

$$p_i^* = 2796.7779 \text{ mmHg}$$

$$k_{acetone} = \frac{2796.7779}{825.27} = 3.3879$$

- **For I-propyl-alcohol**

$$\log p_i^* = 8.37895 - \frac{1788.02}{227.438 + 100.5} = 2.9266$$
\[ p_l^* = 844.5763 \text{ mmHg} \]
\[ k_{IPA} = \frac{828.5142}{825.27} = 1.0233 \]

\[ \text{For water} \]
\[ \log p_l^* = 7.96681 - \frac{1668.21}{228 + 100.5} = 2.8885 \]
\[ p_l^* = 773.6511 \text{ mmHg} \]
\[ k_{H_2O} = \frac{773.6511}{825.27} = 0.9374 \]

**Table (3.10) Specification of stream (S17)**

<table>
<thead>
<tr>
<th>Component</th>
<th>Mole fraction</th>
<th>( k_i )</th>
<th>( \sum x_i = \frac{y_i}{k_i} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetone</td>
<td>0.006598</td>
<td>3.3879</td>
<td>0.00194</td>
</tr>
<tr>
<td>IPA</td>
<td>0.6655</td>
<td>1.0233</td>
<td>0.6503</td>
</tr>
<tr>
<td>Water</td>
<td>0.3278</td>
<td>0.9374</td>
<td>0.3496</td>
</tr>
<tr>
<td></td>
<td>_</td>
<td>_</td>
<td>( \sum x_i = 1.001 \equiv 1 )</td>
</tr>
</tbody>
</table>

So the dew point is 100.5°C

Calculation the bubble point for \( S_{16} \)
\[ P_c = 220.5 \text{ bar} \quad T_c = 647.3 \text{ K} \]
\[ P = 1.0133 \text{ bar} \quad T = 373.15 \text{ K} \text{ (normal boiling point)} \]

\[ \ln 1.0133 = A - \frac{B}{373.15} \]
\[ \ln 220.5 = A - \frac{B}{647.3} \]

Then; \( A = 12.72 \) and \( B = 4743.39 \)

At 1.1 bar pressure, boiling point is;
\[ \ln 1.1 = 12.72 - \frac{4743.39}{T_b} \]
\[ T_b = 375.723 \text{ K} \]
Calculate the reflux ratio $R_m^{[8]}$

Use underwood equation

$$R_m = \frac{1}{\alpha_{AB} - 1} \left[ \frac{x_{DA}}{x_{FA}} - \frac{x_{DB}}{x_{FB}} \right]$$

$$\alpha_{AB} = \frac{k_{acetone}}{k_{water}} = \frac{3.3879}{0.9374} = 3.614$$

$$R_m = \frac{1}{3.614 - 1} \left[ \frac{0.006598}{0.0001359} - \frac{3.614}{0.9862} \right]$$

$$R_m = 18.11368$$

$$R = 1.2 \times R_m = 1.2 \times 18.11368 = 21.73642$$

$$R = \frac{L}{D}$$

$$L = R \times D = 21.73642 \times 10.881 = 236.51394 \text{ kmol/hr}$$

$$V = L + D = 236.51394 + 10.881 = 247.39494 \text{ kmol/hr}$$

Calculation $\Delta H_v = \lambda_{mix}$

At $T = 100.5^\circ C$ and $P = 1.1 \text{ bar}$

**For Acetone:**

$T_C = 508.1 \text{ K}$

$T_b = 331.7 \text{ K}$

$\Delta H_f = 29,140 \text{ kJ/kmol}$

$$\Delta H_{vap \text{ acetone}} = 29,140 \left[ \frac{508.1 - 373.5}{508.1 - 331.7} \right]^{0.38} = 26,294.0334 \text{ kJ/kmol}$$

**For IPA:**

$T_C = 508.3 \text{ K}$

$T_b = 357.65 \text{ K}$

$\Delta H_f = 39,858 \text{ kJ/kmol}$

$$\Delta H_{vap \text{ IPA}} = 39,858 \left[ \frac{508.3 - 373.5}{508.3 - 357.65} \right]^{0.38} = 38,209.3272 \text{ kJ/kmol}$$

**For water:**

$T_C = 647.3 \text{ K}$

$T_b = 375.723 \text{ K}$
\[ \Delta H_f = 40,683 \text{ kJ/kmol} \]

\[ \Delta H_{\text{vap water}} = 40,683 \left[ \frac{647.3 - 373.5}{647.3 - 375.723} \right]^{0.38} = 40,809.2247 \text{ kJ/kmol} \]

\[ \lambda_{\text{mix}} = y_{\text{acetone}} \Delta H_{\text{acetone}} + y_{\text{IPA}} \Delta H_{\text{IPA}} + y_{\text{water}} \Delta H_{\text{water}} \]

\[ \lambda_{\text{mix}} = 0.006598 \times 26294.0334 + 0.6655 \times 38209.3272 + 0.3278 \times 40809.2247 \]

\[ \lambda_{\text{mix}} = 38,982.77151 \text{ kJ/kmol} \]

\[ q_c = V \lambda_{\text{mix}} \]

\[ q_c = 247.39494 \times 38,982.77151 = 9,644,140.4184 \text{ kJ/hr} \]

\[ q_c = m_c C_{p,c} \Delta T \]

\[ C_{p,c} = 4.18 \text{ kJ/kg.K} \]

Take \( \Delta T = 25^\circ C \)

\[ m_c = \frac{q_c}{C_{p,c} \Delta T} = \frac{9644140.4184}{4.18 \times 25} = 92,288.4251 \text{ kg/hr} \]

\[ C_{p,\text{IPA17}} = 1.715 \text{ kJ/kg.K} ; C_{p,\text{acetone17}} = 2.528 \text{ kJ/kg.K} \]

\[ C_{p,\text{water17}} = 2.034 \text{ kJ/kg.K} ; C_{p,\text{water16}} = 2.035 \text{ kJ/kg.K} \]

Overall energy balance

\[ F \Delta H_F + q_r = D \Delta H_D + W \Delta H_W + q_c \]

\[ \Delta H_F = C_{p,mix} \Delta T \]

\[ C_{p,mix} = \sum C_{p,i} x_i \]

\[ C_{p,mix} = 2.1567 \times 0.00013 + 0.0136 \times 1.7205 + 0.9861 \times 2.035 = 2.0303 \text{ kJ/kg.K} \]

\[ \Delta H_F = 2.0303 \times (375.5 - 298) = 157.3482 \text{ kJ/kg} \]

\[ \Delta H_D = C_{p,mix} \Delta T \]

\[ C_{p,mix} = 2.528 \times 0.000659 + 2.034 \times 0.33 + 1.715 \times 0.6655 = 1.8142 \text{ kJ/kg.K} \]

\[ \Delta H_D = 1.8142 \times (373 - 298) = 136.065 \text{ kJ/kg} \]

\[ \Delta H_W = C_{p,mix} \Delta T \]

\[ C_{p,mix} = 2.035 \times 1 = 2.035 \text{ kJ/kg.K} \]

\[ \Delta H_W = 2.035 \times (375 - 298) = 156.695 \text{ kJ/kg} \]
\[ q_r = D \Delta H_D + W \Delta H_W + q_c - F \Delta H_F \]
\[ q_r = 502.9 \times 136.065 + 9330.768 \times 156.695 + 9644140.4184 - 157.3482 \times 9833.7 \]
\[ q_r = 9,627,332.6782 \text{ kJ/hr} \]

Steam required
\[ q_r = m_s \lambda_s \]
\[ m_s = \frac{q_r}{\lambda_s} = \frac{9627332.6782}{2260} = 4259.88172 \text{ kg/hr} \]
Chapter Four

Special Design
4.1 Reactor design

Figure (4.1)  plug flow reactor
4.1.1 Capacity of plant for producing acetone from isopropanol

Acetone is produced by the dehydrogenation of isopropanol according to the following reaction: The reverse of above reaction can be neglected.

The catalyst used for the process decreases in activity as the amount of isopropanol fed increases. This effect on the reaction rate is expressed in the following \[ [8] \):

\[
\text{K} = 0.000254 \frac{\text{NT}}{V} (2.46 \ln \left(\frac{1}{1-\alpha} - \alpha\right))
\]

\[x_A = \text{conversion of isopropanol converted to acetone and side of reaction was neglected}\]

\[= \frac{\text{mole isopropanol converted}}{\text{moles isopropanol supplied}}\]

\[x_A = 0.9\]

\[K = \text{reaction rate constant} \ s^{-1}\]

\[K = 0.35 \ s^{-1}\]

\[N = \text{lb mol of isopropanol fed to converter per hour.}\]

\[N = 176.367 \text{ Ib mol/hr}\]

\[T = \text{absolute temperature R}^\circ\]

\[T = 1098.9 \text{ R}^\circ\]

\[V = \text{catalyst volume ft}^3\]

The fresh catalyst has an activity such that \[K = 0.30 \text{ s}^{-1}\]

After 10,000 lb of isopropanol per cubic foot of catalyst has been fed, \[K = 0.15 \text{s}^{-1}\]

A plot of log K versus total isopropanol fed as pound moles is straight line.

The maximum production of acetone can be considered as at zero time.
A constant temperature of 1098.9 R°(337.5°C) and a constant pressure of 2 atm are maintained throughout the entire process.

4.1.2 calculate volume of catalyst

\[
V = \frac{0.000254 \cdot N \cdot T}{K \cdot 2.46 \cdot \ln \left( \frac{1}{1-x_A} - x_A \right)}
\]

\[
V = \frac{0.000254 \cdot 176.367 \cdot 1098.9}{0.3 \cdot 2.46 \cdot \ln \left( \frac{1}{1-0.9} - 0.9 \right)}
\]

\[
V = 34.4416 \text{ ft}^3 = 0.98 \text{ m}^3
\]

volume of packing

Assume the void fraction equal 0.4, so

the volume of packing = \( \frac{\text{volume of catalyst}}{1-\epsilon} \) = \( \frac{0.98}{1-0.4} \) = 1.6333 m³

4.1.3 Number of tubes

Number of tubes = (volume of packing / volume of tube).

Volume of packing = 1.6333 m³

Volume of tubes = \( \pi (d_i^2 / 4) \) L.

L = 3.66 m.

d_i = 50.8 mm = 0.0508 m = 2 in.

\[
V = (\pi /4) (0.0508)^2 \cdot 3.66
\]

\[
= 0.785 \cdot 0.002581 \cdot 3.66
\]

\[
= 0.0074144 \text{ m}^3
\]

Number of tubes (N_t) = 1.6333 / 0.007414436 = 220.

4.1.4 Outside diameter of tubes
di = 2 in = 0.0508 m

do = di + 2t

t = 0.065 in

do = 2 + (2 * 0.065) = 2.13 in = 5.41 cm = 0.0541 m.

4.1.5 Temperature of downstream

\[ Q = 1146551 \text{ } kJ/hr. = 318486.39 \text{ } J/s \]

\[ A = \pi \times do \times L \times N \]

\[ A = (3.14) (0.0541) (3.66) (220) = 136.9607 \text{ } m^2 \]

assume \( (u) = 100 \text{ } W/m^2.\text{ } ^\circ \text{C} \)

\[ \Delta T_m = \left( \frac{Q}{U \times A} \right) \]

\[ \Delta T_m = \left( \frac{318486.39}{(100 \times 136.9607)} \right) = 23.25^\circ \text{C} \]

4.1.6 Diameter for tube bundle

\[ Db = do \times \left( \frac{N_t}{K_1^{(1/n_1)}} \right) \]

Db = bundle diameter mm

do = tube outside diameter = 0.0541 m = 54.1 mm

Square pitch = \( pt = 1.25 \times do \)

No of passes = 1

\[ K_1 = 0.215, \quad n_1 = 2.207 \quad \text{from Appendix Table (5.1)} \]

\[ Db = 54.1 \times (220 / 0.215)^{(1/2.207)} \]

\[ Db = 1251.0899 \text{ mm} = 1.2511 \text{ m.} \]

4.1.7 Diameter of shell
Ds - Db = 38 mm.

Ds = 38 + 1251.0899 = 1289.0899 mm

4.1.8 Calculate tube side coefficient (h_i):

Flow Area of shell (As) = ((P_t - do) D_s L_B) / P_t.

L_B = 0.2 D_s

Tube pitch (P_t) = 1.25 do = 1.25 * 54.1 = 67.625 mm

As = ((67.625 - 54.1) (1289.0899) (0.2 * 1289.0899)) / (67.625).

As = 66470.111 mm² = 0.06647 m².

Tube cross section area = (π /4) * (0.0508)² = 0.0020258 m²

Tube per pass = (220 / 1) = 220 tubes.

Total flow area = 220 * 0.0020258 = 0.4463 m²

Total mass = 4176 + 144 + 709.2 + 480 = 5509.2 kg / hr = 1.5303 kg / s.

Total mass velocity = (1.5303 / 0.4463) = 3.4289 kg / m² s.

Average gas density:

\[ \rho = \frac{(P * M_w)}{(R * T)} \]

T = (350 + 325) / 2 = 337.5°C

\[ \rho_{acetone} = \frac{(2 * 101.3 * 58)}{(8.314 * (337.5+273))} = 2.1862 \text{ kg} / \text{m}^3 \]

\[ \rho_{IPA} = \frac{(2 * 101.3 * 60)}{(8.314 * (337.5+273))} = 2.2616 \text{ kg} / \text{m}^3 \]

\[ \rho_{H_2} = \frac{(2 * 101.3 * 2)}{(8.314 * (337.5+273))} = 0.0754 \text{ kg} / \text{m}^3 \]

\[ \rho_{H_2O} = \frac{(2 * 101.3 * 18)}{(8.314 * (337.5+273))} = 0.6785 \text{ kg} / \text{m}^3 \]
\[ \rho_{av} = \sum \rho_i \chi_i = (2.2616 \times 0.0417) + (2.1862 \times 0.3761) + (0.0754 \times 0.3761) + (0.6785 \times 0.2058) \]
\[ \rho_{av} = 1.0845 \text{ kg/m}^3 \]

**Mass velocity** \((G_m)\)

\[ G_m = \frac{\text{tube side flow rate}}{N_t \pi d_i^2 / 4} \]
\[ G_m = \frac{1.5303}{220 \times \pi \times 0.0508^2 / 4} = 3.4275 \text{ kg/s m}^2 \]

**The velocity**

\[ v = \frac{G_m}{\rho} = \frac{3.4275}{1.0845} = 3.1604 \text{ m/s} \]

The Reynolds number

\[ Re = \frac{\rho d_i v}{\mu_{av}} \]
\[ \frac{1}{\mu_{av}} = \sum \frac{x_i}{\mu_i} \]

\(\mu\) Viscosity (pa s) of:

\(H_2 = 0.151 \times 10^{-4}\)
\(H_2O = 0.231 \times 10^{-4}\)
\(C_3H_6O = 0.172 \times 10^{-4}\)
\(C_3H_8O = 0.17 \times 10^{-4}\)

\[ \frac{1}{\mu_{av}} = \frac{0.758}{0.172 \times 10^{-4}} + \frac{0.0261}{0.151 \times 10^{-4}} + \frac{0.1287}{0.231 \times 10^{-4}} + \frac{0.0871}{0.17 \times 10^{-4}} \]
\[ \mu_{av} = 1.7701 \times 10^{-5} \text{ pa.s} \]
\[ Re = \frac{1.0845 \times 0.0508 \times 3.1604}{1.7701 \times 10^{-5}} = 9836.4303 \]

Where \( j_F \) "Friction factor " and obtained from the Appendix Figure (5.2)

\[ j_F = 0.005 \]

\[ C_{pav} = 2.6343 \text{ kJ/kg.K} \]

\[ K = \mu \left[ C_p + \frac{10.4}{M_w} \right] \]

\[ K_{H_2O} = 0.231 \times 10^{-1} \times \left( 2.128 + \frac{10.4}{18} \right) = 0.0625 \]

\[ K_{acetone} = 0.172 \times 10^{-1} \times \left( 2.349 + \frac{10.4}{58} \right) = 0.0434 \]

\[ K_{IPA} = 0.17 \times 10^{-1} \times \left( 2.223 + \frac{10.4}{60} \right) = 0.0407 \]

\[ K_{H_2} = 0.151 \times 10^{-1} \times \left( 14.80 + \frac{10.4}{2} \right) = 0.302 \]

\[ K_{av} = \sum K_i x_i = 0.0625 \times 0.1287 + 0.0434 \times 0.758 + 0.0407 \times 0.0871 + 0.302 \times 0.0261 \]

\[ K_{av} = 0.0524 \text{ w/m.K} \]

**The Prandtl number**

\[ Pr = \frac{\mu \cdot C_p}{K} \]

\[ Pr = \frac{1.7701 \times 10^{-5} \times 2.6343 \times 10^3}{0.0524} = 0.8899 \]

**The heat transfer coefficient**

\[ h_i = 1.86 \frac{k_f}{d_i} (Re Pr)^{0.33} \left[ \frac{d_i}{L} \right]^{0.33} \left[ \frac{\mu}{\mu_w} \right]^{0.14} \]
4.1.9 The pressure drop

\[ \frac{\Delta P}{L} = g (\rho_s - \rho)(1 - \epsilon) \]

\[ \Delta P = L g (\rho_s - \rho)(1 - \epsilon) \]

\[ L = Z = 3.66 \text{ m} \]

Assume : \( \epsilon = 0.40 \)

\[ \Delta P = 3.66 \times 9.81(3500 - 1.0845)(1 - 0.40) = 75,376.297 \text{ Pa} = 0.744 \text{ atm} \]
Chapter Five

Piping and Instrumentation
5.1 Introduction

The process flow-sheet shows the arrangement of the major pieces of equipment and their interconnection. It is a description of the nature of the process. The Piping and Instrument diagram (P and I diagram or PID) shows the engineering details of the equipment, instruments, piping, valves and fittings; and their arrangement. It is often called the Engineering Flow-sheet or Engineering Line Diagram\[12\].

The design of piping systems, and the specification of the process instrumentation and control systems, is usually done by specialist design groups, and a detailed discussion of piping design and control systems is beyond the scope of this book. Only general guide rules are given. The piping handbook edited by Nayyaret al. (2000) is particularly recommended for the guidance on the detailed design of piping systems and process instrumentation and control. The references cited in the text and listed at the end of the chapter should also be consulted\[12\].

5.2 The P and I diagram

The P and I diagram shows the arrangement of the process equipment, piping, pumps, instruments, valves and other fittings. It should include\[12\];

1. All process equipment identified by an equipment number. The equipment should be drawn roughly in proportion, and the location of nozzles shown.
2. All pipes, identified by a line number. The pipe size and material of construction should be shown. The material may be included as part of the line identification number.
3. All valves, control and block valves, with an identification number. The type and size should be shown. The type may be shown by the symbol used for the valve or included in the code used for the valve number.
4. Ancillary fittings that are part of the piping system, such as inline sight-glasses, strainers and steam traps; with an identification number.
5. Pumps, identified by a suitable code number.
6. All control loops and instruments, with an identification number. For simple processes, the utility (service) lines can be shown on the P and I diagram. For complex processes, separate diagrams should be used to show the service lines, so the information can be shown clearly, without cluttering up the diagram. The service connections to each unit should, however, be shown on the P and I diagram. The P and I diagram will resemble the process flow-sheet, but the process information is not shown. The same equipment identification numbers should be used on both diagrams\textsuperscript{12}.

### 5.3 Symbols and layout

The symbols used to show the equipment, valves, instruments and control loops will depend on the practice of the particular design office. The equipment symbols are usually more detailed than those used for the process flow-sheet\textsuperscript{12}.

### 5.4 Basic symbols

The symbols illustrated below\textsuperscript{12}:

![Control Valve Diagram](image)

**Figure (5.1) Control valve.**

This symbol is used to represent all types of control valve, and both pneumatic and electric actuators.
Chapter Five: Piping and Instrumentation

The direction of the arrow shows the position of the valve on failure of the power supply\textsuperscript{[12]}. 

![Figure 5.2](image1.png)  

**Figure (5.2)** Failure mode: Fails open, Fails shut, Maintains position.

![Figure 5.3](image2.png) 

**Figure (5.3)** Instruments and controllers: Locally mounted, Main panel mounted.

Locally mounted means that the controller and display is located out on the plant near to the sensing instrument location. Main panel means that they are located on a panel in the control room. Except on small plants, most controllers would be mounted in the control room \textsuperscript{[12]}. 

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5.5 Type of instrument

This is indicated on the circle representing the instrument-controller by a letter code see Table (5.1) \(^{12}\).

**Table (5.1) Letter Code for Instrument Symbols.**

<table>
<thead>
<tr>
<th>Property measured</th>
<th>First letter</th>
<th>Indicating only</th>
<th>Recording only</th>
<th>Controlling only</th>
<th>Indicating and controlling</th>
<th>Recording and controlling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow-rate</td>
<td>F</td>
<td>FI</td>
<td>FR</td>
<td>FC</td>
<td>FIC</td>
<td>FRC</td>
</tr>
<tr>
<td>Level</td>
<td>L</td>
<td>LI</td>
<td>LR</td>
<td>LC</td>
<td>LIC</td>
<td>LRC</td>
</tr>
<tr>
<td>Pressure</td>
<td>P</td>
<td>PI</td>
<td>PR</td>
<td>PC</td>
<td>PIC</td>
<td>PRC</td>
</tr>
<tr>
<td>Quality, analysis</td>
<td>Q</td>
<td>QI</td>
<td>QR</td>
<td>QC</td>
<td>QIC</td>
<td>QRC</td>
</tr>
<tr>
<td>Radiation</td>
<td>R</td>
<td>RI</td>
<td>RR</td>
<td>RC</td>
<td>RIC</td>
<td>RRC</td>
</tr>
<tr>
<td>Temperature</td>
<td>T</td>
<td>TI</td>
<td>TR</td>
<td>TC</td>
<td>TIC</td>
<td>TRC</td>
</tr>
<tr>
<td>Weight</td>
<td>W</td>
<td>WI</td>
<td>WR</td>
<td>WC</td>
<td>WIC</td>
<td>WRC</td>
</tr>
<tr>
<td>Any other property</td>
<td>X</td>
<td>XI</td>
<td>XR</td>
<td>XC</td>
<td>XIC</td>
<td>XRC</td>
</tr>
</tbody>
</table>

Notes \(^{12}\):

1. The letter A may be added to indicate an alarm; with H or L placed next to the instrument circle to indicate high or low.
2. D is used to show difference or differential; eg. PD for pressure differential.
3. F, as the second letter indicates ratio; eg. FFC indicates a flow ratio controller.

Consult the standard for the full letter code.

The first letter indicates the property measured; for example, F = flow. Subsequent letters indicate the function; for example, I = indicating , RC = recorder controller.

The suffixes E and A can be added to indicate emergency action and/or alarm functions.

The instrument connecting lines should be drawn in a manner to distinguish them from the main process lines. Dotted or cross-hatched lines are normally used.
Figure (5.4) A typical control loop.

5.6 Control and instrumentation

Instruments are provided to monitor the key process variables during plant operation. They may be incorporated in automatic control loops, or used for the manual monitoring of the process operation. They may also be part of an automatic computer data logging system. Instruments monitoring critical process variables will be fitted with automatic alarms to alert the operators to critical and hazardous situations. It is desirable that the process variable to be monitored be measured directly; often, however, this is impractical and some dependent variable, that is easier to measure, is monitored in its place. For example, in the control of distillation columns the continuous, on-line, analysis of the overhead product is desirable but difficult and expensive to achieve reliably, so temperature is often monitored as an indication of composition. The temperature instrument may form part of a control loop controlling, say, reflux flow; with the composition of the overheads checked frequently by sampling and laboratory analysis[12].

5.7 Instrumentation and control objectives

The primary objectives of the designer when specifying instrumentation and control schemes are [12].

1. Safe plant operation:
(a) To keep the process variables within known safe operating limits.
(b) To detect dangerous situations as they develop and to provide alarms and automatic shut-down systems.
(c) To provide interlocks and alarms to prevent dangerous operating procedures.

2. Production rate:
To achieve the design product output.

3. Product quality:
To maintain the product composition within the specified quality standards.

4. Cost:
To operate at the lowest production cost, commensurate with the other objectives.
These are not separate objectives and must be considered together. The order in which they are listed is not meant to imply the precedence of any objective over another, other than that of putting safety first. Product quality, production rate and the cost of production will be dependent on sales requirements. For example, it may be a better strategy to produce a better-quality product at a higher cost. In a typical chemical processing plant these objectives are achieved by a combination of automatic control, manual monitoring and laboratory analysis.
The following procedure can be used when drawing up preliminary P and I diagrams\textsuperscript{[12]}:

1. Identify and draw in those control loops that are obviously needed for steady plant operation, such as:
   (a) level controls.
   (b) flow controls.
   (c) pressure controls.
   (d) temperature controls.
2. Identify the key process variables that need to be controlled to achieve the specified product quality. Include control loops using direct measurement of the controlled variable, where possible; if not practicable, select a suitable dependent variable.
3. Identify and include those additional control loops required for safe operation, not already covered in steps 1 and 2.

4. Decide and show those ancillary instruments needed for the monitoring of the plant operation by the operators; and for trouble-shooting and plant development. It is well worthwhile including additional connections for instruments which may be needed for future trouble-shooting and development, even if the instruments are not installed permanently. This would include: extra thermo wells, pressure tappings, orifice flanges, and extra sample points.

5. Decide on the location of sample points.

6. Decide on the need for recorders and the location of the readout points, local or control room. This step would be done in conjunction with steps 1 to 4.

7. Decide on the alarms and interlocks needed; this would be done in conjunction with step 3.

5.8 Typical control system

5.8.1 Level control

In any equipment where an interface exists between two phases (e.g. liquid vapour), some means of maintaining the interface at the required level must be provided. This may be incorporated in the design of the equipment, as is usually done for decanters, or by automatic control of the flow from the equipment. Figure (5.5) shows a typical arrangement for the level control at the base of a column. The control valve should be placed on the discharge line from the pump.\(^{[12]}\)

![Figure (5.5) Level control](image_url)
5.8.2 Pressure control

Pressure control will be necessary for most systems handling vapour or gas. The method of control will depend on the nature of the process. Typical scheme are shown in Figures (5.6) a,b,c,d. The scheme shown in Figure (5.6 a) would not be used where the vented gas was toxic, or valuable. In these circumstances the vent should be taken to a vent recovery system, such as a scrubber\(^{[12]}\).

![Diagram](image)

**Figure (5.6)** (a) Pressure control by direct venting , (b) Venting of non-condensables after a condenser ,  (c) Condenser pressure control by controlling coolant flow , (d) Pressure control of a condenser by varying the heat-transfer area, area dependent on liquid level .
5.8.3 Flow control

Flow control is usually associated with inventory control in a storage tank or other equipment. There must be a reservoir to take up the changes in flow-rate\textsuperscript{[12]}.

To provide flow control on a compressor or pump running at a fixed speed and supplying a near constant volume output, a by-pass control would be used, as shown in Figures (5.7)\textsuperscript{[12]}.

**Figure (5.7)** (a) Flow control for a reciprocating pump, (b) Alternative scheme for a centrifugal compressor or pump.

5.8.4 Heat exchangers

Figure (5.8 a) shows the simplest arrangement, the temperature being controlled by varying the flow of the cooling or heating medium. If the exchange is between two
process streams whose flows are fixed, by-pass control will have to be used, as shown in Figure (5.8 b)\cite{12}.

![Figure (5.8)](image)

**Figure (5.8)** (a) Control of one fluid stream , (b) By-pass control .

### 5.8.5 Condenser control

Temperature control is unlikely to be effective for condensers, unless the liquid stream is sub-cooled. Pressure control is often used, as shown in Figure (5.6 d), or control can be based on the outlet coolant temperature \cite{12}.

### 5.8.6 Reboiler and vaporiser control

As with condensers, temperature control is not effective, as the saturated vapour temperature is constant at constant pressure. Level control is often used for vaporisers; the controller controlling the steam supply to the heating surface, with the
liquid feed to the vaporiser on flow control, as shown in Figure (5.9) An increase in the feed results in an automatic increase in steam to the vaporiser to vaporise the increased flow and maintain the level constant \(^{12}\).

![Figure (5.9) Vaporiser control.](image)

**5.8.7 Cascade control**

With this arrangement, the output of one controller is used to adjust the set point of another. Cascade control can give smoother control in situations where direct control of the variable would lead to unstable operation. The (slave) controller can be used to compensate for any short-term variations in, say, a service stream flow, which would upset the controlled variable; the primary (master) controller controlling long-term variations. Typical examples are shown in Figure(5.10 e) and (5.13) \(^{12}\).
(a) Temperature pattern control. With this arrangement interaction can occur between the top and bottom temperature controllers,
(b) Composition control. Reflux ratio controlled by a ratio controller, or splitter box, and the bottom product as a fixed ratio of the feed flow,
(c) Composition control. Top product take-off and boil-up controlled by feed,
(d) Packed column, differential pressure control.
Figure (5.11) (e) Batch distillation, reflux flow cascaded with temperature to maintain constant top composition.

5.8.8 Ratio control

Ratio control can be used where it is desired to maintain two flows at a constant ratio; for example, reactor feeds and distillation column reflux. A typical scheme for ratio control is shown in Figure (5.12)\textsuperscript{12}.

Figure (5.12) Ratio control.
5.8.9 Distillation column control

The primary objective of distillation column control is to maintain the specified composition of the top and bottom products, and any side streams; correcting for the effects of disturbances in [12]:

1. Feed flow-rate, composition and temperature.
2. Steam supply pressure.
3. Cooling water pressure and header temperature.
4. Ambient conditions, which cause changes in internal reflux.

The compositions are controlled by regulating reflux flow and boil-up. The column over all material balance must also be controlled; distillation columns have little surge capacity (hold-up) and the flow of distillate and bottom product (and side-streams) must match the feed flows. Shinskey (1984) has shown that there are 120 ways of connecting the five main parts of measured and controlled variables, in single loops. A variety of control schemes has been devised for distillation column control. Some typical schemes are shown in Figures (5.10) a, b, c, d, e; ancillary control loops and instruments are not shown.

Distillation column control is discussed in detail by Parkins (1959), Bertrand and Jones (1961) and Shinskey (1984) Buckley et al. (1985). Column pressure is normally controlled at a constant value. The use of variable pressure control to conserve energy has been discussed by Shinskey (1976).

The feed flow-rate is often set by the level controller on a preceding column. It can be independently controlled if the column is fed from a storage or surge tank.

Feed temperature is not normally controlled, unless a feed preheater is used. Temperature is often used as an indication of composition. The temperature sensor should be located at the position in the column where the rate of change of temperature with change in composition of the key component is a maximum; see Parkins (1959).

Near the top and bottom of the column the change is usually small. With multicomponent systems, temperature is not a unique function of composition. Top temperatures are usually controlled by varying the reflux ratio, and bottom temperatures by varying the boil-up rate. If reliable on-line analysers are available they can be incorporated in the control loop, but more complex control equipment will
be needed. Differential pressure control is often used on packed columns to ensure that the packing operates at the correct loading; see Figure (5.10 d). Additional temperature indicating or recording points should be included up the column for monitoring column performance and for trouble shooting.[12]

5.8.10 Reactor control

The schemes used for reactor control depend on the process and the type of reactor. If are liable on-line analyser is available, and the reactor dynamics are suitable, the product composition can be monitored continuously and the reactor conditions and feed flows controlled automatically to maintain the desired product composition and yield. More often, the operator is the final link in the control loop, adjusting the controller set points to maintain the product within specification, based on periodic laboratory analyses[12]. Reactor temperature will normally be controlled by regulating the flow of the heating or cooling medium. Pressure is usually held constant. Material balance control will be necessary to maintain the correct flow of reactants to the reactor and the flow of products and unreacted materials from the reactor. A typical reactor control scheme is shown in Figure (5.13)[12].

![Figure (5.13)](image)

**Figure** (5.13) A typical stirred tank reactor control scheme, temperature: cascade control, and reagent: flow control.
5.8.11 Alarms and safety trips, and enter locks

Alarms are used to alert operators of serious, and potentially hazardous, deviations in process conditions. Key instruments are fitted with switches and relays to operate audible and visual alarms on the control panels and annunciator panels. Where delay, or lack of response, by the operator is likely to lead to the rapid development of a hazardous situation, the instrument would be fitted with a trip system to take action automatically to avert the hazard; such as shutting down pumps, closing valves, operating emergency systems[12].

The basic components of an automatic trip system are[12]:

1. A sensor to monitor the control variable and provide an output signal when a preset value is exceeded (the instrument).
2. A link to transfer the signal to the actuator, usually consisting of a system of pneumatic or electric relays.
3. An actuator to carry out the required action; close or open a valve, switch off a motor. A description of some of the equipment (hardware) used is given by Rasmussen (1975).

A safety trip can be incorporated in a control loop; as shown in Figure (5.14 a). In this system the high-temperature alarm operates a solenoid valve, releasing the air on the pneumatic activator, closing the valve on high temperature. However, the safe operation of such a system will be dependent on the reliability of the control equipment, and for potentially hazardous situations it is better practice to specify a separate trip system; such as that shown in Figure (5.14 b). Provision must be made for the periodic checking of the trip system to ensure that the system operates when needed[12].

![Figure (5.14)](image)

**Figure (5.14)** (a) Trip as part of control system, (b) Separate shut-down trip.
5.8.12 Interlocks

Where it is necessary to follow a fixed sequence of operations for example, during a plant start-up and shut-down, or in batch operations interlocks are included to prevent operators departing from the required sequence. They may be incorporated in the control system design, as pneumatic or electric relays, or may be mechanical interlocks. Various proprietary special lock and key systems are available [12].

5.8.13 Computers and microprocessor in process control

Computers are being increasingly used for data logging, process monitoring and control. They have largely superseded the strip charts and analogue controllers seen in older plant. The long instrument panels and (mimic) flow-chart displays have been replaced by intelligent video display units. These provide a window on the process. Operators and technical supervision can call up and display any section of the process to review the operating parameters and adjust control settings. Abnormal and alarm situations are highlighted and displayed [12]. Historical operating data is retained in the computer memory. Averages and trends can be displayed, for plant investigation and trouble shooting. Software to continuously update and optimise plant performance can be incorporated in the computer control systems [12]. Programmable logic controllers are used for the control and interlocking of processes where a sequence of operating steps has to be carried out: such as, in batch processes, and in the start-up and shut down of continuous processes. A detailed discussion of the application of digital computers and microprocessors in process control is beyond the scope of this volume. The use of computers and microprocessor based distributed control systems for the control of chemical process is covered by Kalani (1988) [12].

5.9 Piping and Instrumentation for Acetone Production Process

An instrumentation flow sheet for Acetone process is given in Figure (5.15).
Chapter Five: Piping and Instrumentation

Figure (5.15) Process flow sheet for Acetone Production
Chapter Six

Safety & Loss Preventions
6.1 Introduction

Any organization has a legal and moral obligation to safeguard the health and welfare of its employees and the general public. Safety is also means working without accidents, believes that all accidents can be prevented, and efficient production.

All manufacturing processes are to some extent hazardous, but in chemical processes there are additional, special hazards associated with the chemical used and the process condition.

6.2 Identification of Hazardous

The hazard of Chemicals is divided into (the reaction heats, flammability, explosiveness, toxicity, corrosiveness and chemical interaction).

6.2.1 Toxicity

Most of the materials used in the manufacture of chemicals. The potential hazard will depend on the inherent toxicity of the material and the frequency and duration of any exposure. Toxic substance must first be absorbed into organism before having a biological effect [9]. In case of man and animals three portals of entry.

1. Inhalation.
2. Ingestion.
3. Skin contact.
4. Eye contact.

Toxicity of acetone:

Acetone is believed to exhibit only slight toxicity in normal use, and there is no strong evidence of chronic health effects if basic precautions are followed.

At very high vapor concentrations, acetone is irritant and, like many other solvents, may depress central nervous system. It is also a severe irritant on contact with eyes, and a potential pulmonary aspiration risk. In one documented case, ingestion of substantial amount of acetone led to systemic toxicity, although the patient eventually fully recovered.

6.2.2 Flammability

Flammability is the case with which a substance will ignite, causing fire. To cause the combustion of a substance is subject to quantification through fire testing.

The hazard caused by a flammable material depends on a number of factors:

1. The flash point of the material.
2. The auto ignition temperature of the material.
3. The flammability limits of the material.

4. The energy released in combustion.

1. **The Flash Point:**
   The flash-point is a measure of the ease of ignition of the liquid. It is the lowest temperature at which the material will ignite from an open flame. The flash-point is a function of vapor pressure and the flammability limits of the material (for acetone -20°C).

2. **Auto Ignition Temperature:**
   The auto ignition temperature of a substance is the temperature at which it will ignite spontaneously in air, without any external source of ignition (for acetone 465°C).

3. **The Flammability Limits:**
   The flammability limits of a material are the lowest and highest concentrations in air, at normal pressure and temperature, at which a flame will propagate through the mixture. The show the range of concentration over which the material will burn in air, if ignited flammability limits are characteristic of the particular material, and differ widely for different materials (for acetone UFL 2.5%, LFL 12.8%).

6.3 **Safety Considerations**

6.3.1. **Fire Hazard**
   A fire hazard is any situation in which there is a greater than normal risk of harm to people or property due to fire. Fire hazards can take the form of ways that fires can easily start, such as a blocked cooling vent, or overloaded electrical system, ways fires can spread rapidly, such as an insufficiently protected fuel store or areas with high oxygen concentration. Fire hazards include things which, in the event of fire, pose a hazard to people, such as materials that produce toxic fumes when heated or objects that block fire exits.
6.3.2 Fire Fighting Equipment

![Fire Fighting Equipment](image)

**Figure (6.1) Fire Fighting Equipment**

6.3.3 Fire Protection Systems

1. Foam
2. Water spray
3. Chemical and special agent extinguishing systems:
   - Dry Chemical Systems
   - Carbon Dioxide Systems
   - Inert System
   - Vaporizing Liquids (Halon System)

6.3.4 Emergency Action

In the event of a fire, wear full protective clothing-approved self-contained breathing apparatus with full face piece operated in the pressure demand or other positive pressure mode. Use water spray to blanket cool fire, cool fire exposed containers, and to flush non-ignited spills vapors away from fire.
6.4 Explosion Hazard

Explosion is the second hazard that can occur in our plant. The violence of the explosion depends on the rate at which the energy is released. And there are three types of energy:

- Physical energy.
- Chemical energy.
- Nuclear energy

**Explosion Kinds:**

There are two kinds of explosions:

1. **Deflagration:** in a deflagration the flammable mixture burns relatively slowly. For hydrocarbon air mixture the deflagration velocity is typically of the order of 1.0m/s.

2. **Detonation:** in a detonation the flame front travels as a shock wave followed closely by a combustion wave which releases the energy to sustain the shock wave.

6.5 Environmental Effects

Acetone evaporates rapidly, even from water and soil. Once in the atmosphere, it's degraded by UV light with a 22-day half-life. Acetone dissipates slowly in soil, animals, or waterways since it's sometimes consumed by microorganisms; however, it is a significant issue with respect to ground water contamination, since its highly soluble in water. Environmental half-life is about 1 to 10 days. But acetone may pose a significant risk of oxygen depletion in aquatic systems due to the microbial activity consuming it \(^{[10]}\).
6.6 General Safety Rules:

6.6.1 Working Practices

1. Employees must not use any equipment unless they have been trained and authorized to do so.

2. Employees must report immediately any fault or damage to equipment.

3. Employees must use all substances, chemicals; liquids etc. in accordance with all written instructions and should familiarize themselves with relevant Hazard Data Sheets and Risk Assessments.

4. Employees must return all substances, chemicals, liquids etc to their designated safe storage area when not in use.

6.6.2 Working Conditions/Environment

1. Employees must make proper use of all equipment and facilities provided to control working conditions/environment.

2. Employees must keep all areas clear and in a clean and tidy condition.

3. Employees must dispose of all rubbish, scrap and waste materials using the facilities provided. Chemical, radioactive and biological waste must be disposed of through the Safety Office in accordance with the relevant Code of Practice.

4. Employees must clear up any spillage of liquids immediately.
6.6.3 Personal Equipment Protective

1. Employees must use all items of protective clothing/equipment provided as instructed.
2. Employees must not misuse or willfully damage any of protective clothing/equipment provided.
3. Employees must report any damage, loss, fault or unsuitability of protective clothing/equipment to their supervisor\(^{[11]}\).

Figure (6.3) Personal Protective Equipment (PPE)
Chapter Seven

Plant Location and Layout
7.1 Plant Location

The geographical location of the final plant can have strong influence on the success of an industrial venture. Considerable care must be exercised in selecting the plant site, and many different factors must be considered. Primarily, the plant should be located where the minimum cost of production and distribution can be obtained, but other factors, such as room for expansion and safe living conditions for plant operation as well as the surrounding community, are also important.

A general consensus as to the plant location should be obtained before a design project reaches the detailed estimate stage, and a firm location should be established upon completion of the detailed estimate design. The choice of the final site should first be based on a complete survey of the advantages and disadvantages of various geographical areas and, ultimately, on the advantages and disadvantages of available real estate. The following factors should be considered in selecting a plant site:

1. Raw Material Availability.
3. Energy Availability.
4. Climate.
5. Transportation Facilities.
10. Site Characteristics.

The factors that must be evaluated in a plant location study indicate the need for a vast amount of information, both quantitative (statistical) and qualitative. Fortunately, a large number of agencies, public and private, publish useful information of this type greatly reducing the actual original gathering of the data.
7.1.1 Raw Materials Availability
The source of raw material is one of the most important factors influencing the selection of a plant site. This is particularly true if large volumes of raw materials are consumed, because location near the raw materials source permits considerable reduction in transportation and storage charges.

Attention should be given to purchased price of the raw materials, distance from the source of supply, freight or transportation expenses, availability and reliability of supply, purity of the raw materials, and storage requirements.

7.1.2 Markets
The location of markets or intermediate distribution centers affects the cost of product distribution and the time required for shipping. Proximity to the major markets is an important consideration in the selection of a plant site, because the buyer usually finds it advantageous to purchase from nearby sources. It should be noted that products as well as for major final products need for markets.

7.1.3 Energy Availability
Power and steam requirements are high in most industrial plants, and fuel is ordinarily required to supply these utilities. Consequently, power and fuel can be combined as one major factor in the choice of a plant site. Electrolytic processes require a cheap source of electricity, and plants using electrolytic processes are often located near large hydroelectric installations. If the plant requires large quantities of coal or oil, location near a source of fuel supply may be essential for economic operation. The local cost of power can help determine whether power should be purchased or self-generated.

7.1.4 Climate
If the plant is located in a cold climate, costs may be increased by the necessity for construction of protective shelters around the process equipment, and special cooling towers air conditioning equipment may be required if the prevailing temperatures are high. Excessive humidity or extremes of hot or cold weather can have a serious effect on the economic operation of a plant, and these factors should be examined when selecting a plant site.\[^{13}\]
7.1.5 Transportation Facilities
Water, railroads, and highways are the common means of transportation used by major industrial concerns. The kind and amount of products and raw materials determine the most suitable type of transportation facilities. In any case, careful attention should be given to local freight rates and existing railroad lines. The proximity to railroad centers and the possibility of canal, river or ocean transport must be considered. Motor trucking facilities are widely used and can serve as a useful supplement to rail and water facilities.

If possible, the plant site should have access to all three types of transportation, and, certainly, at least two types should be available. There is usually need for convenient air and rail transportation facilities between the plant and the main company headquarters, and effective transportation facilities for the plant personnel are necessary.

7.1.6 Water Supply
The process industries use large quantities of water for cooling, washing, steam generation, and as a raw material. The plant, therefore, must be located where a dependable supply of water is available. A large river or lake is preferable, although deep wells or artesian wells may be satisfactory if the amount of water required is not too great.

The level of the existing water table can be checked by consulting the state geological survey, and information on the constancy of the water table and the year round capacity of local rivers or lakes should be obtained.

If the water supply shows seasonal fluctuations, it may be desirable to construct a reservoir or to drill several standby wells. The temperature, mineral content, site or sand content, bacteriological content, and cost for supply and purification treatment must also be considered when choosing a water supply.

7.1.7 Waste Disposal
In recent years, many legal restrictions have been placed on the method for disposing of waste materials from the process industries. The site selected for a plant should have adequate capacity and facilities for correct waste disposal. Even though a given area has minimal restrictions on pollution, it should not be assumed that this
condition would continue to exit. In choosing a plant site, the permissible tolerance levels for various methods of waste disposal should be considered carefully, and attention should be given to potential requirements for additional waste treatment facilities.

7.1.8 Labor Supply
The type and supply of labor available in the vicinity of a proposed plant site must be examined. Consideration should be given to prevailing pay scales, restrictions on number of hours worked per week, competing industries that can cause dissatisfaction or high turnover rates among the workers, and variations in the skill and productivity of the workers.

7.1.9 Taxation and Legal Restrictions
State and local tax rates on property income, unemployment insurance, and similar items vary from one location to another. Similarly, local regulations on zoning building codes, nuisance aspects, and transportation facilities can have a major influence on the final choice of a plant site. In fact, zoning difficulties and obtaining the many required permits can often be much more important in terms of cost and time delays than many of the factors discussed in the preceding sections.

7.1.10 Site Characteristics
The characteristics of the land at a proposed plant site should be examined carefully. The topography of the tract of land the soil structure must considered, since either or both may have a pronounced effect on construction costs. The cost of the land is important, as well as local building costs and living conditions. Future changes may make it desirable or necessary to expand the plant facilities.

7.1.11 Flood and Fire Protection
Many industrial plants are located along rivers or near large bodies of water, and there are risks of flood or hurricane damage. Before selecting a plant site, the regional history of natural events of this type should be examined and the consequences of such occurrences considered. Protection from losses by fire is another important factor in selecting a plant location. In case of a major fire, assistance from outside fire departments should be available. Fire hazards in the immediate area surrounding the plant site must not be overlooked.
7.1.12 Community Factors

The character and facilities of a community can have quite an effect on the location of the plant if a certain minimum number of facilities for satisfactory living of plant personnel do not exist; it often becomes a burden for the plant to subsidize such facilities. Cultural facilities of the community are important to sound growth. Mosques, libraries, schools, civic theaters, concert association, and other similar groups, if active and dynamic, do much to make a community progressive.

The problem of recreation deserves special consideration. The efficiency character, and history of both state and local government should be evaluated. The existence of loss taxes is not in itself a favorable situation unless the community is already well developed and relatively free of debt.

7.2 Plant Layout

One of the first duties of the project engineer will be to develop the plant layout (including the details equipment arrangement) which serves as a starting point for many of the specialized design function such as Civil Eng. And piping designer it will also influence every other design function, including process design.

Because of its influence on all other work, the plant layout along with process design is one of the most important factors in determining the sources of failure of the project.

7.2.1 Functions of Plant Layout

One of the prime function of the layout is determine the dimensions of the plot of ground that will be required for the plant or to determine whether the plant can be arranged to fit on our available site. If the development of the layout proceeds simultaneously with the development of the process design is likely to be obtained.

Among other things, simultaneous development will help:

i. Determine the optimum proportions of various items of equipments.
ii. Determine whether gravity flows or pumps are desirable for liquid transport.
iii. Achieve maximum utilization of necessary building and structures while avoiding a design that would lead to wastage of structures.

The lay-out assists the project engineer in co-coordinating the work of various designers by allotting space for equipment and facilities so mechanical engineers can
do their work simultaneous without interference. For instance by allocating blocks of space for piping runs, the lay out assures the piping designers that they can work in those spaces.

Without risking interferences with structural members and assurer the Civil engineer that they can place their structural members in other spaces without interfering with piping. The development of layout also permits the orientation (Locating precisely) of those nozzles and vessels and heat exchanges so the designs of these items can be finalized before piping design has advanced very far.

### 7.2.2 Factors to be considered in Plant Layout

During the development of layout and the process designer the project engineer should consider the needs for plant expansion. Shelter is required whenever there is need to protect operator equipment from weather, and very elaborate buildings may be required necessary to maintain a special atmosphere such as in the packing rooms of some pharmaceutical plants.

In large size continuous process plants less and fewer shelters are being provided as the equipment becomes larger and more reliable and as the techniques for remote surveillance and control become better developed. It must be remembered that if shelter is provided, it may necessary to provide exceptionally ventilation in order to prevent the accumulation of hazardous vapors etc.; Maintenance requirements can be the most important factor in arrangement of equipment for some plants. Some equipments such as complex machinery and heat exchanges in severely complex machinery and heat exchanges in severely corrosive a severely fouling services, may require frequent maintenance.

At the very least such equipment requires easy access and attention should be paid to the major safety instruction in layout of isolation of hazards and escape for operators. One or more escape should be provided as to reduce to minimum the responsibility of fire or other hazards blocking his escape.
Information required for plant layout:

1. A process flow sheet showing:
   i) Every item of major equipment and its size.
   ii) Materials of construction of equipment and piping if these will introduce special support for other layout problems.

2. Factors having a significant effect on piping design such as:
   i) Operating pressure and temperature.
   ii) Flow quantity.
   iii) The nature of flowing fuel example vapor liquid slurry paste. Etc.

3. Drawing for mechanical equipment showing:
   i) Vertical dimension.
   ii) Space required to be left clear for maintenance.
   iii) Location of connection.

4. Hazards of materials handled as they affect requirements for:
   i) Separation of equipments.
   ii) Ventilation.
   iii) The water other barriers.

5. An area plan that show neighboring features that may influence the layout such as:
   i) Steam, water sewage disposal and other sewage.
   ii) Raw material and product storage at pipe lines.
   iii) Sources of the soil and subsurface condition.

6. Load bearing ability of the soil and subsurface condition.

7. Atmospheric condition with regard to:
   i) Extremes of weather which may make it desirable to provide shelter.
   ii) Prevailing wind direction if there are items such as in take or exhaust stack or furnaces, that should be located up or down wind of the remain of the plant.

8. Preferred operating and maintenance practices as they affect:
   i) The need for the permanent or temporary shelter when performing maintenance of mechanical equipment such as pumps, Compressors, Centrifuges etc.
   ii) The need for the permanently installed or mobile cranes for maintenance.
iii) The location of locker room, Lunch rooms etc. at each operating unit or at a central location.

9. Design Standards including the following:
   a) Minimum permissible clearance between adjacent equipment or between equipment and adjacent structures.
   b) Preferred tube lengths for shell and tube heat exchanges.
   c) Maximum permissible straight slopes and minimum rise between landings.
   d) Placement of overheads conduit either overheads or buried.
   e) Location of motor starter near the motor in the operating area or in a remote motor control center.
Chapter Eight

Conclusion
Conclusions

- Many different processes have been investigated for the manufacture of Acetone. A many of them catalytic dehydrogenation of Iso-propyl-alcohol (IPA) was considered for commercial and economic production.

- production of Acetone from IPA was designed with capacity of 33,000 metric tons per year of Acetone with a conversion of 90%.

- the summary of the design calculations for the reactor is as follows:
  - Type of reactor: plug flow reactor
  - Volume of packing: 1.6 m³
  - Volume of catalyst: 0.98 m³
  - Number of tubes: 220
  - Heat transfer coefficient = 45.85 w/m²°C
  - Pressure drop: 1552 pa.
References


13. Internet Sites : http://wikipedia.org
Appendix

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Figure (5.2)