

PROCESS FUNDAMENTALS



HRD CENTRE

Chennai Petroleum Corporation Limited

(A group Company of IndianOil)

चेन्नै पेट्रोलियम कॉर्पोरेशन लिमिटेड

(इंडियनऑयल की ग्रुप कम्पनी)

PROCESS FUNDAMENTALS HAND BOOK



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FOREWORD

Petroleum Refinery is process of separation of the different hydrocarbons and conversion of some of the hydrocarbons into products having desired specification and also to suit the market requirements. With the technological advancement, modernization in the Refineries that had taken place over a period of time in various sections of our Refinery, Process Fundamental Book prepared in mid 1990's has been revised duly incorporating the above process changes, flow charts and Refinery III additions.

The updated version is a comprehensive documentation incorporating the various Process Fundamentals purported to be used by the refinery operating personnel/trainees. The typical contents of the revised Process Fundamentals covers and details of Basic Chemistry, Physical Properties of Matter, Crude Oil Refining, Unit Operations/Separation Techniques, Characteristics of Crude Oil, Refinery I, Refinery II, LEB/DHDS Refinery III, Sampling, Glossary.

I am sure this hand book will be useful for the freshers and also to the experienced Operators/Engineers / Managers in refreshing their knowledge familiarizing with the various refinery operations including the changes that occurred during the last few years.

We thank all the Engineers / Technicians for their valuable contribution in bringing out this comprehensive booklet on Process Fundamentals. We special thanks to the Training centre for all their efforts in bringing out an updated version. We would be glad to receive suggestions and comments for further improvements of this handbook.


S. Chandrasekaran
Director (Technical)

Dated: 09.08.2007

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1. BASIC CHEMISTRY

Materials and Hydrocarbons

All the matter that exists in the world can be classified into three categories viz., elements, compounds and mixture of compounds. For example, crude oil is a mixture of many compounds. Iron and gold are elements, while water is a compound. Elements can exist in three states of matter namely gas, liquid or solid.

Elements

Elements can be defined as the basic materials from which all the substances are made. There are over 92 elements, but five of these elements oxygen, silicon, aluminium, iron and calcium make up more than 90% of the things in the world.

Atoms

An atom is the smallest particle of an element which can exist and still have the properties of the element. They are the pieces that combine to form molecules. For example, methane molecule (gas) is made up of one atom of carbon and four atoms of hydrogen (CH_4). When the atoms of the same kind cling to one another they form an element. They are held together by the mutual attraction of their masses.

Atoms are incredibly small. There are many millions of atoms in the smallest spec that can not be seen with the naked eye. Each atom consists of a nucleus composed of protons and neutrons with electrons orbiting around the nucleus. The atoms or none of its parts can be seen even with most powerful microscope. The nucleus gives the atom its mass and electrons determine the many chemical properties of the atom.

Molecules

Molecules are the smallest particles of a matter that can exist in the free state and maintain the properties of original substance. It may be a single chemical combination of two or more atoms. e.g. sodium hydroxide (NaOH), or two or more like atoms, e.g. Hydrogen (H_2) and Oxygen (O_2).

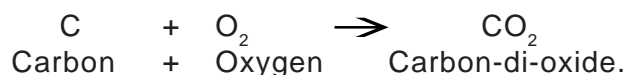
Compounds

Compounds are the result of chemical reaction between two or more elements in which two or more atoms combine in a fixed pattern to form molecules. This action is not to be confused with the simple mixing of two substances. The burning of carbon involves the combination of atoms of carbon with atoms of oxygen. This is a chemical reaction and a new product of carbon-di-oxide is formed.



Chemical Formula

The chemists use symbols for the elements and combine them into formulae to show the constitution of chemical compounds. Every atom is identified by a symbol. For example, H stands for Hydrogen, O stands for Oxygen, C stands for carbon, N stands for Nitrogen, Na stands for sodium, Pb stands for Lead and so on. The formula for a compound is a combination of the symbols of the atoms that compose its molecule. Thus water is H₂O, carbon-di-oxide is CO₂, Methane is CH₄ and so on. The chemical reaction of carbon and oxygen mentioned earlier can be represented by an equation as given below:



Formation of Hydrocarbons

From the reaction of the carbon and oxygen, one might think that heating hydrogen with carbon could make hydrocarbons. But this is true only for two of the simple hydrocarbons viz., methane and acetylene. Fortunately, hydrocarbons are formed by nature through slow decomposition of marine organisms and organic substances as crude oil in the underground cavities of earth. As mentioned earlier, crude oil is a complex mixture of many different hydrocarbons.

This leads to two new compounds, organic compounds and inorganic compounds which can be defined as follows. Organics compounds are the compounds of carbon which forms the largest group of compounds that we come across in our everyday life. All the hydrocarbons that we deal within the refinery are organic compounds.

Inorganic compounds, the other main group of compounds are the compounds that do not include carbon in the molecular structure.

Types of Hydrocarbons

Hydrocarbon is the name given to the large family of chemical compounds made up entirely of carbon and hydrogen. The carbon atoms can be joined together as long chains, short chains, single rings, double rings and many combinations of these. While the number of carbon atoms in any particular type of skeleton may vary, the properties of that particular kind of skeleton bear some similarity and these skeletons are called families of hydrocarbons.

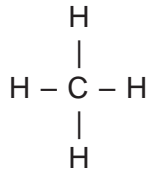
The most important hydrocarbon families are listed below:

Hydrocarbon Family Distinguishing Characteristics

1. Paraffins Straight carbon chain.
2. Iso-Paraffins Branched Carbon Chain.
3. Olefins One pair of carbon atoms held together with two arms.
4. Napthenes 5 or 6 carbon atoms in a ring.
5. Aromatics 6 Carbon atoms in a ring with 3 Two armed linkages.

Paraffins

The simplest of a paraffin hydrocarbon is methane. It is composed of 1 carbon atom and 4 hydrogen atoms and is usually written as CH₄ and the structural formula is



The carbon atom has 4 valencies and can be thought to have four arms and hydrogen is monovalent or has only one arm. The structural formula is very important because the several hydrocarbons having the same carbon and hydrogen atoms can have different structures and quite different properties.

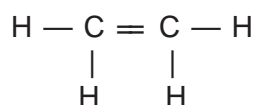
Carbon atoms can join with other carbon atoms as well as with hydrogen. When the carbon atoms are joined in a chain, they are called paraffin hydrocarbons or members of paraffin family. All members of paraffin family have a name ending in "ane" and the first part of the name generally indicates how many carbon atoms are attached together. The boiling point increases as the number of carbon atoms increase. As the molecules become longer, having as many as 25 to 40 carbon atoms, they become waxy solids familiarly known as paraffin wax. The molecules in asphalt may be even larger. The straight chain compounds are commonly referred to as normal paraffins. Normal paraffins do not make good gasoline because they knock in the engine and are said to have a low octane number.

The first six members of the paraffin family and their structure and boiling points are as follows

Name	Molecular Formula	Structural Formula	Form & Boiling Point	Name	Formula	Structural Formula	Form/ Boiling Point
Methane	CH ₄	$\begin{array}{c} \text{H} \\ | \\ \text{H} - \text{C} - \text{H} \\ | \\ \text{H} \end{array}$	Gas -162°C	Butane	C ₄ H ₁₀	$\begin{array}{cccc} & \text{H} & \text{H} & \text{H} & \text{H} \\ & | & | & | & | \\ \text{H} & - \text{C} & - \text{C} & - \text{C} & - \text{C} - \text{H} \\ & | & | & | & | \\ & \text{H} & \text{H} & \text{H} & \text{H} \end{array}$	Gas -0.5°C
Ethane	C ₂ H ₆	$\begin{array}{cc} & \text{H} & \text{H} \\ & | & | \\ \text{H} & - \text{C} & - \text{C} - \text{H} \\ & | & | \\ & \text{H} & \text{H} \end{array}$	Gas -89°C	Pentane	C ₅ H ₁₂	$\begin{array}{ccccc} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\ & | & | & | & | & | \\ \text{H} & - \text{C} & - \text{C} & - \text{C} & - \text{C} & - \text{C} - \text{H} \\ & | & | & | & | & | \\ & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \end{array}$	Liquid +36.1°C
Propane	C ₃ H ₈	$\begin{array}{ccc} & \text{H} & \text{H} & \text{H} \\ & | & | & | \\ \text{H} & - \text{C} & - \text{C} & - \text{C} - \text{H} \\ & | & | & | \\ & \text{H} & \text{H} & \text{H} \end{array}$	Gas -42.1°C	Hexane	C ₆ H ₁₄	$\begin{array}{cccccc} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\ & | & | & | & | & | & | \\ \text{H} & - \text{C} & - \text{C} & - \text{C} & - \text{C} & - \text{C} & - \text{C} - \text{H} \\ & | & | & | & | & | & | \\ & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \end{array}$	Liquid +69°C

Olefins

The second general family of hydrocarbons consists of straightchain unsaturated compounds called olefins. These do not occur in the crude oil, but are found during processing like cracking of gas oil. They differ from straight chain compounds because they do not carry as many hydrogen atoms as they can carry and are generally short of hydrogen atoms. In absence of these hydrogen atoms, two of the carbon atoms are linked together by two hands to satisfy the valency of carbon. This linkage is called a double bond. The names of the olefin family hydrocarbons are similar to that of paraffin family except that they all end in - "ene". The simplest member of the family is ethylene C_2H_4 (C_nH_{2n}) which can be structurally written as:



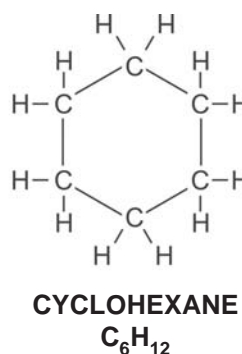
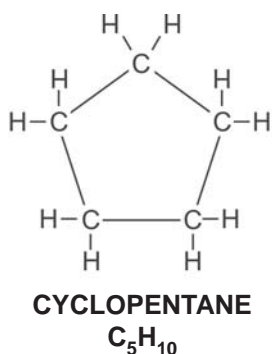
Since the molecules are not saturated with hydrogen, olefins are referred to as unsaturated compounds.

Contrary to the normal logical assumption, the double bond is a point of weakness than strength and is the point of "high chemical activity". These hydrocarbons enter into chemical reactions more readily than paraffins. Just like paraffins, all olefinic compounds can exist in isomeric forms provided the molecules contain four or more carbon atoms. The possible isomers for olefins are many more than paraffins as the double bond can occur between any two carbon atoms.

The low molecular weight olefins have, in general, good anti-knock properties when present in petrol but are excluded from aviation gasolines. The anti-knock properties of olefins cannot be improved much by the addition of TEL. Olefins can easily react with hydrogen to form paraffins and also have a strong tendency to combine with the other molecules and form polymers.

Napthenes

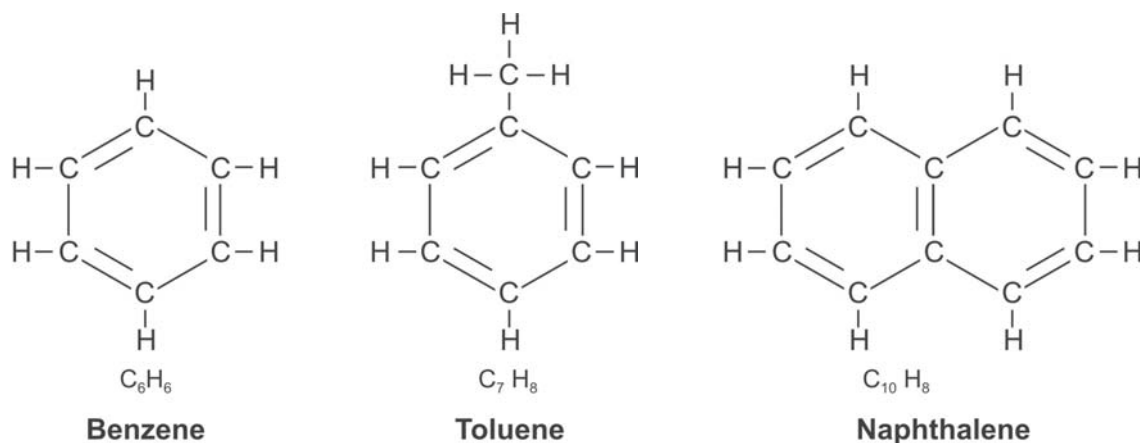
The third group of hydrocarbons are the saturated and ring compounds and are known as napthenes. Their structure is represented in a ring and therefore in naming napthenes the word "cyclo" is used as a prefix to indicate that the carbon atoms are linked to form rings. Two examples of Cyclopentane and Cyclohexane are shown below:



These ring compounds can have side branch chain also. These cycloparaffins or naphthenes are modestly good components of gasoline having about 80 octane number. However their greatest importance is that they can be converted into aromatics. This conversion is done by catalytic reforming which is the process used in the platformer unit. The chemical reaction is referred to as dehydrogenation because hydrogen is removed from the compound. The hydrogen produced is used in the unifier to combine with sulphur compounds converting the undesirable sulphur compounds into H_2S and removing the hydrogen sulphide by normal means of separation. Unifining of naphtha yields higher quality gasoline.

Aromatics

Aromatic hydrocarbons are the most desired components of gasoline because of their octane number. They derive their high name from the word "Aroma" meaning sweet smell and have their characteristic odour. They are also called the members of Benzene family, Benzene being the simplest member of the aromatic family. For example three compounds of Benzene family Benzene, Toluene and Naphthalene are structurally represented as follows:



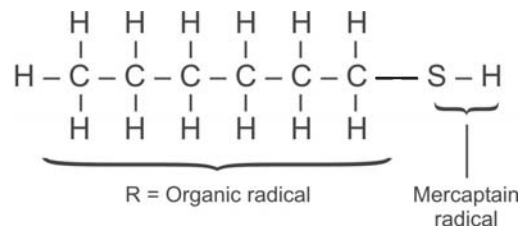
Aromatics are easily attacked by acid, but do not form gum in storage. They are low in hydrogen content and consequently have a low heating value and therefore are not desirable components of Aviation gasoline. Aromatics make a poor lubricating oil stock as they easily oxidize to form sludge. Aromatics are very harmful when breathed or when it comes in contact with skin and proper protective equipments must be worn when handling them.

Sulphur Compounds in Crude Oil

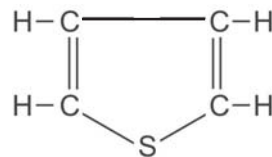
Some of the sulphur compounds generally present in Crude oil are Hydrogen Sulphide and mercaptans. Both of these are undesirable and hence processes are always incorporated in refineries to remove these compounds from finished products either by chemically converting them to other compounds, like in Merox fixed bed process, or removing them by converting the mercaptans to H_2S as is

done in the Hydrodesulphurisers. The sulphur is recovered from the hydrogen sulphide thus formed in our sulphur recovery plant.

Mercaptans are the compounds of hydrocarbon and sulphur. They have the general formula R-SH where R stands for hydrocarbon chain and SH is the Mercaptan portion of the molecule. Mercaptans have a foul odour and therefore have to be converted into odourless compounds or removed by reduction. Presence of mercaptans in gasoline components reduces lead susceptibility of component and the sulphur in the molecule combines with oxygen in the car engine forming corrosive Sulphurous acid. A typical mercaptan can be represented as-follows



The process of converting mercaptans into odourless disulfides is called "Sweetening". Sulphur is present in the crude oil in third form called Thiophenes. Thiophene is represented as

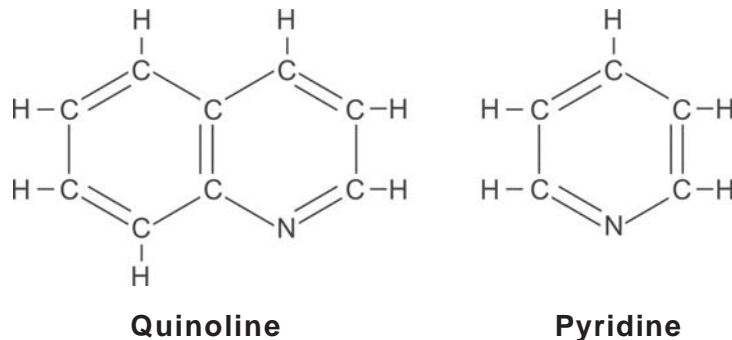


During the process of hydrodesulphuring, this compound is converted into a hydrocarbon and H₂S.

Nitrogen and Oxygen Compounds in Crude Oil

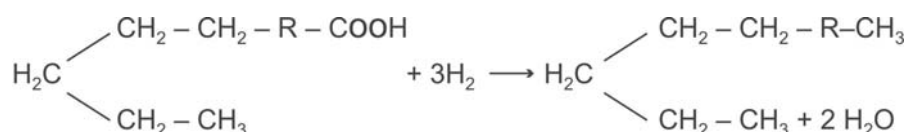
Crude petroleum also contains nitrogen and oxygen compounds in various proportions, usually less than 0.1%, but some may contain as high as 1 to 2% and they create problems in processing and storage of the petroleum products.

Nitrogen compounds such as quinoline, pyridine, pyrrole and indole have been identified in crude oil. The structural formula of Quinoline and Pyridine are given below:



Presence of nitrogen compounds in gasoline and kerosene degrades the colour of the products on exposure to sunlight. In gasoline, they may cause gum formation. Nitrogen is removed from the products by a hydrogenation reaction in which the organic compounds are converted into hydrocarbons and nitrogen into ammonia. Stripping or fractionation easily removes the ammonia. This is achieved in hydrogen treaters.

The oxygen compounds present in crude oil as organic acids or phenols, are usually concentrated in the gas oil fraction of the crude. The organic oxygen compounds are converted into water and hydrocarbons in a desulphuriser plant as shown in the following reaction:



Application of Chemistry in Petroleum Refining

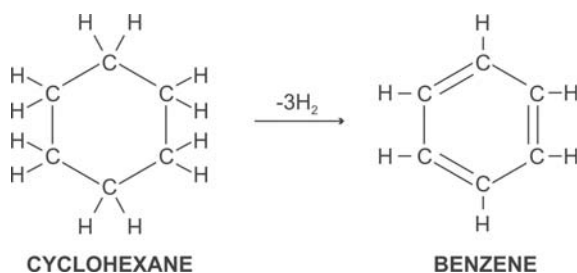
The application of chemistry in crude oil refining ranges from simple neutralisation of acidic compounds to chemical processes like reforming, hydrodesulphurisation, cracking and so on.

Injection of ammonia in the fractionator tower overheads, caustic soda to the waste neutralisation section and addition of soda ash to the reclaimers in MEA treating system are examples of the neutralisation of acidic compounds.

Removal of undesirable components by converting the compounds (by chemical reaction) to easily separable compounds and improving product quality and rearrangement of the molecular structure are carried out in the process units like Hydrodesulphurisers, Platform and Thermal Cracker and Visbreaker Units.

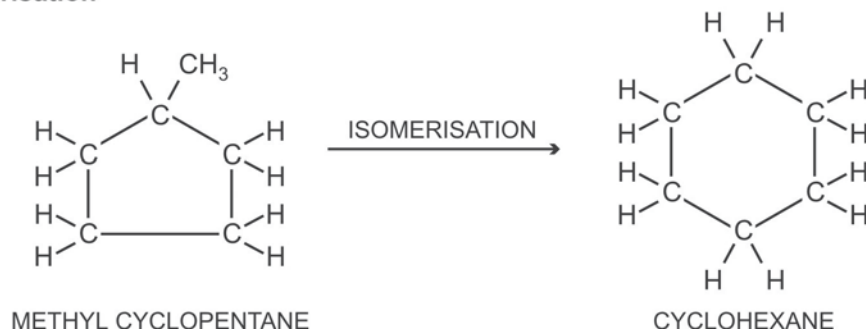
The platformer rearranges the molecules of low Octane Naphtha obtained by fractionation of crude in presence of a catalyst to produce high-octane naphtha. The general name of this process is catalytic reforming. The basic chemical reaction taking place in the platformer are a) Dehydrogenation b) Isomerization c) Dehydrocyclization and d) Hydrocracking.

Dehydrogenation is the removal of hydrogen from saturated molecules to form higher-octane molecule. The most important type of Dehydrogenation in the platformer unit is the changing of cycloparaffins (Naphthene) to aromatic. A typical reaction is represented below:

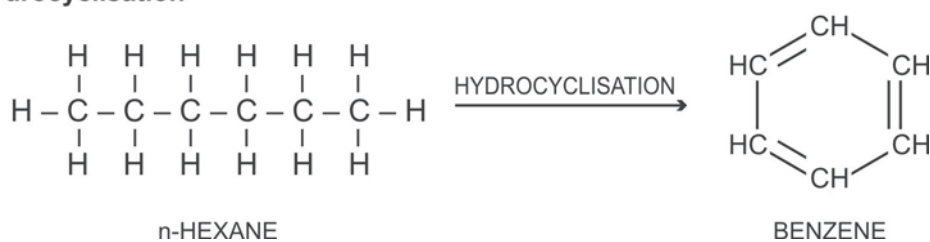


Isomerization is the rearrangement of molecules and hydrocyclisation is the closing of straight chain molecules into ring type molecules. Hydrocracking is the break up of large molecules into smaller molecules in presence of hydrogen. The typical reactions are given below.

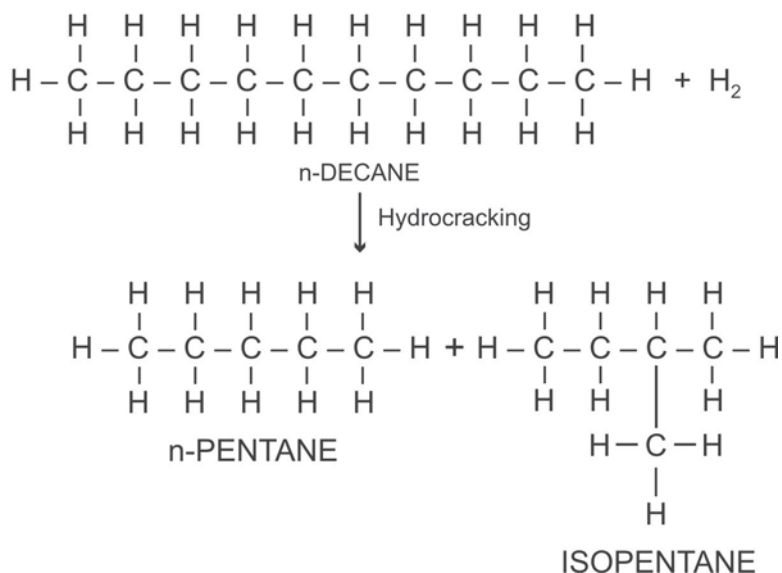
A. Isomerisation



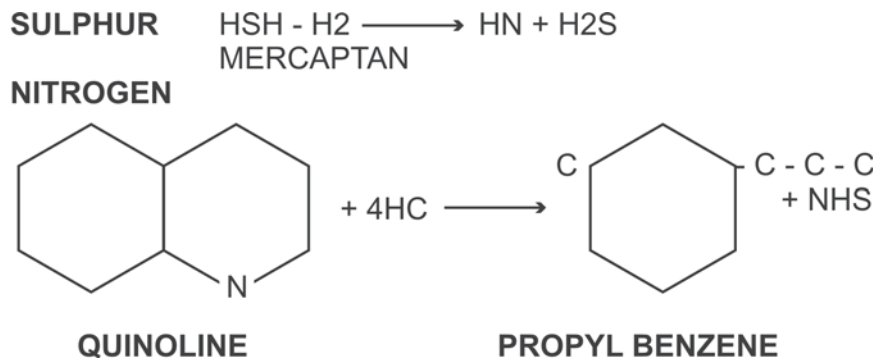
B. Hydrocyclisation



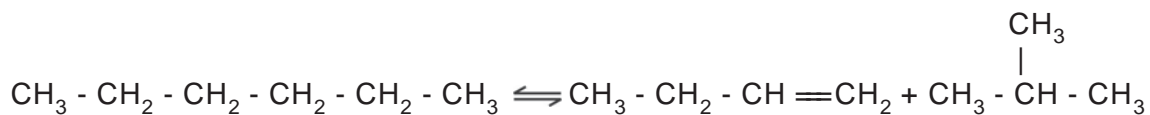
C. Hydrocracking



The hydro-desulphurisers convert the undesirable compounds of sulphur, nitrogen and unstable olefins into H_2S , NH_3 and stable hydrocarbons respectively in presence of a catalyst. The typical reactions are given below



In thermal cracking and visbreaking of heavy oil, the oil is kept for a period of time under high temperature which causes the larger molecules to break up. The resultant product has random distribution of molecular sizes. The products obtained range from gas to heavy gas oils, thereby upgrading the heavy oils to more valuable products. Depending on the temperature and residence time, the production of lighter hydrocarbons can be varied. The chemical reactions that takes place is represented in a typical reaction below:



The visbreaker is essentially a thermal cracker operating in milder conditions where the cracking of larger molecules of vaccum residium is cracked into molecules in gas oil range. But for this operation the vaccum residium will have to be blended with other lower viscosity materials to meet fuel oil specification, which otherwise would have constituted more valuable products like HSDO or lubrication oil.

2. BASIC PHYSICS AND PHYSICAL PROPERTIES OF MATTER

Physics is the Science, which covers the various laws, which govern the behavior of matter. These laws are so fundamental that everyone has some knowledge of physics although he may not consider his knowledge as being classified under the physical characteristics of the materials we process in the refinery and the energy used in refining. It is not possible to cover the minute details of the physics and cover the extensive subject that are classified under physics. For our purpose, we will confine ourselves to the basic physics and their applications to refining industry.

Definition of Matter

By definition, matter is anything that occupies space and has weight. Matter may exist in different form like solids, liquids or gases.

Inertia

Inertia is another property of matter first introduced by Sir Isaac Newton. Newton's law states that a body in motion will remain in motion and a body at rest will remain at rest, unless acted upon by an outside force. Simply inertia means that a moving body will continue to move unless something is done to stop it or change its direction. Likewise a stationary body will remain stationary unless some force is applied to move it.

Density

Density is the other property of matter and is defined as weight (mass) of a unit volume. One cubic centimeter of water weights 1 gram at 0°C and therefore the density of water is 1 gram per cubic centimeter at 0°C. Similarly one cubic centimeter of mercury weights 13.6 grams at 0°C and therefore the density of mercury is 13.6 grams per cubic centimeter at 0°C.

Specific Gravity

Many times the density of a liquid or a solid is compared to the density of an equal volume of water. When this is done, the ratio of densities is called specific gravity. Hence specific gravity can be defined as ratio of density of the matter and density of water at a certain temperature. Since the rate of expansion of different materials for unit temperature is different, it is necessary to specify the temperature too. In oil industry the temperature specified is 60°F for English system (FPS) and 15°C for metric system (CGS). In laboratory temperature used is 0°C several types of scales and devices have been developed from time to time measure the specific gravity of liquids. The most familiar in the refining



industry are the API, Baume hydrometers. The API hydrometer is used for measuring the specific gravity of oil and was developed to give a positive figure even though the density of most of the oil fractions is less than 1-the density of water. As the number on the API gravity scale increases, the oil density becomes less. The Baume hydrometer is employed to measure the specific gravity of liquids heavier or lighter than water and is used in the refining industry for caustic soda and acids. The large the number on Baume scale the higher is the density of the liquid. The relation between specific gravity and API gravity and Baume is empirical is related by the following equation.

$$\text{Degree API} = \frac{141.5}{\text{Sp.Gr. at } 60^{\circ}\text{F}} - 131.5$$

$$\text{Degree Be} = 145 - \frac{145}{\text{Sp.Gr.}}$$

Basic Properties of Matter

Nearly all the matter exists in one of the three states, solid, liquid or gas and may pass from one state to another, depending on temperature and pressure. The most common example is the conversion of ice (solid-water) to water (liquid-water) by heat and further conversion of water to steam (Water Vapour) by heat. Another example is the conversion of liquid LPG to gas when pressure is lowered.

The molecules of all matter are constantly in motion and application of heat will increase their molecular motion. Likewise, cooling will decrease the molecular motion. The molecules in solids are packed so closely together that there is barely any room for them to move about. The molecules in liquids are much less compact and therefore they do not take any regular shape, but conform to the shape of vessel containing them. The molecules of gases are even more spaced and have more freedom of movement than liquids. They move about filling the entire volume of the containing vessels. Theoretically, the molecular movements stop at an estimated temperature of 459.4°F i.e. -273°C . This temperature is called absolute zero or absolute.

The additional freedom of movements of gas molecules gives gases special properties. One of these properties is called elasticity. The gas molecules bounce about colliding with each other and with the wall of the vessels containing them and then bounce back with their original speed and force. This property of bouncing back without loss of energy is called perfect elasticity. Heavier gas molecules move slower than the lighter gas molecules.

Pressure

When gas molecules bounce off the walls of the containing vessel, pressure results. The number of molecules in a container determines the pressure in the container. If more molecules are forced into a container, then more molecules bombard the wall of the vessel and higher pressure results.

If the temperature is increased, the molecules bombard the vessel walls resulting in higher pressure.

Pressure is most commonly measured in pounds per square inch or kilograms per square centimeter. The air around us is made up of a mixture of gases and at sea level exerts a pressure of 14.7 pounds per square inch or 1.033 kilograms per square centimeter or one atmosphere or 760 mm of mercury. This is termed as absolute pressure, which is different from "gauge" pressure. Normally the pressure gauges are calibrated to read 0 at atmospheric pressure above atmospheric pressure. This pressure is normally referred to as gauge pressure and is expressed as pounds per square inch gauge or kilograms per square centimeter gauge. In normal practice, unless specified as absolute, the pressure reading is assumed to be "gauge" reading. To convert "Gauge" reading to "absolute" reading, add atmospheric pressure to the gauge readings i.e. absolute pressure = gauge pressure + atmospheric pressure.

Head is another manner in which pressure is often measured in the refinery, especially with regard to pumps. Head is usually expressed in terms of height of the column of fluid in unit length (meters). For example, if a pump will develop a discharge pressure of 50 meters of water, it will pump a column of water 50 meters high. Knowing that 1 cc of water weighs 1 gram a column of water, i.e. 5000 Cm high on 1 sq. cm will weigh 5000 grams or will have a pressure of 5000 gm/sq.cm. ie 5 kg/cm². If we take a glass tube 90 cms long, fill it up with mercury, and invert the open end into a dish containing mercury without allowing air to enter the tube, we will find that the mercury comes down to a level in the dish. The atmospheric pressure acting on the surface of the mercury in the dish is supporting the head of mercury in the tube. In other words, the atmospheric pressure is equal to the 76 cm of mercury head. We know that mercury has a specific gravity of 13.6 and hence if we were, to do the experiment with water the atmospheric pressure will be able to support a column of water 13.6 X 76 = 1033.6 cms water.

Vacuum

If from an enclosed container containing air at atmospheric pressure, some air is removed, the remaining air in the container does not exert pressure on the walls of the container equal to the pressure on the exterior walls. Under this condition, the container is said to be under partial vacuum. If all the air from the container is removed, then the container will be under perfect vacuum. Vacuum is, in other words, negative pressure measured by a gauge. Perfect vacuum is 0 kg/cm² absolute.

Vacuum readings are generally expressed in the millimeters of mercury. Thus 50 mm of mercury vacuum is below atmospheric pressure by an amount equal to 760 - 50 or 710 mm of mercury. In other words the absolute pressure corresponds to 50 mm of mercury. Since 1 mm of mercury exerts a pressure corresponds to 50 mm of mercury. Since 1 cm of mercury exerts a pressure of 0.0136 kg/cm² the absolute pressure in the container is 0.0136 x 5=0.068 kg/cm² or 1.03 - 0.068 =0.962 kg/cm² less than atmospheric pressure.



To calculate the pressure (p) exerted by a column of liquid the following formula is used

$$p = \rho \times g \times h$$

where h = height of liquid in cms
 ρ = density of liquid in gm/cm³
 g = acceleration due to gravity cm²/second

Temperature

Heat increases the molecular activity of matter. Temperature is a measurement of molecular activity. Hence temperature is used as a measure for the level of heat. The three most widely used temperature scales are absolute, Fahrenheit and Centigrade. For normal operations, we will be using centigrade scale.

It is observed that all matters expand on application of heat and the expansion is proportional to the increase in temperature. This property is used for making mercury thermometers. For setting standards, the boiling point and freezing point for water is used. Fahrenheit scale uses 32^oF as freezing point and 212^oF as boiling point of water giving a 180^o as span whereas centigrade scale uses 0^o as freezing point and 100^o as boiling point giving a span of 100^o. The relationship for conversion of centigrade to Fahrenheit is as follows:

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32) \times 5/9$$
$$[\text{or } ^{\circ}\text{F} = (1.8) (^{\circ}\text{C}) + 32]$$

Absolute temperature is defined as the temperature at which all the molecular motion ceases. The zero point on the scale has not been achieved, but estimated to be -273^oC or -459.7^oF. Any centigrade reading can be converted to absolute temp by adding 273 to the reading and Fahrenheit reading by adding 45.7 to the reading.

In refinery operations the temperature is measured using a thermocouple. The principle used is that the E.M.F. generated by a bimetal is proportional to the temperature. The EMF is compared with another thermocouple at a constant temperature and is used to indicate the temperature. This is particularly useful in measuring temperature at higher ranges.

Properties of Gases

As previously mentioned the molecules in gases are spaced far apart compared to liquids and are very active. They rapidly bombard the walls of the container in which they are held. This results in pressure, because the molecules are spaced apart, gases exhibit many interesting characteristics, the understanding of which will aid greatly in visualizing the problems involved in handling them in the oil industry.

As explained earlier, gases possess perfect elasticity and the molecules rebound from the walls of the container with the original speed and energy. Each molecule of gas contains at least two atoms with their electrons on the outside of the

molecules. The molecules in motion also collide with other molecules and change direction with perfect elasticity.

The Gas Laws

The volume of a given sample of gas depends on the temperature and pressure applied to it. Any change in temperature or pressure will affect the volume of the gas. The relationship among the pressure, temperature and volume of a given mass of gas are called the gas laws.

Boyle's Law / Charles Law / Gay Lussac's Law

Boyle's Law

Gases can be compressed and the changes in the volume that results can be accurately predicted by a law called Boyle's Law. The law states that at constant temperature the volume of a fixed mass of a gas varies inversely with its pressure. In simpler terms, if pressure on a gas is doubled, its volume decreases to one half of the original volume. Boyle's Law may be expressed mathematically as

$$\frac{P_1}{P_2} = \frac{V_2}{V_1} \quad \text{at constant temperature}$$

where P_1, V_1 are the initial pressure and volume of a given sample of gas and P_2, V_2 the changed pressure and volume.

Charles' Law

This law deals with the effect of change of temperature on the volume of a fixed amount of gas at constant pressure. The law states that at constant pressure, the volume of a given mass of a gas varies directly as the absolute temperature.

Charles' Law may be expressed mathematically as

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad \text{at constant pressure}$$

Where V_1, T_1 are the initial volume and temperature of a given mass of gas at constant pressure and V_2, T_2 the changed volume and temperature.

The Combined Gas Law

Boyle's Law and Charles' Law can be combined into a single relationship called the combined Gas Law. The combined Gas Law can be stated as for a fixed mass of gas, the volume is directly proportional to Kelvin Temperature and inversely proportional to the pressure. Mathematically, it can be expressed as



$$\frac{PV}{T} = K \text{ (a proportionality Constant)}$$

or

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Where P_1 , V_1 and T_1 are the initial pressure, volume and temperature, P_2 , V_2 and T_2 are the changed pressure, volume and temperature.

Example

Calculate the resultant volume of a gas originally 25.8 litre in volume under a pressure of 0.908 atm at a temperature of 290K when subjected to a pressure of 1.85 atm at a temperature of 345K.

Solution

Initial Conditions

$$V_1 = 25.8 \text{ litres}$$

$$P_1 = 0.908 \text{ atm}$$

$$T_1 = 290 \text{ K}$$

Final Conditions

$$V_2 = ?$$

$$P_2 = 1.85 \text{ atm}$$

$$T_2 = 345 \text{ K}$$

Substituting values in the equation

$$\begin{aligned} \frac{P_1V_1}{T_1} &= \frac{P_2V_2}{T_2} \\ \frac{0.908\text{atm} \times 25.8 \text{ litre}}{290 \text{ K}} &= \frac{1.85 \text{ atm} \times V_2}{345 \text{ K}} \\ V_2 &= \frac{0.908 \times 25.8 \times 345}{290 \times 1.85} \\ &= 15.1 \text{ litres} \end{aligned}$$

Gay Lussac's Law

This Law establishes a general relation between the pressure and temperature of a gas. It states that at constant volume, the pressure of a fixed mass of a gas varies directly with the Kelvin temperature or absolute temperature. Mathematically, the law may be expressed as

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \quad \text{at constant volume}$$

Where P_1 , T_1 are the initial pressure and temperature of a given sample of gas and P_2 , T_2 the changed pressure and temperature.

Partial Pressure

The preceding laws deal with individual gases, but the refinery gases are mostly mixture of gases. A law, called Dalton's law of partial pressures, states that two or more gases held in a single container will exert a pressure equal to the sum of the pressure each gas will exert if separately held in the container.

Still another law called as Avagadro's principle states that equal volumes of gases under the same conditions of temperature and pressure contain the same number of molecules.

The Dalton's law of partial pressures and Avagadro's principle are involved in the important process of stripping, lighter hydrocarbons from the heavier hydrocarbons and although stated simply are difficult to understand. The practical application of Avagadro's principle will be dealt with in detail later.

Applying Avagadro's principle 1 cc of hydrogen and 1 cc of oxygen have the same number of molecules and since the atomic weight of hydrogen is 1 and that of oxygen is 16, 1 cc of oxygen weighs 16 times the weight of 1 cc hydrogen under the same temperature and pressure. Or conversely 2 grams of hydrogen and 32 grams of oxygen will occupy the same volume. Experiments have proved that this volume is 22.4 liters at 0°C and 760 mm of mercury pressure (atmospheric pressure). This volume is known as gram molecular volume or commonly referred to as molar volume.

Density & Specific Gravity of Gases

Density is already defined as weight per unit volume. Since gases have very little weight, expressing density per cubic centimeter will be a fraction of one and hence the density of gases are expressed in grams per liter (1000 c.c.). Air has a density of 1.293 gms per litre at atmospheric pressure and temperature of 0°C. The relative density of a gas is the ratio of its density to that of air. The easiest way to determine the relative density of any gas is to use the gram molecular weight. Air consists of 4 parts nitrogen and 1 part oxygen and therefore its gram molecular weight is

$$\frac{1 \times 32 \text{ (mol.wt of O}_2\text{)} + 4 \times 28 \text{ (Mol.wt of N}_2\text{)}}{5} = 28.8$$



The Molecular formula of propane being C_3H_8 , the gram molecular weight of propane is 3×12 (carbon) + 8×1 (Hydrogen) = 44

Relative density of propane is,

$$\frac{\text{Gram molecular weight of propane}}{\text{Gram molecular weight of air}} = \frac{44}{28.8} = 1.64$$

Properties of Liquids

Liquids like gases have special properties of their own. The main difference in the three states of matter is in the magnitude of repulsive and attractive forces of the molecules. Gas molecules have weak attractive and repulsive forces, solid molecules have strong attractive and very little repulsive forces and liquids molecules have considerable attractive forces and yet enough repulsive forces to give them mobility. Liquid molecules are much closer together than gas molecules, but there is enough space between them so that it can slide over around each other. This is what makes the liquid to be fluid, pour easily and take the shape of vessels that contain them.

The attraction that liquid molecules have for each other is what causes them to form drops. Otherwise a single drop of water would spread over the entire surface of anything it is placed on. This property of liquid is called cohesion. Some liquid exhibit more cohesion than the others. The common example of the property of cohesion is that water sprayed from a hose forms drops when falls down. Also water placed on any surface tends to cling together and form drops.

The attractive forces of molecules under the surface of the liquid are applied equally in all direction whereas on the surface it is applied only downwards and sidewise. Consequently the sidewise pull is greater than the average pull in the molecules below the surface. This gives the surface of a liquid an elastic quality known as surface tension, a form of energy.

Viscosity

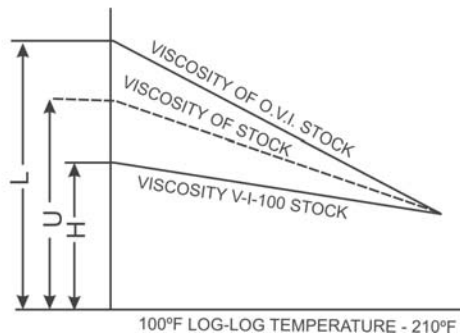
A property of liquid widely used in refinery is viscosity. This may be thought as internal friction of the molecules resisting movement relative to each other when subjected to external force. Viscosity is related to cohesion of the liquid molecules for one another and therefore density does not affect the viscosity. The viscosity of a liquid changes with temperature and in most of the liquids viscosity reduces with increase in temperature. This property is used to keep waxy oils and asphalts in less viscous state and enable the products to be pumped easily. There are different units for measuring viscosity and they can be converted to equivalent reading in another. The viscosities of liquids affect us in pumping of liquids, atomisation of furnace fuels and lubrication of machines.

Viscosity Index

The effect of temperature on viscosity is different for different oils. This property is important for lubrication oils as they should remain sufficiently fluid at low temperature and yet remain sufficiently viscous at higher operating temperature. The most generally used temperature viscosity relationship is developed by Dean & Davis. The viscosity index is based on comparison of viscosity of oil with that of two-reference oil, both of which have the same viscosity at 210°F as the oil under test. The reference oil is prepared from a Pennsylvania crude and a Gulf Coast crude both of which are assumed to have a viscosity index of 100 and 0 respectively.

This viscosity index is then defined as

$$V.I = \frac{(L - U) \times 100}{L - H}$$



Where U = Viscosity of unknown oil at 100°F
 L = Viscosity of '0' V.I oil at 100°F
 H = Viscosity of 100 V.I oil at 100°F

In actual Practice tables giving the value of L and H are used for finding the viscosity index of a product.

In case of petroleum products, the viscosity of hydrocarbons in the same family like paraffins, aromatics, etc, increases with increasing molecular weight. Therefore a viscosity reduction is achieved by breaking high molecular weight hydrocarbons by the process of cracking. The cracking can be achieved either thermally or catalytically.

This phenomenon is the basic principle of the Visbreaker and Thermal Cracker units. Subjecting it to high temperature and pressure in a fired heater thermally cracks the feed stream to these units. The products obtained have lower molecular weight and therefore have lower viscosity.

There are two kinds of viscosity, absolute and kinematic. Absolute viscosity concerns only with the cohesive strength of the liquid whereas kinematic viscosity combines this property with the fluid density. Kinematic viscosity is a better measure of the fluid characteristics in motion. Kinematic viscosity is equal to the absolute viscosity divided by its density. The kinematic viscosity of a liquid is



measured by using a viscometer. This apparatus measures the time taken for a fixed volume of liquid to flow through an orifice of standard diameter. The test is determined at constant temperature. The viscosity thus determined is expressed in seconds and the units are Saybolt Universal Seconds (S.S.U.) and Saybolt fural seconds (S.F.S) in the English system and centistokes and stokes in the metric system.

Boiling Point

Liquids can become gases by evaporation. The molecules of liquids on the surface has enough energy to escape and pass into gaseous state. This is true even of cold liquids but the extent of vaporisation will be different for different liquids. When no external source of heat is applied, each molecule has to absorb its heat of vaporization from the liquid and surrounding atmosphere. This produces a cooling effect on the liquid or surrounding atmosphere. An example of this is the cooling effect produced on the body by the evaporation after perspiration. The rate of evaporation depends on the surface area of the liquid exposed since larger the surface area, the larger is the tendency for the molecules to escape. The cooling increases with increased evaporation. This property is used in a refinery to minimise the evaporation loss of volatile product like gasoline and naphtha by storing them in floating roof tanks.

If we pour some carbon tetrachloride in an open vessel, the carbon tetrachloride starts vaporizing, till the liquid gets finally converted into gaseous state. In these cases, the escaping molecules are being removed away from the surface and more and more molecules escape from the surface of the liquid. Water kept in an open vessel is also emitting vapours at atmospheric temperature and pressure. If we apply heat to the vessel, more molecules escape and more vaporisation results. The continued heating, till the temperature reaches 100°C will result in the boiling of water. This temperature is called boiling point of water at atmospheric pressure. Let us assume that the vessel is enclosed. The molecules escaping from the surface fills available space and builds up the pressure in the vessel. On application of pressure it will be observed that the temperature at which boiling starts will be different from 100°C and the boiling will vary according to pressure in the container. In other words, boiling point of a liquid varies with pressure. The standard boiling points are expressed in unit of temperature at atmospheric pressure.

Vapour Pressure

When a liquid is confined to a vessel, the molecules still escape from the surface, and they collide with the walls of the vessel and produce pressure. Some of the escaping molecules will collide with other molecules and may be knocked back into the liquid. When enough molecules escape, the space inside gets saturated as many molecules are returned back to the liquid as the ones escaping either by collision with the walls of the container or with other molecules and when this point is reached, the container will be under a certain pressure. This pressure is called vapour pressure of the liquid. Heat increases the vapour pressure of a liquid, as more the heat applied, more is the number of molecules colliding against

the vessel walls. Therefore, it is necessary to specify the temperature when expressing vapour pressure. The vapour pressure of any liquid at a standard temperature of 100°F is called Reid vapour pressure. The boiling of a liquid starts when the vapour pressure of the liquid equals the pressure exerted on the liquid surface and hence boiling point can be defined as the temperature at which vapour pressure of the liquid is equal to the pressure to which it is subjected to.

Condensation

The reverse of vaporisation i.e. gases becoming into liquid state is called condensation. Compression, cooling or a combination of both can bring this about. The gaseous molecules contain excess heat called the heat of condensation that must be absorbed in some manner when they become liquids. In the case of compression, the resultant liquid absorbs the heat. The common example of condensation by cooling is the condensation of water on the lid covering a vessel containing water that is boiling. The heat from the vapour is absorbed by the lid and condensation results. Changing of gases into liquids and vice versa is the basic principle in the refinery operation as it permits use of smaller pipes and vessels. Condensation reduces the volume considerably.

Properties of Solids

Hydrocarbon molecules also exist as solids at ambient temperature (Examples: waxes and asphalts) by application of heat, thereby increasing the molecular activity. Solids can be converted to liquids and further to vapours (gaseous state). Solids like iron are difficult to convert into liquid or vapour state. But ice, which is solid water, is easily converted into liquid state, (i.e. water) and steam (i.e. gaseous state) by application of heat and is a common example that we come across in daily life. In refinery the asphalts and sulphur are kept in liquid state by maintaining them at higher temperature.

Fundamentals of Processing

In this section, the discussion will be on the properties of fluids, the effect of pressure, heat and characteristics of fluid flow.

A fluid is any substance which easily yields to pressure, which has no definite shape and which will flow readily. Both the liquids and gases conform to this requirement and are classified as fluids. Although we have already learned many differences in the characteristics of these two states of matter, they also have certain properties in common. For instance both have inertia, impenetrability and density. Both these can be pumped mechanically from one place to another, stored in containers of any shape and both take shapes of their containers. The greatest difference between gases and liquids is the fact that gases can be compressed and liquid, for practical purposes, cannot be compressed.

In studying the properties of fluids, we must understand the differences between the terms force, weight and pressure. In simple terms force means a push or a pull, weight indicates heaviness and pressure means the force per unit area of



the surface acted upon. Hence pressure can be related to weight and force as follows.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area acted upon}}$$

$$\text{Pressure} = \frac{\text{Weight}}{\text{Area acted upon}}$$

Pressures on Fluids at Rest

Pressure has been earlier defined as the force per unit area. There are two kinds of pressures that can exist on a fluid at rest. They are (a) pressure due to gravity or static pressure, (b) Induced pressure. The induced pressure is the pressure applied by an external force. One of the interesting facts about the behavior of fluids is that pressure, has no definite direction regardless of where it is measured. At any point in a fluid under pressure, the downward pressure equals the other.

Static Pressure

Everything on the surface of earth exists under the static pressure created by air which we call as atmospheric pressure. As mentioned previously, this pressure is 1.033 kg/cm² at sea level. If we were to go up to a level 40 meters higher than the surface of earth the pressure will reduce to the extent of the reduced column of air above and will be equal to.

$$1.033 - \frac{0.00129 \times 40 \times 100}{1000}$$

1.033 - 0.00516 = 1.02784kg/cm² since the density of air is 0.00129 gm/cc at atmospheric pressure. Similarly if a body is immersed in a tank of water, to a depth of 50 meters the pressure of the body will be subjected to is the sum of the atmospheric pressure and static pressure due to the column liquid. The static pressure of the liquid will be exerted on the body in all directions.

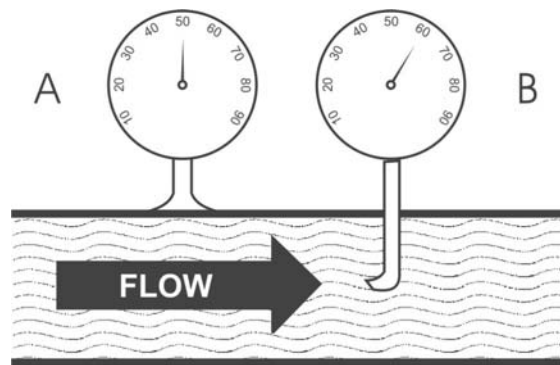
Induced Pressure

Before pressure can be induced in a fluid, it must be put into a vessel which can be sealed off from the atmosphere. Induced pressure is in addition to static pressure and the sum of both is the total pressure when the fluid is at rest. Pressure can be induced by heating or mechanical force. If we take a container sealed off from atmospheric pressure and containing its own vapour and liquid and if this container is heated, the pressure increase. This induced pressure is the same in both the substances.

When force is applied to a given area on the surface of an enclosed fluid, that force will be transmitted without gain or loss of intensity to every equal area in the vessel. This is known as PASCAL'S LAW. Any applied force induces pressure

in an enclosed fluid. This pressure is exerted against the walls of the vessel. Regardless of the shape of the vessel, this pressure acts at right angles to the vessel walls.

An important application of the Pascal law is the hydraulic lift. A small force applied to a small area induces pressure. Even when the induced pressure is small, if it can be applied to another large area, it will exert a larger force. Work is the product of a force succeeding in moving the object acted upon. Therefore the induced pressure in a small area gives large force in a larger area, but will move the object for a shorter distance. Pressure measurements in pipelines vary according to the pressure gauge installed. The figure below shows two ways in which the pressure gauges are installed. The gauge A will read the static and induced pressure whereas gauge B will measure the static pressure, induced pressure and velocity pressure. The velocity pressure is the pressure that is created by the inertia of moving a mass of liquid

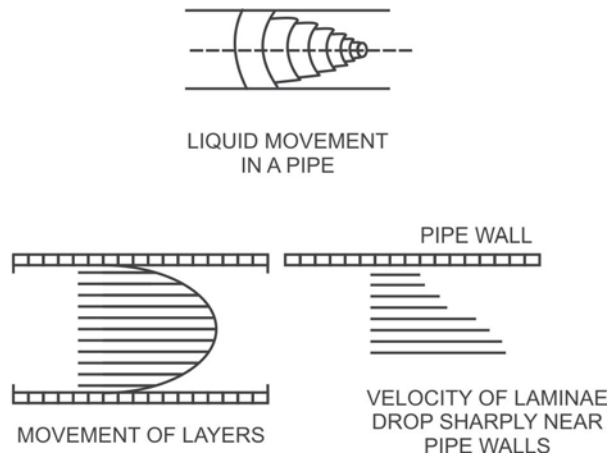


Flow

Fluids tend to move in thin sheets, called laminae. As long as they are moving in parallel lines at the same speed there is no tendency for one layer to drag another.

This ideal condition is called streamline flow or laminar flow. However this condition never exists in actual practice. Molecules of all liquids have a tendency to cling together i.e., have the property of cohesion. This causes an internal friction, which has been previously defined as viscosity. Also, the fluids tends to adhere to the other substances like pipewalls. This adhesion is the primary problem in fluid flow, because adhesion causes drag on laminae at the pipewalls and the cohesive forces create drag on the adjacent laminae near the pipewalls finally resulting in turbulent flow.

This drag caused by adhesion at the pipewalls causes the laminae to break a great deal of congestion in the fluid, which flows. The laminae in a pipe can be visualized as cylinders of liquid one inside the other. The outside cylinders cling against the pipewall causing the next cylinder to break its flow pattern which in turn acts on the next cylinder and so on towards the centre of the pipe. Each of these cylinders are disturbed slightly, less than the one before it. Consequently, if the pipe is large enough, the interior fluid is able to flow smoothly. The velocity



is the greatest at the pipe axis and decreases sharply to nearly zero at the pipewalls. The over all effect of the turbulent flow is a reduction in effective pipe size.

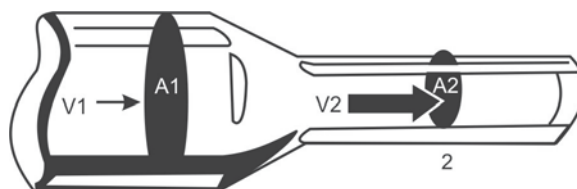
Relation between Cross - Sectional Area, Quantity of Flow and Velocity

Total quantity of liquid that enters a pipe must leave the pipe from the other end immaterial of cross section, as liquids are incompressible. If the liquid is being pumped through a pipe having different cross-sectional area, the same quantity of liquid must pass every point in the same length of time. Consequently, the velocity of flow must change every time the diameter changes. The volume of liquid passing any cross-sectional area of the pipe is the product of velocity and cross-sectional area at the point. This is expressed by the formula.

$$Q = A \times V$$

where Q is the Quantity of liquid, A is the cross-sectional area of the pipe and V is the velocity of the liquid. Let us consider a case of pipeline where the diameter of the pipe is reduced to half its original size. The cross - sectional area of the reduced section is calculated as follows:

The original cross - section area



$$A_1 = \frac{\pi D_1^2}{4} \quad (D_1 \text{ is original diameter})$$

And reduced cross - sectional area

$$A_2 = \frac{\pi D_2^2}{4} \quad (D_2 \text{ is reduced diameter})$$

$$\begin{aligned} \text{Since } D_2 &= \frac{D_1 A_2}{2} = \frac{\pi D_1^2}{4} \\ &= \frac{A_1}{4} \end{aligned}$$

For a fixed quantity of flow the velocities V_1 in the reduced original section and velocity V_2 in the section are related as follows:

$$Q = A_1 \times V_1 = A_2 \times V_2$$

$$\begin{aligned} \text{Therefore } V_2 &= \frac{A_1 \times V_1}{A_2} = A_1 V_1 \times 4 / A_1 \\ &= 4 V_1 \end{aligned}$$

To generalise the example, the velocity of the flow of a liquid through a pipe changes inversely proportional to the square of its diameter for a given flow:

Resistance to Flow

Fluid will flow in a pipeline if there is a difference in the pressure between its ends. The pressure difference can be static pressure resulting from a difference in elevation of the ends or it may be an induced pressure difference created by a pump. In oil refinery, most pressures are induced with pumps. In both the cases, some pressure loss occurs in any pipelines through which it flows.

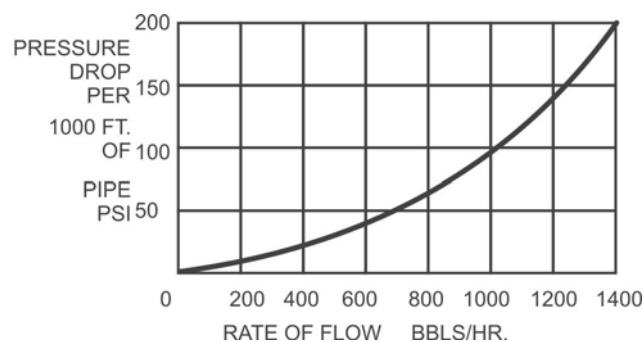
The magnitude of the pressure loss in a piping system depends on a number of factors. Some of which are:

1. Line size (pipe diameter)
2. Line length
3. Roughness inside the pipe
4. Pipe bends
5. Velocity of fluid flow
6. Viscosity of the fluid
7. Density of the fluid



Line size affects the resistance to fluid flow through turbulence. When pipe diameter is small, streamline flow is not possible. The line length causes more resistance to flow because it multiplies all the other resistance factors. Surface roughness produces turbulence and its effect is more objectionable in small diameter pipeline. Turbulence can occur in a perfectly smooth pipe, if the velocity is high because adhesion disrupts the flow pattern of laminae near the pipewall. Pipe bends create resistance to flow in two ways. Firstly because pipe bend is usually a point of roughness and secondly because force is required to change the direction of flow. At any pipe bend, the force required to change the direction of flow mostly acts against the direction of flow.

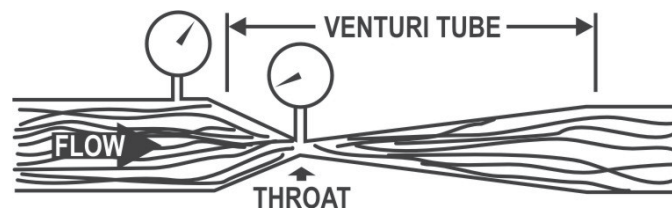
Excessive fluid velocity in a system can greatly increase the pressure drop. As the speed of the flow increase, turbulence begins and the loss of pressure downstream increases, as previously mentioned, the liquid in a pipe tends to flow in thin cylinders or laminae at low velocities, these cylinders shear past one another easily at different speeds. This type of flow allows the greatest quantity of liquid to be moved with the least possible effort but to achieve this condition larger diameter pipes are required which becomes uneconomical. Normally, piping systems are designed for a fluid velocity near to the velocity where turbulence starts. This velocity is called critical velocity. This velocity is related to the viscosity and density of the fluid. The change from the streamlined flow to a turbulent flow occurs when the flow rates, pipe diameter and viscosity reach a certain ratio values. The practical application of streamline of turbulent flow is more important for designing than for operation. Pipes are designed for near stream-line flow where the pressure drops through the line must be kept low and design for turbulent flow is made where mixing and heat transfer are desired. A typical chart below shows how the pressure drop increases with the velocity of fluid flow.



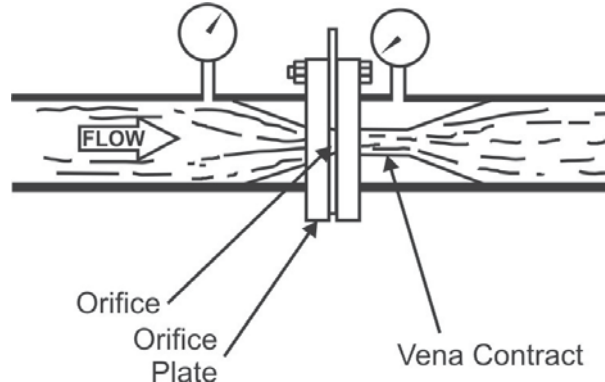
Change in the density will also affect the pressure drop. An increase in density will decrease pressure drop. Density of a liquid increases with cooling and therefore the pressure drop reduces if the product is cooler. If two fluids having same viscosity but different densities are pumped through similar piping system at the same velocity, more dense fluid creates less turbulence and thereby less pressure drop. The reason for this is the deflection of the laminae is less in case of denser liquid than lighter liquids.

The above-mentioned properties of liquids are used in the refinery to measure flow rates. The pressure drop through a cross section of a pipe is proportional to the square of the velocity. The pressure drop is also affected by viscosity and density as mentioned earlier.

The venturi tube is device that is used to measure fluid flow using the pressure differential created by increased velocity. Since the total head in the system is the same at all points, excluding friction in a given system, the drop in pressure though the venturi increases as the velocity is greater. Shaping the venturi to get higher velocity in a streamlined manner minimizes the friction pressure drop. The difference in pressure between low velocity point A and high velocity point B (called throat) is measured and related to the amount of fluid flowing through the venturi tube: - (Refer fig. Below)



The most common means of measuring fluid flow in the refinery is by using an orifice plate. It uses the same principle like a venturi tube and is cheaper although not so streamlined.



Basic Principles of Energy

A body is said to possess energy when on account of its condition it is capable of doing work. By virtue of its position, velocity, temperature, pressure or chemical composition, a body may be capable of doing work. Heat, electricity, magnetism etc., are different forms of energy. Energy is measured in different units in the English and Metric system and can be converted into the one and the other. The energy possessed by a body by virtue of its position is called potential energy. A common example is water stored in reservoirs at high level. The energy possessed by a body by virtue of its velocity is called kinetic energy. Energy can be converted from one form to other.



Work is the useful product of expended energy. It is the result of force being applied through a distance and is measured in gram-centimeter. By this definition a man does not work holding a heavy load as the distance moved, is zero. But the person is spending heat energy to hold the heavy load therefore the conclusion is that it is possible to spend energy without doing useful work.

Power is the time rate of doing work. The familiar term horsepower is defined as the work done to move 550 lbs. weight by one foot in one second.

Heat

Heat is a form of energy. Heat flows from one mass to another because of the temperature difference between them and it is independent of the weight or the mass. Heat energy represents a store of useful work and is a quantity. If a work requirement is small, only a part of the total quantity will have to be used.

Measurement of Heat

Heat is the quantity of energy flowing from one mass to another. It is customary to think of heat in terms of temperature, but temperature is indication of the level of heat or intensity of the heat and does not directly indicate the quantity of heat. Measurement of temperature has been previously discussed.

Heat is measured in gram calories, kilocalories and British thermal unit's (B.T.U). Since heat is a form of energy it can be expressed in gram centimeter also. The heat required to raise the temperature of 1 gm of water by 1°C (15°C - 16°C) is called calorie and the heat required to raise the temperature of one pound of water through one degree Fahrenheit (60°F to. 61°F) is called BTU and is equal to 252 calories. Using the definition, the amount of heat required to raise the temperature of one litre of water at 30°C to its boiling point of 100°C can be calculated as follows.

Since specific gravity of water is 1, one litre water weighs 1000 grams, therefore.

Calories required = Temperature difference X weight = (100 - 30) x 1000 = 70 x 1000 = 70,000 Calories

Specific Heat

Specific heat is the heat required to raise the temperature of one gram of substance through one degree centigrade. By the definition, the specific heat of water is 1. It is interesting to note that the specific heat values of all substances are independent of the system of measurement. The specific heat of water is one BTU per pound or 1 calorie per gram. The specific heat of most of the substances is less than that of water. Specific heat of some of the typical substances are listed below.

Gasoline	- 0.500	Aluminum	- 0.224
Toluene	- 0.400	Copper	- 0.092
Kerosene	- 0.500	Iron	- 0.122

Crude Oil	-	0.500		Sulphur	-	0.175
Coke	-	0.203		Mercury	-	0.033

In general, the denser a substance, the lower is its specific heat. It is also interesting to note that the common Refinery Oils have the same specific heat.

The following formula can be used to calculate heat requirements.

$$Q = W \times T \times C$$

Where	Q	=	Quantity of heat required
	W	=	Weight of the substance
	T	=	Temperature differential
	C	=	Specific heat.

Using this formula let us calculate how many calories are required to raise 2000 liters of kerosene from 15°C to 85°C - the specific gravity of kerosene is 0.80

$$Q = W \times T \times C$$

$$\text{Weight of 2000 liters} = 2000 \times 0.80 = 1600 \text{ grams} = W$$

$$T = 85 - 15 = 70^\circ\text{C}, C = 0.500$$

$$\text{Therefore, } Q = 1600 \times 70 \times 0.500 = 56,000 \text{ calories}$$

The foregoing heat requirement calculation involves changing the temperature of the substance without change of state (from liquid to gas etc.,) taking place. This is called sensible heat. This term is used to distinguish it from the additional heat required to change the state of the substance.

Latent Heat

If we take a beaker of water and heat it up, we find the temperature rising. The temperature continues to rise till boiling starts and remains steady at 100°C even though heat is applied. In this case the heat applied is utilised by the liquid to change its state to vapours. The heat required to change the state of a substance is called latent heat. The heat required for a solid to change its state to liquid is called latent heat of fusion and that for liquid to change to vapours is called latent heat of vaporisation,

The latent heat of vaporisation of water is 539.6 calories/gram at standard atmospheric pressure. Under less pressure, the latent heat increases and under higher pressure, less latent heat is required. The latent heat of vaporisation of oils is considerably less than that of water. The latent heat of vaporisation of gasoline, kerosene and sulphur are 75,60 and 66 calories per gram respectively.



The Law of Conservation of Energy

The study of the various forms of energy and the transformation of one kind of energy into another has led to the statement of a very important basic principle of energy known as the conservation of energy. This may be stated as follows. In any body or a system of bodies which is not receiving or giving up energy, the total amount of energy remains unchanged. In other words, energy can neither be created or be destroyed, but can be transformed from one form to another, the total amount remaining unchanged.

A bullet leaving the nozzle of a gun receives its energy on account of the work done by expanding gases. As it passes through the air, it loses some of its kinetic energy because of friction of air in the atmosphere. This kinetic energy is transferred to air in the form of heat. When it strikes an object heat will be developed, part of which will be absorbed by the target and part of the energy may get converted to sound and light also. Thus the total energy of the bullet is converted into various forms of energy and will be equal to the initial energy the bullet possessed.

Another example of transformation of energy, which is commonly found in the refinery, is in the boilers. Fuel oil burned in the boiler converts the stored chemical energy into heat energy by combustion. The heat energy is transferred to the water to produce steam with energy stored in the form of heat and pressure. This steam can be used to drive a turbine, which transforms the heat and pressure to the kinetic energy. The turbine can be used to drive a generator where the kinetic energy is transformed into electrical energy.

The main purpose of most of the equipments in the refinery is either to change energy from one form to another or to transfer energy from one form to another or to transfer energy from one place to another. A heat exchanger, or an electric cable or a compressed airline move or transfer energy from one place to another.

Efficiency

Efficiency is the ratio of output to input. No machine gives out as much energy or power as is put into it in the form it is intended for. There are some losses even in the most perfectly constructed machines. Efficiency is usually expressed as a percentage. For example, if we say that the efficiency of a motor is 80%, it means that only 80% of the energy or electric power received by the motor is delivered as available driving force and balance used to overcome friction, inertia, transformed into heat energy, etc. Furnace efficiency, for example, is the percentage of the heat input from the burning fuel to the heat absorbed by the feed stock. If furnace efficiency is 70%, for every 100 calories fired - only 70 calories are absorbed in the process stream and the rest of the energy is used for heating things that the furnace is not intended for.

Energy when it is under control is very useful but can be hazardous when it is out of control, a pound of gasoline can do more damage than a pound of dynamite, since gasoline has more stored chemical energy than dynamite. Compressed air

can expel a rock or a piece of metal at a high velocity like bullet equipments moving at high speed contain large amount of kinetic energy.

Heat Transfer

As previously mentioned heat always flows from a higher temperature to a lower temperature. It can flow through all forms of matter as well as exist within it. Heat can be emitted from one body to another. It can also be reflected. Temperature is the indication of heat or energy level.

In general there are three methods of heat transfer. These are known as conduction, convection and radiation.

Conduction

Heat that flows from one part of a substance to another part of a substance or from substance to another by physical contact is said to flow by conduction. The heat felt on the handle of a spoon after keeping it immersed in hot liquid is the result of heat being conducted from the liquid to the handle of the spoon. There are some substances such as stone, wood, plastics, cork which are poor conductors of heat and are called insulators. All metals are good conductors of heat, although there is difference in their conductivity. Liquids and gases are much poorer conductor than metals. Insulating materials like magnesia, glass wool, cork are used in the refinery around pipelines and vessels to prevent loss of heat to the air.

Convection

Heat also can be transferred from one place to another by a moving stream of air or some other fluid. All systems of ventilation or heating of rooms depend on the convection currents, which in turn depends on the expansion of the fluids. Any time a gas or a liquid is heated, there is an increase in volume and consequently a decrease in density. The decrease in density causes the fluid surrounding it, to replace soon the dense fluid will get heated and the process of displacement continues. Thus there is a motion set up and this motion is called convection currents. The convection currents transport the heat from the source to a different area or to a different substance, The convection currents can be caused naturally by a temperature difference creating density difference or they can be caused artificially or boosted by blowers.

Radiation

A third way by which heat can be transferred from one body to another is by radiation. Radiation can heat up a body even if it is under vacuum. Radiant heat is said to be carried by electromagnetic waves, which will travel through space in straight lines at the speed of light. The heat from the sun travels to the earth's atmosphere through the vacuum in the outer space by radiation. The heat felt from a campfire by a camper is also by radiation. Since radiant heat travels in straight lines, the camper will feel colder on the side away from the fire.



Factors Affecting Heat Transfer

The principal factors affecting heat transfers are a) temperature difference, b) thermal resistance, c) thickness of scale and films on the heat transfer surface. d) Velocity of hot and cold fluids.

Heat Exchanger

The efficient use of heat in the refinery is achieved by an equipment commonly called heat exchangers. They are made in many designs and they do a variety of jobs. They can be classified as follows:

- 1) Coolers and condensers
- 2) Heaters and reboilers
- 3) Heat exchangers (oil to oil)

Coolers generally have water flowing through the tubes, which reduces the temperature of the oil by removing sensible heat. Moving air with fans over the tubes containing oil also uses air coolers. Condensers work the same way except that the vapours entering the condenser change the state of liquid by removal of latent heat of condensation. Heaters usually have steam on the inside of tubes, which raises the temperature of cold oil outside of tubes by providing sensible heat. Reboiler does the same except that the oil is vaporized and the latent heat of vaporization is also involved.

This term heat exchanger is usually used where oil is on both sides of the tubes. The objective is to use hot oil that needs to be cooled as a source of heat to warm up the cold oil.

Fired furnaces are commonly used to heat up oil or water. The heat is transmitted to the oil or water flowing through the tubes in the furnace

A simple example of direct heat exchange is mixing of hot and cold liquids. This is generally avoided when temperature differential is high due to the potential hazards involved.

The cooling tower used for lowering the temperature of cooling water uses a combination of convection and evaporation heat transfer. The heat transfer is direct. The cooling medium used is air. The amount of moisture air can absorb increases greatly with increase in temperature. The water is sprayed on the top section of the tower to have a good contact with air. The internals of the tower aids to keep the water in small drops. In a spray the convection is taking place between air and water. Heat is also dissipated through evaporation thereby cooling the water.

Heat Transfer Coefficients

Heat transfer coefficient is a means of evaluating the performance of an exchanger. This indicates the amount of heat an exchanger can interchange during a given period of time for a given surface area with a given temperature difference between

the hot and cold fluids. For exchangers in operation the heat transfer coefficient helps to determine whether a heat exchanger is fouled and needs cleaning.

For a particular exchanger, the number of tubes and the size of tubes fix the area of heat transfer; the temperature of the hot liquid is fairly fixed due to operating conditions. Therefore, if the heat transfer coefficient drops, then it is due to the fouling of the exchanger.

The principal factors affecting the heat exchange in an exchanger are a) the area of surface available for heat transfer, b) temperature difference between hot and cold liquid c) Velocity of the hot and cold fluids and d) thickness of scale and films on the heat transfer surface.

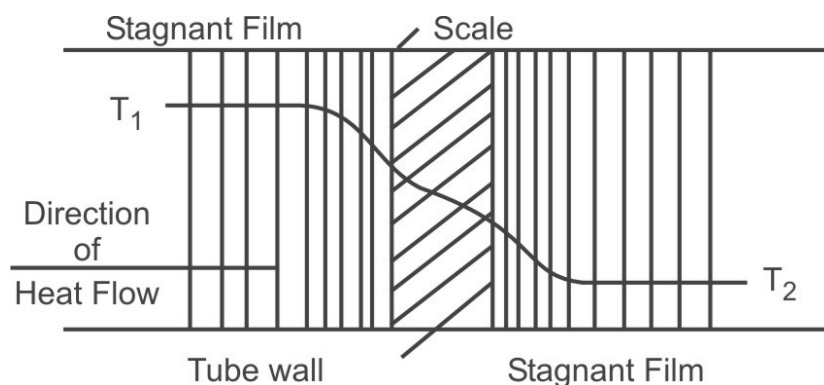
The surface area is determined by the number of tubes and the tube diameter. Usually it is a practice to minimize the diameter of the tubes consistent with the flow requirement and pressure available so as to have maximum heat transfer area for a given cross sectional area of the exchanger. The greater the area, the greater will be the heat transfer.

Temperature difference is the driving force to make the heat transfer. The greater the temperature difference, the greater the heat transfer will be, In order to take full advantage of the temperature difference, the hot and cold streams are designed to flow in the opposite direction.

Velocity affects heat transfer because the faster the fluid flows, the thinner is the stagnant film dragging on the wall of the tubes. The stagnant film is the result of property of adhesion of liquids. This film offers resistance to the flow of heat and therefore reducing the thickness of this film better heat transfer results. Smaller diameter tubes reduce the film thickness by increasing the velocity.

The thermal resistance offered by scale formation affects the heat transfer. This is termed as fouling. Thermal conductivity of the scaling substances is usually very low. Scales are often formed in working units by the nature of process and can cause unit shut down due to reduced heat transfer.

The accompanying illustration shows the effect of scales and stagnant film in a heat exchanger.





The flow of heat from a higher temperature T_1 to the lower temperature T_2 decreases due to the resistance offered by tube side stagnant film, tube side scale, shell side scale and shell side stagnant film. The temperature drop is the greatest through the stagnant film and scale, as they offer the greatest thermal resistance. The tube wall itself offers resistance, which is minimized in an exchanger by using thinnest possible tube and from metals that are good conductors of heat. The effect of all thermal resistance is gathered into one mathematical term denoted as U .

The total amount of heat transferred in a given time in an exchanger can be expressed as follows

$$Q = UADT$$

Where Q = Quantity of heat transferred

U = the heat transfer coefficient

DT = The temperature difference between the hot and cold liquid

A = the total surface area of the exchanger.

3. CRUDE OIL REFINING

We have seen images of thick, black crude oil gushing out of the ground or a drilling platform in TV or News. But when you pump the gasoline for your car, you've probably noticed that it is clear. And there are so many other products that come from oil, including crayons, plastics, heating oil, jet fuel, kerosene, synthetic fibers and tires. How is it possible to start with crude oil and end up with gasoline and all of these other products?

Crude Oil

Crude oil is the term for “unprocessed” oil, the stuff that comes out of the ground. It is also known as petroleum. Crude oil is a fossil fuel, meaning that it was made naturally from decaying plants and animals living in ancient seas millions of years ago -- anywhere you find crude oil was once a sea bed. Crude oils vary in color, from clear to tar-black, and in viscosity, from water to almost solid.

Crude oils are such a useful starting point for so many different substances because they contain hydrocarbons. Hydrocarbons are molecules that contain hydrogen and carbon and come in various lengths and structures, from straight chains to branching chains to rings.

There are two things that make hydrocarbons exciting to chemists:

- Hydrocarbons contain a lot of energy. Many of the things derived from crude oil like gasoline, diesel fuel, paraffin wax and so on take advantage of this energy.
- Hydrocarbons can take on many different forms. The smallest hydrocarbon is methane (CH_4), which is a gas that is lighter than air. Longer chains with 5 or more carbons are liquids. Very long chains are solids like wax or tar. By chemically cross-linking hydrocarbon chains you can get everything from synthetic rubber to nylon to the plastic in tupperware. Hydrocarbon chains are very versatile!

On average, crude oils are made of the following elements or compounds:

- Carbon - 84%
- Hydrogen - 14%
- Sulfur - 1 to 3% (hydrogen sulfide, sulfides, disulfides, elemental sulfur)
- Nitrogen - less than 1% (basic compounds with amine groups)



- Oxygen - less than 1% (found in organic compounds such as carbon dioxide, phenols, ketones, carboxylic acids)
- Metals - less than 1% (nickel, iron, vanadium, copper, arsenic)
- Salts - less than 1% (sodium chloride, magnesium chloride, calcium chloride)

The major classes of hydrocarbons in crude oils include:

Paraffins

- general formula: C_nH_{2n+2} (n is a whole number, usually from 1 to 20)
- straight- or branched-chain molecules
- can be gasses or liquids at room temperature depending upon the molecule
- examples: methane, ethane, propane, butane, isobutane, pentane, hexane

Aromatics

- general formula: $C_6H_5 - Y$ (Y is a longer, straight molecule that connects to the benzene ring)
- ringed structures with one or more rings
- rings contain six carbon atoms, with alternating double and single bonds between the carbons
- typically liquids
- examples: benzene, naphthalene

Napthenes or Cycloalkanes

- general formula: C_nH_{2n} (n is a whole number usually from 1 to 20)
- ringed structures with one or more rings
- rings contain only single bonds between the carbon atoms
- typically liquids at room temperature
- examples: cyclohexane, methyl cyclopentane

Other Hydrocarbons

Alkenes

- general formula: C_nH_{2n} (n is a whole number, usually from 1 to 20)
- linear or branched chain molecules containing one carbon-carbon double-bond
- can be liquid or gas
- examples: ethylene, butene, isobutene

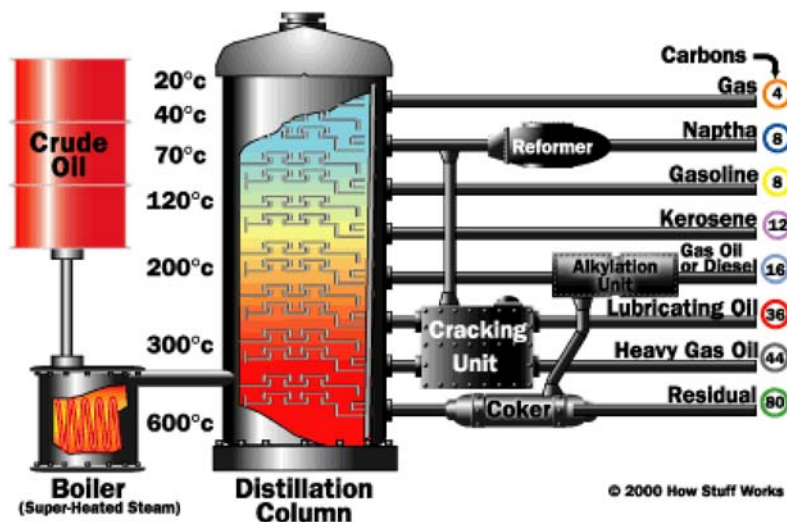
Dienes and Alkynes

- general formula: C_nH_{2n-2} (n is a whole number, usually from 1 to 20)
- linear or branched chain molecules containing two carbon-carbon double-bonds
- can be liquid or gas
- examples: acetylene, butadienes

Now that we know what's in crude oil, let's see what we can make from it.

From Crude Oil

The problem with crude oil is that it contains hundreds of different types of hydrocarbons all mixed together. You have to separate the different types of hydrocarbons to have anything useful. Fortunately there is an easy way to separate things, and this is what oil refining is all about.



The oil refining process starts with a fractional distillation column.



Different hydrocarbon chain lengths all have progressively higher boiling points, so they can all be separated by distillation. This is what happens in an oil refinery - in one part of the process, crude oil is heated and the different chains are pulled out by their vaporization temperatures. Each different chain length has a different property that makes it useful in a different way.

To understand the diversity contained in crude oil, and to understand why refining crude oil is so important in our society, look through the following list of products that come from crude oil:

Petroleum gas - used for heating, cooking, making plastics

- small alkanes (1 to 4 carbon atoms)
- commonly known by the names methane, ethane, propane, butane
- boiling range = less than 104 degrees Fahrenheit / 40 degrees Celsius
- often liquified under pressure to create LPG (liquified petroleum gas)

Naphtha - intermediate that will be further processed to make gasoline

- mix of 5 to 9 carbon atom alkanes
- boiling range = 140 to 212 degrees Fahrenheit / 60 to 100 degrees Celsius

Gasoline - motor fuel

- liquid
- mix of alkanes and cycloalkanes (5 to 12 carbon atoms)
- boiling range = 104 to 401 degrees Fahrenheit / 40 to 205 degrees Celsius

Kerosene or ATF - fuel for jet engines and tractors; starting material for making other products

- liquid
- mix of alkanes (10 to 18 carbons) and aromatics
- boiling range = 350 to 617 degrees Fahrenheit / 175 to 325 degrees Celsius

Gas oil or Diesel distillate - used for diesel fuel and heating oil; starting material for making other products

- liquid
- alkanes containing 12 or more carbon atoms
- boiling range = 482 to 662 degrees Fahrenheit / 250 to 350 degrees Celsius

Lubricating oil - used for motor oil, grease, other lubricants

- liquid
- long chain (20 to 50 carbon atoms) alkanes, cycloalkanes, aromatics
- boiling range = 572 to 700 degrees Fahrenheit / 300 to 370 degrees Celsius

Heavy gas or Fuel oil - used for industrial fuel; starting material for making other products

- liquid
- long chain (20 to 70 carbon atoms) alkanes, cycloalkanes, aromatics
- boiling range = 700 to 1112 degrees Fahrenheit / 370 to 600 degrees Celsius

Residuals - coke, asphalt, tar, waxes; starting material for making other products

- solid
- multiple-ringed compounds with 70 or more carbon atoms
- boiling range = greater than 1112 degrees Fahrenheit / 600 degrees Celsius

You may have noticed that all of these products have different sizes and boiling ranges. Chemists take advantage of these properties when refining oil. Look at the next section to find out the details of this fascinating process.

The Refining Process

As mentioned previously, a barrel of crude oil has a mixture of all sorts of hydrocarbons in it. Oil refining separates everything into useful substances. Chemists use the following steps:

1. The oldest and most common way to separate things into various components (called fractions), is to do it using the differences in boiling temperature. This process is called fractional distillation. You basically heat crude oil up, let it vaporize and then condense the vapor.
2. Newer techniques use Chemical processing on some of the fractions to make others, in a process called conversion. Chemical processing, for example, can break longer chains into shorter ones. This allows a refinery to turn diesel fuel into gasoline depending on the demand for gasoline.



3. Refineries must treat the fractions to remove impurities.
4. Refineries combine the various fractions (processed, unprocessed) into mixtures to make desired products. For example, different mixtures of chains can create gasolines with different Octane ratings.

The products are stored on-site until they can be delivered to various markets such as gas stations, airports and chemical plants. In addition to making the oil-based products, refineries must also treat the wastes involved in the processes to minimize air and water pollution.

In the next section, we will look at how we separate crude oil into its components.

Fractional Distillation

The various components of crude oil have different sizes, weights and boiling temperatures; so, the first step is to separate these components. Because they have different boiling temperatures, they can be separated easily by a process called fractional distillation. The steps of fractional distillation are as follows:

1. You heat the mixture of two or more substances (liquids) with different boiling points to a high temperature. Heating is usually done with high pressure steam to temperatures of about 1112 degrees Fahrenheit / 600 degrees Celsius.
2. The mixture boils, forming vapor (gases); most substances go into the vapor phase.
3. The vapor enters the bottom of a long column (fractional distillation column) that is filled with trays or plates.
 - The trays have many holes or bubble caps (like a loosened cap on a soda bottle) in them to allow the vapor to pass through.
 - The trays increase the contact time between the vapor and the liquids in the column.
 - The trays help to collect liquids that form at various heights in the column.
 - There is a temperature difference across the column (hot at the bottom, cool at the top).
4. The vapor rises in the column.
5. As the vapor rises through the trays in the column, it cools.
6. When a substance in the vapor reaches a height where the temperature of the column is equal to that substance's boiling point, it will condense to form a liquid. (The substance with the lowest boiling point will

condense at the highest point in the column; substances with higher boiling points will condense lower in the column.).

7. The trays collect the various liquid fractions.
8. The collected liquid fractions may:
 - pass to condensers, which cool them further, and then go to storage tanks
 - go to other areas for further chemical processing

Fractional distillation is useful for separating a mixture of substances with narrow differences in boiling points, and is the most important step in the refining process.

Very few of the components come out of the fractional distillation column ready for market. Many of them must be chemically processed to make other fractions. For example, only 40% of distilled crude oil is gasoline; however, gasoline is one of the major products made by oil companies. Rather than continually distilling large quantities of crude oil, oil companies chemically process some other fractions from the distillation column to make gasoline; this processing increases the yield of gasoline from each barrel of crude oil.

In the next section, we'll look at how we chemically process one fraction into another.

Chemical Processing

You can change one fraction into another by one of three methods:

- breaking large hydrocarbons into smaller pieces (cracking)
- combining smaller pieces to make larger ones (unification)
- rearranging various pieces to make desired hydrocarbons (alteration)

Cracking

Cracking takes large hydrocarbons and breaks them into smaller ones.

There are several types of cracking:

Thermal - you heat large hydrocarbons at high temperatures (sometimes high pressures as well) until they break apart.

- steam - high temperature steam (1500 degrees Fahrenheit / 816 degrees Celsius) is used to break ethane, butane and naptha into ethylene and benzene, which are used to manufacture chemicals.
- visbreaking - residual from the distillation tower is heated (900 degrees Fahrenheit / 482 degrees Celsius), cooled with gas oil



and rapidly burned (flashed) in a distillation tower. This process reduces the viscosity of heavy weight oils and produces tar.

- coking - residual from the distillation tower is heated to temperatures above 900 degrees Fahrenheit / 482 degrees Celsius until it cracks into heavy oil, gasoline and naphtha. When the process is done, a heavy, almost pure carbon residue is left (coke); the coke is cleaned from the cokers and sold.

Catalytic - uses a catalyst to speed up the cracking reaction. Catalysts include zeolite, aluminum hydrosilicate, bauxite and silica-alumina.

- fluid catalytic cracking - a hot, fluid catalyst (1000 degrees Fahrenheit / 538 degrees Celsius) cracks heavy gas oil into diesel oils and gasoline.
- hydrocracking - similar to fluid catalytic cracking, but uses a different catalyst, lower temperatures, higher pressure, and hydrogen gas. It takes heavy oil and cracks it into gasoline and kerosene (jet fuel).

After various hydrocarbons are cracked into smaller hydrocarbons, the products go through another fractional distillation column to separate them.

Unification

Sometimes, you need to combine smaller hydrocarbons to make larger ones -- this process is called unification. The major unification process is called catalytic reforming and uses a catalyst (platinum, platinum-rhenium mix) to combine low weight naphtha into aromatics, which are used in making chemicals and in blending gasoline. A significant by-product of this reaction is hydrogen gas, which is then either used for hydrocracking or sold.

Alteration

Sometimes, the structures of molecules in one fraction are rearranged to produce another. Commonly, this is done using a process called alkylation. In alkylation, low molecular weight compounds, such as propylene and butylene, are mixed in the presence of a catalyst such as hydrofluoric acid or sulfuric acid (a by-product from removing impurities from many oil products). The products of alkylation are high octane hydrocarbons, which are used in gasoline blends to reduce knocking.

Now that we have seen how various fractions are changed, we will discuss the how the fractions are treated and blended to make commercial products.

Treating and Blending the Fractions

Distillated and chemically processed fractions are treated to remove impurities, such as organic compounds containing sulfur, nitrogen, oxygen, water, dissolved metals and inorganic salts. Treating is usually done by passing the fractions through the following:

- a column of sulfuric acid - removes unsaturated hydrocarbons (those with carbon-carbon double-bonds), nitrogen compounds, oxygen compounds and residual solids (tars, asphalt)
- an absorption column filled with drying agents to remove water



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4. UNIT OPERATIONS/ SEPARATION TECHNIQUES

Petroleum refining is the process of separation of the different hydrocarbons and conversion of some of the hydrocarbons into products having higher quality performance and also to suit the market requirements. Crude oil, as taken off the ground does not contain the fractions in the proportion of consumer demands and of the right quality. For example gasoline cut or naphtha has a poor octane number, kerosene has undesirable odour and high sulphur content, Furnace oil content may be of higher proportion than the product demand. From the time crude oil was discovered, the refining process has advanced from a simple batch distillation process to separate only the kerosene fraction to a highly technical process utilising the last fraction of the crude to make as many as 200-250 different products. The multitude of equipment and pipelines in the modern refineries, is of paramount importance that the operating personnel have a basic understanding of the hydrocarbon molecule and the changes that can be made to it to improve quality and produce new products.

Origin of Crude Oil

Crude petroleum is believed to be formed by the transformation of organic materials and marine organism deep under the surface of the earth under the conditions that exist in that layer of earth. It is believed that this transformation has taken place in the course of million of years. The presence of crude oil is detected by seismographic survey and is pumped out by drilling wells. The composition of the crude changes depending on the geographical area of the source and it may change even from well to well in the same area.

Crude oil as it comes from the wells can rarely be used directly except for burning. The recovery of the products by separation of the components of the mixture is essential to put crude oil to effective use. The need for separating and refining these products increased with industrial revolution and rising standards of living.

The physical separation of mixtures can be achieved by various methods and are used in our refinery as indicated below

- a) By Size - Filtration - e.g. pump strainers, filters, etc.
- b) By density - setting in overhead distillate drums caustic wash system
- c) By solubility - Furfural extraction, NMP extraction
- d) By boiling point - Distillation of crude, vapour recovery unit



- e) By electromotive force - Desalter
- f) By crystalliation - MEK Dewaxing

In oil refining, separation by distillation is the most used method compared to the other

Distillation

In the distillation process, part of the liquid mixture is changed into vapours by application of heat and then condensed into liquid by cooling. This process is known as fractionation.. Thus fractionation is a process of vaporisation and condensation. Therefore, the two essential requirements for the fractionation of a mixture are (a) source of heat to raise the temperature of the mixture and supply latent heat required to vaporize the part of the component and (b) a facility to condense the separated vapour of the mixture a condenser. A third requirement is pressure that is required to condense the separated vapour. The pressure also has the effect of reducing the volume of vapours and permit use of smaller equipments, but adversely affects the temperature requirement, Normally, distillation columns are designed to strike a happy balance between these two opposite effects.

We have seen that water can be vaporised and when the water starts boiling, the temperature remains constant till all the water is evaporated. But if we have a mixture of alcohol and water, we will find that the alcohol vapourises from the mixture as soon as the temperature reaches the boiling point of the mixture. The boiling point of any liquid has been defined as the temperature at which vapour pressure exerted by the liquid is equal to the pressure to which the liquid is subjected to. Hence the mixture of alcohol and water will have a vapour pressure higher than that of water and lower than that of alcohol or in other words, the boiling point of the mixture will be between those of the pure liquids. When the vapour from this mixture is collected, it is found that the more volatile liquid alcohol has contributed more molecules to the vapour than the other liquid, water. The amount of molecules of higher boiling point liquid present in the vapours are related to concentration of the more volatile or the lower boiling point fraction in the mixture Also, the closer the boiling point of the liquids in the mixture, the larger the concentration of the higher boiling point liquid in the vapours.

Condensation is the change of state of a substance from vapour to liquid state. This can be accomplished in two ways; (a) by removal of the latent heat under constant pressure by cooling and (b) by increased pressure followed by heat removal. However, for every gas there is a temperature above which condensation cannot take place regardless of the pressure applied. This temperature is called critical temperature. The pressure required to condense the vapours of a substance at its critical temperature is called critical pressure. The separation of higher boiling point components from a mixture of vapours can be achieved by partial condensation. This is usually accomplished by adjusting the pressure of the equipment as required for the condensation of the heavier component at

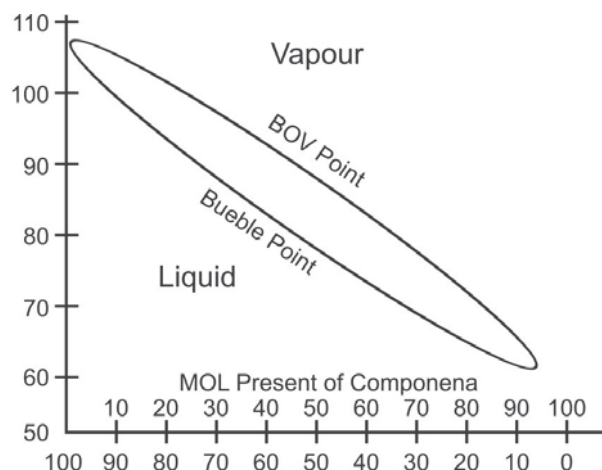
ambient temperature or by adjusting the cooling to the required temperature keeping a constant pressure.

The actual temperature at which condensation begins to take place depends on the composition of the material and pressure. The temperature at which the first drop of liquid forms in the condensation process is called dew point.

Fractional Distillation

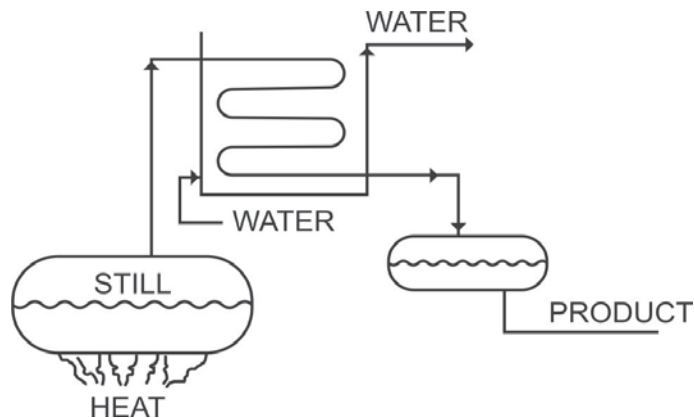
In fractional distillation, two actions that go hand in hand are vaporization and condensation. Thus, the process of fractionation revolves around the interaction between vaporising or boiling liquid and condensing vapour. Given a boiling liquid and a condensing vapour at a uniform temperature and pressure, a condition will tend to exist whereby the components of the mixture will be distributed between the liquid and the vapour space. Molecules tend to escape from the liquid to the vapour or vice versa. The continuous interchange of molecule between the liquid and vapour is equal or a balance existing between the vapour and liquid. This condition is called equilibrium condition.

The accompanying graph shows the shape of a curve of a mixture of normal butane, and normal pentane in equilibrium at 7 kg/cm².



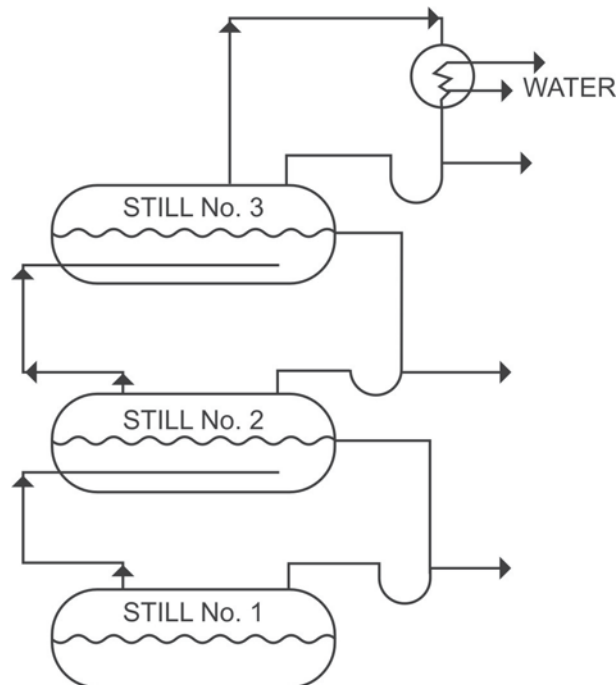
Below the liquid line the mixture is a liquid, above the vapour line the system is a complete vapour, and between the two lines both liquid and vapour are present. Knowing the conditions prevailing in any system, we can tell whether to expect the component in a liquid or vapour form.

Shell stills were the first stills used to fractionate crude oil continuously. There were horizontal tanks with fire under them and condenser coils to condense the vapours. The stills do not produce very pure boiling ranges, but the understanding of their operation makes it easier to understand the distillation in modern fractionator.



The temperature of the still is adjusted according to the fraction required overhead and then the temperature is raised to get the next fraction. In other words, the process of separation of different components was achieved in batches. As previously mentioned, the purity of the overhead component depends on the concentration of the component in the original mixture i.e., higher the concentration, higher the purity.

Therefore, to get a purer component, the overhead product or the bottom product has to be redistilled. The redistillation will be the repetition of the same system. The external heat has to be applied for every still and the overhead condenser removes the heat. This involves more equipment and increased fuel costs.



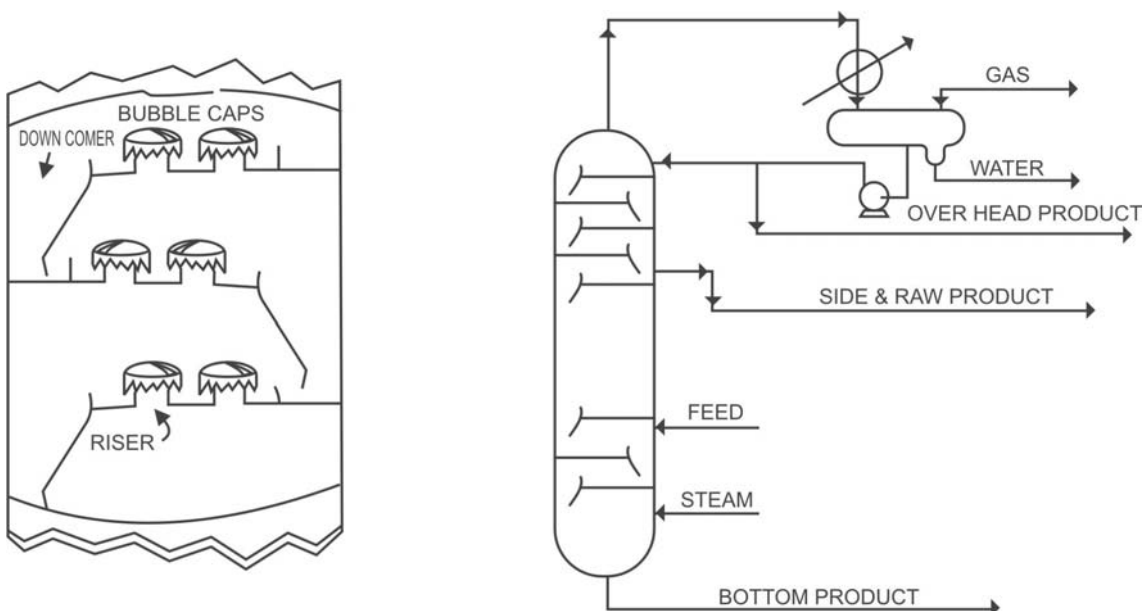
Let us consider the case of a series of shell still as depicted in the figure. This represents the functioning of modern fractionators and accomplishes the same separation more efficiently.

Suppose the first still contains a mixture of gas oil and residum and second still contain a mixture of kerosene and gas oil and third still contains a mixture of kerosene and naphtha. The liquid mixture in still No. 1 will boil at 340°C and that in second still boil at 260°C and that in third boil at 190°C, Upon the application of heat the vapours of gas oil from still No. 1 at 340°C will be driven to still No. 2 and bubbles through the liquid in No. 2 the gas oil vapours are, therefore condensed by the cooler liquid and the latent heat from the vapours is used to vaporise the kerosene in still No. 2. This liquid is allowed to flow back into still No. 1, thereby enriching still No.1 with gas oil. Simultaneously the kerosene fraction vapours are kerosene and naphtha. The vapours give up their latent heat to naphtha and vapourises naphtha fraction from still No. 3. By such successive steps, the vapours from each still are progressively enriched in the lower boiling point liquid and only the fraction having lowest boiling point passes through overhead condenser and purer components can be withdrawn from the respective stills.

Fractionating Columns

The fractionation columns carry out the same process in one vessel by using what is called fractionating trays. There are different types of trays but all of them work on the same principle. A portion of a fractionating tower with bubble cap trays is represented in the figure.

The plates are provided with a cover with a bubble cap so designed that the vapours passing through the riser are forced to bubble through the liquid on the tray where latent heat of higher boiling point liquid is given to the lower boiling point liquid vaporising it and itself condensing on the tray.





The accumulated liquid flows down the next tray through the downcomer supplying reflux to the tray below. The top tray will receive its reflux by external pumping.

Consider the fractionating column as being divided into two sections. One being section above the feed tray and the other being the section below the feed tray. The lower portion is known as the stripping section and portion above the feed tray is known as fractionating section.

The bottom section removes the liquid of all lighter fractions not desired in the bottom product. The stripping of the feed in this section is accomplished from the stream of vapours originating from the base of the column. This vapour is either steam or hydrocarbon vapour originating from reboiling action. The vapour pass through the bubble caps and strips the fractions desired in the overhead from the liquid flowing down the column. Some fractions desired in the bottoms are also stripped or vaporised from the descending liquid, so that the fractions, which belong to the bottoms, are found in the tray above this section. The vapours from the stripping section mix with the partially vaporised feed and start upward through the column. The vapours passing through the top of the fractionating column are condensed and part of it is returned back to the top tray to cool the rising vapours. Thus, the top tray is the coolest point in the column. On each tray there condenses a liquid fraction that is condensable at the temperature of the tray.

As the vapour condenses on a tray, the condensed liquid spills over a weir into the downcomer and soon to the tray below. This liquid is vaporised again there and joins the other rising vapours to bubble up and condense into liquid and so on, until it is removed from the system. Each of the vaporisation and condensation cycles tend to segregate on each tray more and uniform fraction, more and more free from lighter or heavier fractions. Where separation of more than two fractions is desired, fractions are allowed to flow out through draw off as side streams.

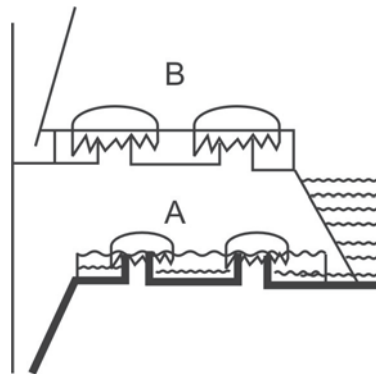
The heat input into any fractionating column is below the fractionating section. This means that the heat is either totally introduced in the feed or a combination of heat in the feed and in the base of the column (by using a reboiler). The heat input is removed as latent heat plus sensible heat in the overhead condensers and as sensible heat from the product streams.

In a fractionating tower each tray is cooler than the next tray below and the liquid flowing through the downcomer tends to cool the lower tray and offset the heating effect of the rising vapours. This effects of reflux results in keeping each tray at the desired temperature. The heavier boiling fractions descend through the tower and the lighter boiling fractions rise through the tower so that the mixture of the two fractions at any given tray is at the boiling point of the mixture.

From this it can be seen that it is very important to keep as much temperature difference between the top and much bottom of the tower to obtain pure fraction. This is referred to as the temperature gradient across tower. Upto the point the tower becomes overloaded, which can be accomplished by maximum reflux to the top of the tower for stripping. However, since the reflux is a means of heat

removal, it should not be used greater than required to achieve the desired fractionation as it increases heat input requirement.

The tower overloading occurs when the liquid flow downward and the vapour rate upward are sufficiently high to cause flooding of the trays. The reasons for this is as follows. Refer to the figure below.



The pressure at the point A must be greater than the pressure at the point B or vapour will not flow up the tower. This difference is equal to the pressure drop across the bubble cap and riser plus the liquid head above the slots in the caps.

The higher pressure at A exerts a backpressure on the liquid in the down comer causing a level build up. If the vapour velocity increases causing higher pressure drop through the caps, liquid level in the down comer rise to balance pressure drop through the caps, liquid level in the down comer rise to balance the pressure increase at point A. If the quantity of liquid flowing through the down comer increases, the liquid level in the down comer increases to supply extra head required for the higher volume of liquid flow.

When the liquid level reaches the top of the down comer due to any of the reasons mentioned, the tray will begin to flood. Liquid will build up above bubble caps on the flooding tray and the liquid is carried to the next tray by entrainment. Also the pressure drop through the tray increase causing further build up of liquid in the down comer. This causes further liquid build up on the tray above. Thus, the tray above starts flooding and eventually the liquid will be carried overhead in slips.

This is termed as piking. Tower flooding results in poor fractionation.

Flooding can be caused by excessive liquid and or vapour loading or because of physical obstruction. Some of the common mechanical causes of flooding are

- a) Scale deposit especially between the risers and bubble caps.
- b) Obstructions in the down comers.
- c) Concentration of water on the trays.
- d) Mechanical failure such as a tray or part of a tray falling down.

Reducing the vapour and liquid loading in the tower controls flooding. This can be accomplished by lowering the reflux rate or by reducing the heat input by lowering the feed temperature of reboiler output as the case may be. Typical symptoms of flooding are erratic pressure through the tower, high overhead temperature and irregular liquid level in bottom and overhead drums.

Flooding can cause serious contamination of the products and should be corrected promptly.

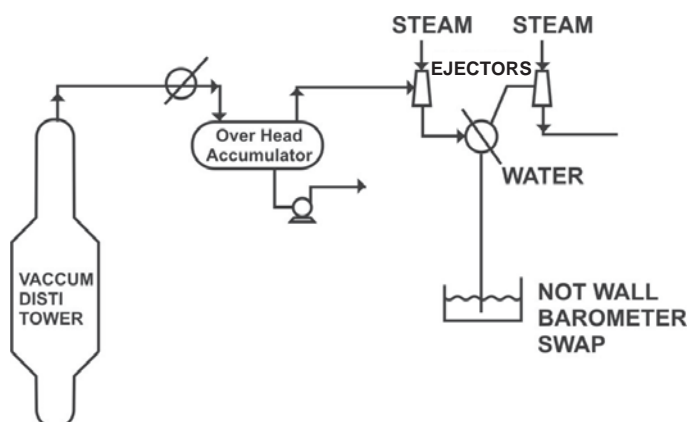
Vacuum Distillation

One of the methods used to boil the liquid at temperature below their normal boiling points is distillation under reduced pressure or as more commonly called vacuum distillation. Vacuum distillation means that the pressure on the oil being distilled is below atmospheric pressure.

In order that distillation may take place, the vapour pressure of the liquid being distilled must be a little greater than the pressure above it. The molecules of a liquid are held together by two forces, natural cohesion and the pressure pressing down. As boiling begins only when the vapour pressure exceeds the pressure holding down and therefore a reduction in pressure will lower the temperature required for starting boiling. Vacuum distillation is of particular importance in the refinery. The lower boiling points permit fractionation of oils that otherwise would decompose into smaller molecules and carbon at temperatures required to distill them at atmospheric pressures.

Except for the lower pressure, the vacuum distillation tower functions the same way as the normal fractionators. The column has usually larger diameter and have trays spaced further apart than pressure fractionators because the vapours occupy much more space at lower pressure. A sketch of a typical vacuum system is given below

Vacuum is maintained either by using a vacuum pump or by using ejectors for creating vacuum in the vacuum distillation unit. The overhead vapours are condensed using a condenser and the noncondensable hydrocarbons or inerts



are removed by using the ejectors. The ejectors pull the gases using steam and the steam used is condensed in by a condenser either by direct contact or by exchange and is removed as water. This water is removed by gravity flow by situating the condenser at an elevation of over 34 ft. (more than the column of water required to balance atmospheric pressure) or can be removed by pump. Two or more stages of ejectors may be used to boost the vacuum. Varying the amount of water through the condenser after the ejector usually attains the control.

The reduced crude from the atmospheric tower is vacuum distilled to separate the lube oil components and to heavy up the bottoms for making asphalts.

Stripping Operation

Stripper towers are used to remove low boiling point or gaseous component from a liquid stream. There are many strippers used in the refinery, but they fall into three major types namely steam strippers, reboiled strippers and flash drums. The principle of operation is based on Avagadro's law and the Dalton's law of partial pressures. Dalton's law of partial pressure states that the pressure exerted by a mixture of gases is equal to the sum of the separate pressures which each gas would exert if it alone occupied the same volume. Avagadro's principle states that equal volumes of gases at the same conditions of temperature and pressure will contain the same number of molecules regardless of the type or weight.

Consider a closed vessel containing equal number of two different kinds of molecules say kerosene and steam and at a pressure of 10 kg/cm². The pressure exerted by kerosene molecule will be half of the total pressure of 5 kg/cm². If the mixture in the proportion of 7 : 3 (steam : Kerosene), the pressure exerted by kerosene molecules will be 3/10 of the total pressure of 3 kg/cm². This is known as the partial pressure effect. A peculiar thing about the partial pressure is that each types of molecules act independently of the other. This means that the only pressure apparent to the molecule is that caused by the same type of molecules. This partial pressure effect is used in stripping out light hydrocarbons from the side stream of the fractionating column.

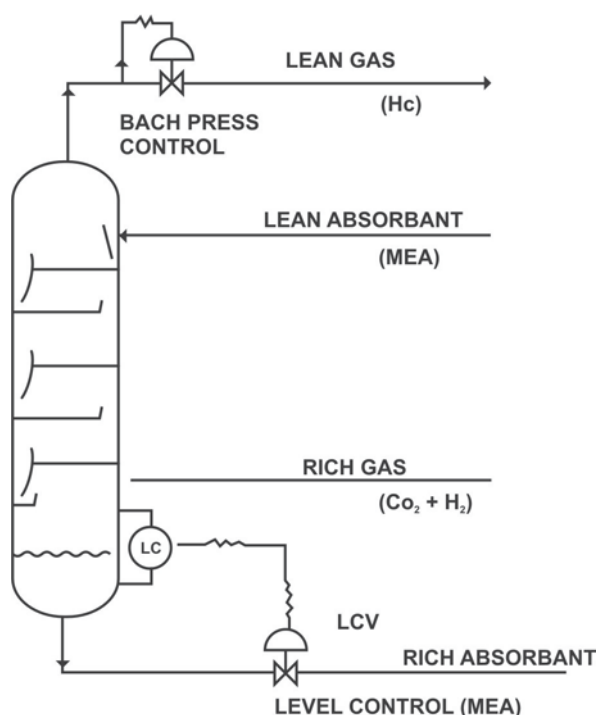
Let us examine how the partial pressure effect is applied to strip out kerosene from gas oil. The temperature at which the liquid vapourises varies directly as the pressure. Or if the temperature is held constant, the amount of liquid vaporized will be varying inversely to the change of pressure above in kerosene molecules weight about 10 times that of steam molecules. Therefore if 100 kg per minute of kerosene is present in the total mixture charge to the stripper, and 10 kg per minute of steam is charged to the stripper there are equal number of kerosene and steam molecules (by Avagadro's principle). The kerosene is therefore subjected to the half of the total pressure and will vaporize although the system pressure is much higher. If more steam is added, the partial pressure reduces further and kerosene can be distilled under lower pressure.

Removal of the small quantities of kerosene from oil increases the flash point of gas oil. Strippers are also used to remove gases like oxygen, nitrogen or H₂S from liquid streams.

Reboiler strippers use additional heat to strip the lighter components. Flash drum strippers use a reduction in pressure to achieve the same result. Flash strippers are used in separation of the mixture where the boiling point of the components to be removed are considerably different.

Absorption Towers

The purpose of absorber is to absorb valuable light liquid products from gas or to remove an undesirable gas from a mixture of gases. In our refinery, absorbers are used in separating Carbon dioxide from Hydrogen and to remove H₂S from fuel gas or hydrogen recycle using Mono Ethanolamine. This is a method of separation using the preferential solubility of the gases in the absorbent.



Essentially an absorber is a vertical vessel partitioned with suitable trays. The design of the trays causes the gas to be divided into small bubbles so as to have greater surface area for absorption. Packings like raschig rings could substitute the trays.

The lean absorbent admitted at the top of the absorber meets the counter current flow of the gases and are intimately mixed dissolving the soluble gases. The absorbent liquid now rich in dissolved gases, called rich absorbent, is removed from the bottom of the absorber and stripped out.

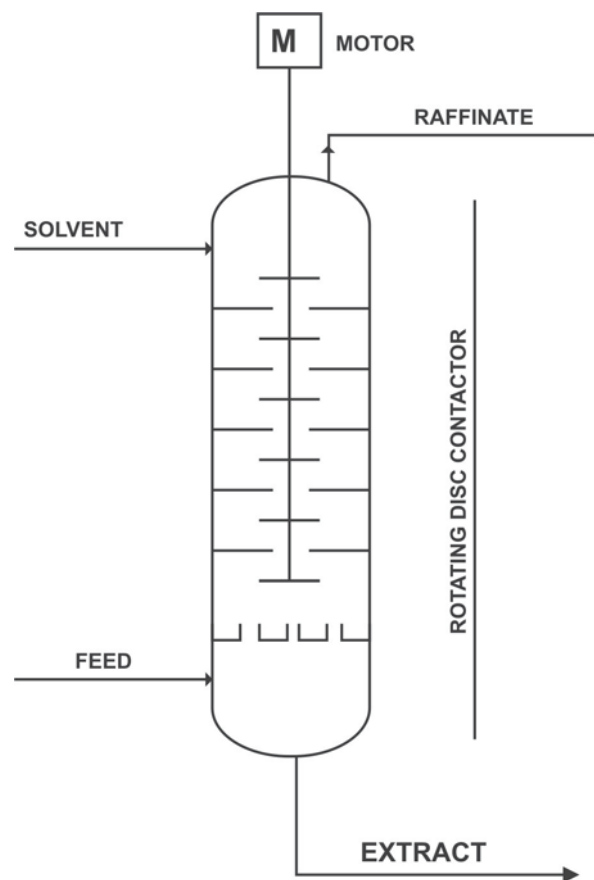
Because of the counterflow of the gas and absorbent solution, the feed gas (H₂ + CO₂) first comes in contact with the already partly rich absorbent. However, the absorbent does have some capacity left and picks up some of the impurity (CO₂). By the time the gas reaches the top tray, it is relieved of most of the impurity. The

lean absorbent entering the top section will pick up any left over CO_2 so that the gases leaving the top of absorber is free of CO_2 .

The factors affecting absorption are pressure and temperature. Higher the pressure, better is the absorption where as higher the temperature, the poorer is the absorption.

Extraction

The furfural extraction unit separates undesirable aromatics from the lube oil plant by using the solubility of aromatics in Furfural. The aromatics have low viscosity index and have to be removed from the lube oil to improve the quality of lube oil.



The system works like an absorber with the main difference that the feed and solvent are liquids. The dissolving liquid is called solvent, extracted aromatics liquid is called extract and the aromatic free product is called raffinate. The solvent is admitted on top section of the tower and the feed at the bottom section to provide counter current flow. Rotating discs does the mixing. The extract and solvent flow downward to the bottom section because of difference in the gravity.



Separation by Crystallisation

If sugar solution (sugar & water) is cooled, the sugar separates out from solution and can be removed by filtration. The solubility of the substance A in the solvent B increases with increasing temperature. Therefore, cooling a solution separates the substances which is dissolved called solute from the solvent. This method of separation is called crystallisation.

The extent of separation from the solution will depend on the concentration of solute in the solvent and the extent of solubility of the solute in the solvent at the temperature to which it is cooled.

MEK dewaxing unit uses this method for separating waxy paraffins from the feed to improve the pour point of the product. The solvent used is a mixture of Methyl Ethyl Ketone and Toluene. The solubility of the waxy paraffins is less than that of the paraffin oils at lower temperatures. The feed stock is mixed with the solvent and is then chilled by exchanging heat with cold ammonia from refrigeration system to a temperature where the wax is crystallised. The wax is then removed by filtration.

The factors that affect the separation by crystallisation are:

- (a) Difference in the crystallisation point of the components.
- (b) Concentration of the waxy material in the feed stock.

The greater the difference in the crystallization point, the easier is the separation. Normally solvents are selected so as to have a good difference in the crystallisation point. If the crystallisation point of the components of the feed stock is widely different, the use of solvent may not be necessary.

The concentration of the substance to be removed helps separation by forming good crystals, which can be effectively removed by filtration.

5. CHARACTERISTICS OF CRUDE OIL

Just as in any other industry, profit is one of the main considerations in the petroleum industry. Along with many other factors, the profit is governed by the demand for the product. Whether or not the required quantity and quality of the products can be obtained economically from the raw material available is an important consideration. Crude oil, being the raw material for the petroleum industry, its study is important.

Crude oil is composed almost entirely of infinite combination of the two elements carbon and hydrogen. Therefore, all the oil products like gasoline, kerosene or fuel oil are made up of hydrocarbons. Hydrocarbons in crude, as previously mentioned, usually belong to the paraffin series $C_n H_{2n+2}$ the aromatic series ($C_n H_{2n+2}$) and the naphthenic series ($C_n H_{2n}$)

A small percentage of the combination of hydrocarbons with elements like oxygen, sulphur and nitrogen is also present in the crude oil. The oxygen is found in the form of naphthenic acids. Nitrogen is most often found in the naphthenic base oils and is generally supposed to be in the form of basic compounds. Sulphur may be found as free sulphur, hydrogen sulphide or as organic compounds such as thiophenes, mercaptans, alkylsulphates or sulphides. Sulphur compounds are particularly bad because they are foul smelling and corrosive.

Types of Crude Oil

Crude oil is a mixture of hydrocarbons with some sulphur, nitrogen and oxygen compounds. Crudes with very little sulphur are called sweet Crudes, and those with high sulphur content of the order of one percent or more are called sour Crudes. A crude with high percentage of naphtha or and other low boiling range distillates will have a high American Petroleum Institute (API) gravity or low density and are known as light Crudes. Those with a small percentage of naphtha and a large percentage of high boiling range hydrocarbons will have a low API or high density and therefore, are known as heavy Crudes.

Crudes are also broadly classified into four categories-paraffin base, mixed base, naphthene base and aromatic base. Paraffin base crudes contain principally paraffins in the lighter fractions and alkyl naphthenes in the heavier fractions. The kerosene, diesel fuel and lubricants obtained from this crude are usually high and of best quality. Naphthene base crude oils have a high percent of naphthenes with very little of wax. Gasoline obtained from naphthenic crudes are normally good and the lube oil fractions respond well to the extraction process. Aromatic base crude oil contains a high percentage of the lower aromatic hydrocarbons. The asphalt base Crude oils are of high specific gravity and yield poor quality gasoline. The diesel and kerosene obtained from the asphalt Crudes are of poor quality. The fuel oil and asphalt fractions obtained from these crude are usually



high. These classifications along with the other properties like sweet and sour, heavy and light is used for evaluating the crude. Complete data of a crude oil, however, is determined by an assay test, which consists of a true boiling point distillation and correlation of properties such as octane number, vapour pressure, Aniline point, sulphur content, etc.,

As mentioned previously, Crudes from different geographical locations vary considerably in the physical properties and composition. They may be heavy and viscous or may be light and less viscous.

The usual product obtained from a refinery are gas, naphthas, kerosene, diesel oil, lubrication oils and fuel oils. The maximum percentage yield of the product of a certain boiling range from a given crude by distillation is fixed by the amount of the materials present in the crude.

In general, the refining processes consist basically of physical operations such as fractionation, extraction and chemical operations like platforming and hydrogen treating.

Crude Oil Assay

The classification of Crudes as paraffin base, naphthene base and aromatic base does not provide sufficient information for a refiner to determine the type of crude to be used for refining. The complex nature of crude oil makes it difficult to evaluate crude oil by determining the individual components. Therefore, a crude oil assay procedure has been developed and is accepted as the most suitable technique for evaluation of crude oil. A crude oil assay essentially consists of a complete inspection of the oil, a true boiling point distillation to obtain cuts that can be correlated with refinery operation, a quality evaluation of the cuts and a series of correlations to interpret the data.

The petroleum inspection carried out on a crude oil provides general information on the character of the crude and indicate in many instances when special processing is required. The typical inspection is tabulated below.

- | | |
|----------------------------|-----------------------------|
| 1. Gravity | 6. Salt Content |
| 2. Sulphur | 7. Distillation |
| 3. Pour point | 8. H ₂ S content |
| 4. Reid Vapour Pressure | 9. Viscosity |
| 5. Bottom Sediment & Water | |

API gravity and viscosity inspections provide a broad indication of the gasoline, kerosene and diesel oil yields. High viscosity may indicate high asphalt content. Viscosity and pour point also provide information on crude oil pumping characteristics. Salt content of crude indicates whether a desalter is necessary or not.

True boiling point distillations have wide application in determining the yields of several fractions that may be obtained from crude. The true boiling point distillation

is carried out at high reflux rates to obtain effective fractionation. In this, distillation crude is split into narrow increments of increasing boiling point. Blends of appropriate increments are recombined to provide fractions, which are tested to determine their quality.

The gasoline portion of the crude is evaluated by preparing a series of blends such that the blends contain all the materials boiling from a temperature of 65°F (18.3°C) upto the following final boiling points (a) 250°F (121.1°C), (b) 325°F (162.8°C). The gravity and volatility of each blend and other properties like sulphur and octane number are determined to find its suitability as gasoline.



CHENNAI PETROLEUM CORPORATION LIMITED

6. REFINERY - I

Refinery I - Process Description

The crude oil is separated into several fractions, all of which require further processing or blending to meet the quality requirements. The separation is effected in atmospheric tower and two stage vacuum towers. The streams obtained are gas, overhead distillate naphtha, heavy naphtha, kerosene, diesel from atmospheric tower and gas oil, spindle oil, light neutral oil, intermediate neutral from first stage vacuum tower and 500 Neutral, Heavy neutral and vacuum residuum from second stage vacuum tower.

The gas is used as refinery fuel gas along with the off gases from Unifiner (plant-No.3), kerosene hydrodesulphuriser (plant No.4) and thermal cracker and visbreaker (plant No.6) now scrapped, after recovering the H₂S by amine treating in plant 12.

The overhead naphtha is sent to Vapour Recovery Unit (VRU) where it is split up into gas, LPG, light straight run gasoline and light naphtha. The gas is used as feed to Hydrogen plant after amine treating. The light naphtha splits up into two streams. Light straight run gasoline (LSR) is partly blended to gasoline sweetening after merox and the balance is sent to naphtha pool. A part is desulphurised in Unifiner and forms the feed stock for Platformer.

The light naphtha stream is reformed in platformer to improve its octane number and blended to gasoline. Catalytic reforming of naphtha produces hydrogen as by-product which is used for desulphurising the naphtha feed to the platformer in the Unifiner and the surplus is used in the other desulphurisers.

The heavy naphtha stream from the atmospheric tower is the first side stream. Part of the heavy naphtha is sweetened using merox catalyst and blended with SK. The balance will be blended with diesel oil draw off to produce high-speed diesel oil.

The second side stream from atmospheric tower is kerosene. This draw off is adjusted to make Aviation Turbine fuel (ATF - K50) to meet the specifications whenever the plant is producing ATF K 50. The balance of the period the plant will be on superior Kerosene operation. The stream is desulphurised in the plant 4 with hydrogen and sent to product tankage. The third sidestream of the atmospheric tower is diesel, part of this is desulphurised in plant 5 using hydrogen. The raw diesel, desulphurised diesel and heavy naphtha form the components of high speed Diesel oil.

The bottom, product of atmospheric tower is the feed to the first stage vacuum distillation. Four streams are separated from the first stage VDU; - they are the hot well oil, spindle oil, light neutral and intermediate neutral.



These form the feed stock for the plants 8, 9, NMP and thermal cracker. The spindle oil, light neutral and intermediate neutral streams required meeting the feed stock requirement of Furfural, NMP Extraction and MEK dewaxing units are sent to intermediate tanks. The feed stock to the thermal cracker now scraped was desulphurised in plant 13. The cracked gas oil and thermal tar produced in plant 6 were used for blending fuel oil. The light gasoline produced as a result of the cracking was used for gasoline blending.

The bottom product of first stage vacuum tower is separated into vacuum residue, Heavy Neutral and 500N fraction in the second stage vacuum tower. 500N and Heavy neutral is drawn off as side stream and vacuum residuum is used partly as feed to PDA, and to the Visbreaker, partly to produce asphalts and the balance is blended directly as Refinery fuel or fuel oil. Asphalts are produced by air blowing of the vacuum bottoms. The heavy neutral is stored in an intermediate tank and is processed in Furfural or NMP Extraction and MEK dewaxing units.

The Furfural extraction unit processes Spindle oil, Light Neutral, Intermediate Neutral, 500N and Heavy Neutral as feed stocks on a blocked out operation to produce high viscosity index lubricating oil base stock. Furfural NMP extracts the aromatics, which improves the viscosity index. Furfural is used as solvent in plant 8 and N-Methyl pyrrolidone (NMP) as solvent in Plant - 73 to extract the aromatics and to improve the viscosity index of lubes. The products from the extraction units are routed through the MEK dewaxing unit and then to storage Tanks extracted aromatics called lube extracts. The heavy neutral extract is sent to fuel oil blending directly.

MEK dewaxing unit processes all the finished Raffinate from Furfural/NMP extraction unit. The unit removes the wax from the feed stock and improves the pour point of the product. The slack wax is blended directly to fuel oil and the finished product are sent to storage.

Lube oil hydrofinisher processes the MEK dewaxed lube oil components to improve colour stability, oxidation stability and remove part of the sulphur and nitrogen compounds. The dewaxed oil from MEK unit is fed to the hydrofinisher (plant 10) on a blocked out operation. The finished lube oil components are stored and blended to give various grades of lube oil outside the refinery in lube oil blending plant.

The H₂S rich gases from plant No.3,4,5,10 and 13 are amine treated to recover the H₂S. Thus recovered H₂S is converted into sulphur in plant 75.

The previous section described the manner in which the crude oil is received, passed through the various units to produce finished products or finished components that are blended to make finished products. The purpose of this section is to describe in detail how each of these processes by practical application of the many principles covered earlier.

Each process unit in the refinery has a specific function to purify or to rearrange the-molecular structure or crack the molecules to make more desirable products.

In all the units great emphasis is placed on the conservation of heat by the use of heat exchangers.

Plant No. 1 - Crude Distillation Unit / Vacuum Distillation Unit

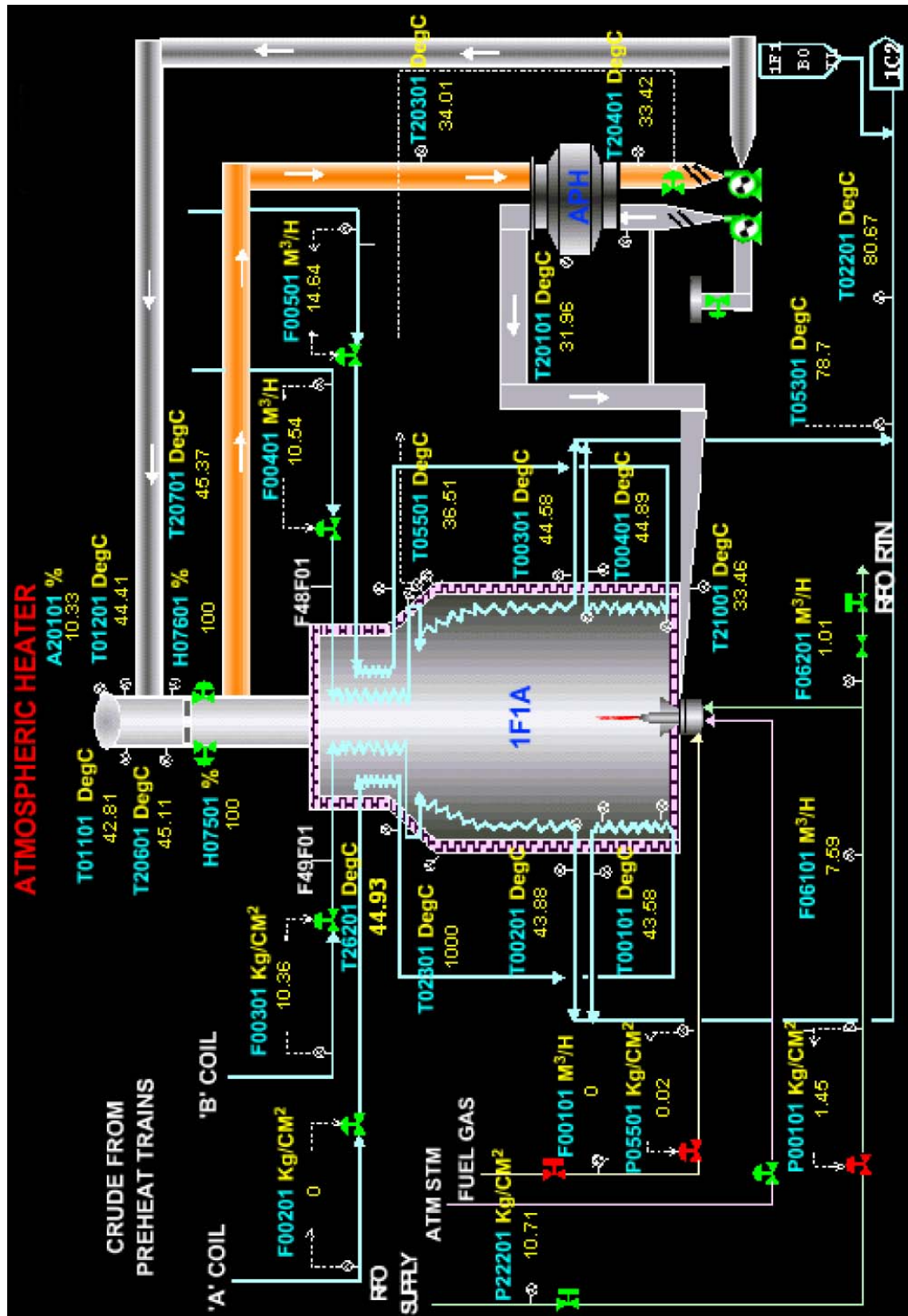
The crude unit is the starting point for all refinery operations. The separation of crude oil into raw products is accomplished in the crude unit by fractional distillation in fractionating columns, based on their distillation range,. The process does not involve any chemical changes. The unit consists of an electrostatic desalter, an atmospheric distillation column and a two stage vacuum distillation sections. The unit is designed to process P.G. Crude having a specific - Gravity of 0.855 at a design rate of 348.6 m³/hr. This has been increased to 410 m³/hr after modifications.

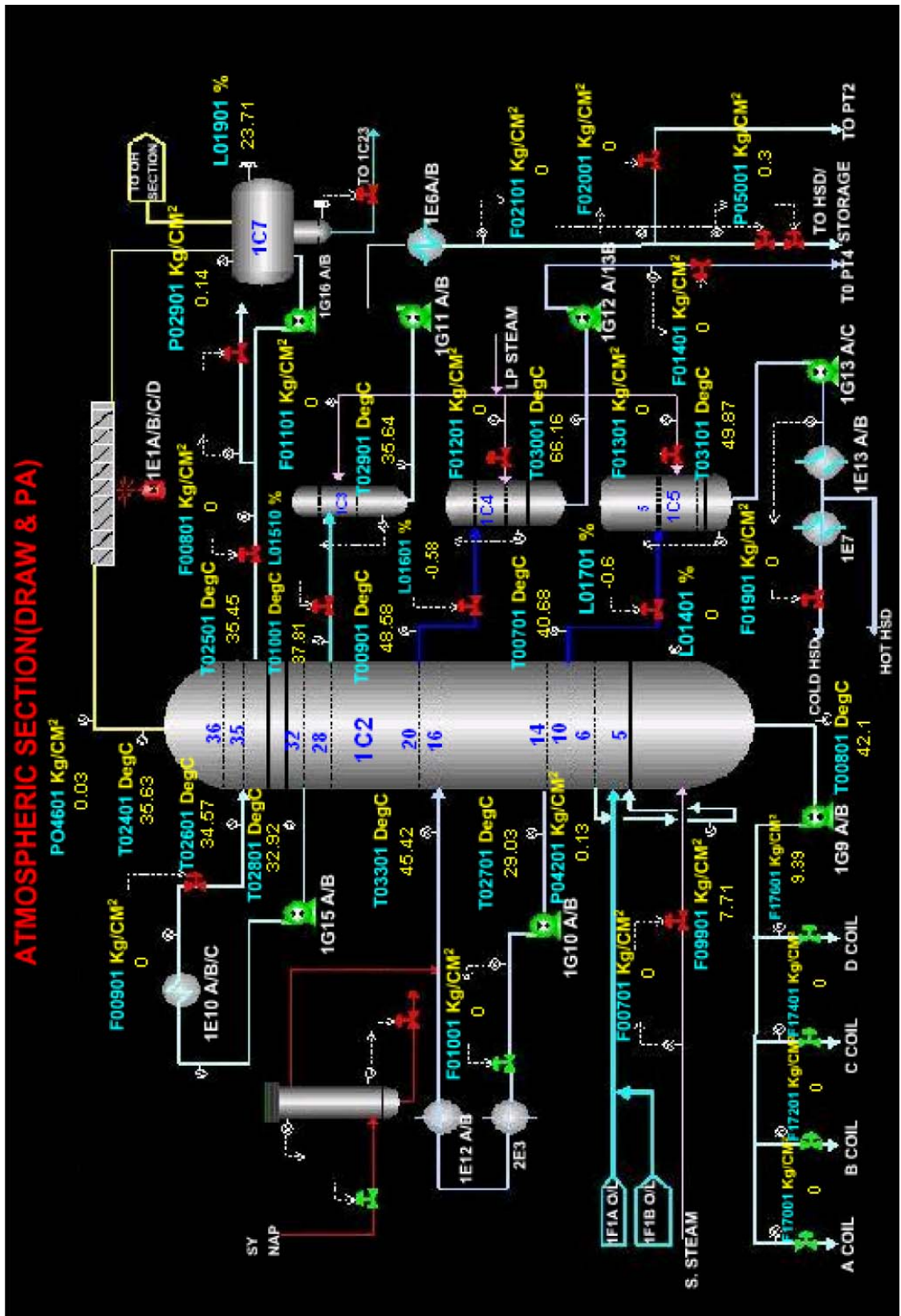
A schematic representation of the crude oil and product flow is attached. The two crude feed pumps, located near the crude storage tanks, supplies the feed to the unit. The feed to the unit is passed through a desalter, where the chlorides of calcium, magnesium and sodium are removed. These salts form corrosive acids during processing and therefore are detrimental to process equipments. By injecting water to the crude oil stream these salts are dissolved in the water and the solution is separated from the crude by means of an electrostatic separator in a large vessel. The electrically charged grids coalesces the water and aids separation from the crude. After desalting, the crude is heated through a series of heat exchangers and then by a furnace to a temperature of 373°C and admitted to the flash zone of the atmospheric distillation tower.

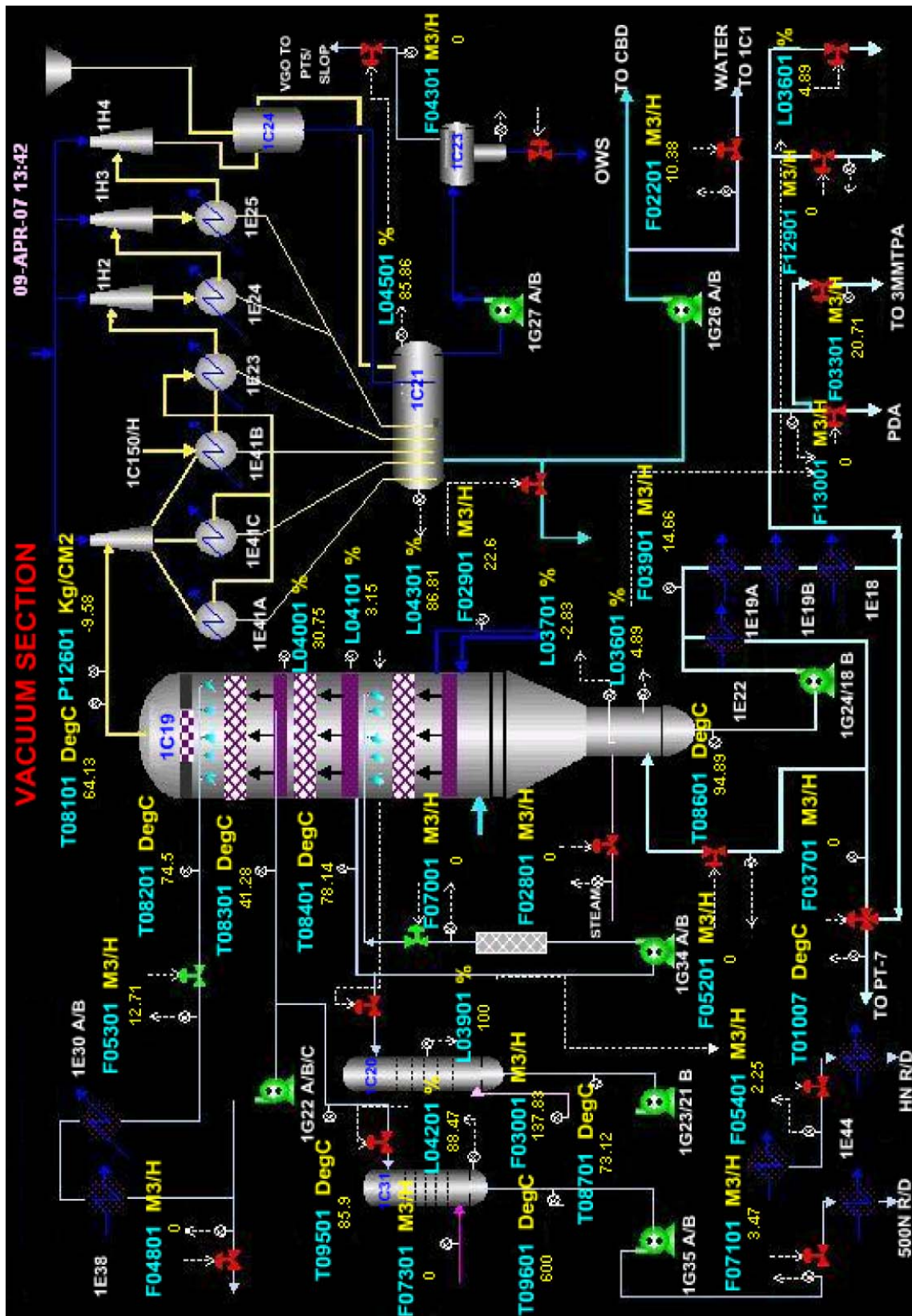
Four fractions are separated in the atmospheric tower. The overhead vapours are condensed in a two-stage system. The condensed liquid from the first stage is used as reflux to the tower. The second stage liquid together with the compressed and condensed vapours from the second stage is collected in the stabilizer feed accumulator. The liquid in the stabilizer feed accumulator is fed to the Vapour Recovery Unit. The uncondensed vapours from the stabilizer feed accumulator is routed to fuel gas system after removal of H₂S in the sulphur plant. The other three products separated are heavy naphtha, kerosene, and diesel. The heavy naphtha is drawn from tray 28 and is steam stripped to improve flash. The majority of this product is blended with diesel from HSD desulphurisation unit (Plant 5) and raw diesel to make finished High Speed Diesel Oil

Kerosene drawn from Tray No. 20 is steam stripped and is charged hot to kerosene hydrodesulphuriser plant (Plant 4). When this unit is shut down, Kerosene is cooled and sent to intermediate storage tank through the kerosene product cooler at plant 4.

Diesel oil is drawn from Tray No. 10. Approximately 50% of the diesel oil is routed to H.S.D. Hydrodesulphuriser (Plant 5) after heat exchange with crude and the balance is cooled and blended with desulphurised diesel oil to produce HSD product. When plant 5 is shut down, the total stream is cooled in the product cooler at plant 5 and sent to storage.







The stripped overhead liquid streams from kerosene hydrodesulphuriser, HSD desulphuriser and tube oil hydrofinisher are sent to the atmospheric distillation tower after separating the water in a dewatering drum.

The hot reduced crude from the bottom of atmospheric distillation tower is fractionated in the two-stage vacuum distillation section. The vacuum maintained in these fractionators makes it possible to fractionate the reduced crude at much lower temperatures. But for this vacuum, the higher temperatures required to fractionate reduced crude will result in cracking of the products. The reduced crude from atmospheric tower bottoms is further heated in presence of steam in the first vacuum heater and introduced into first stage vacuum tower. Three side-stream products spindle oil, light neutral and intermediate neutral and an overhead product-gas oil are separated in the first stage vacuum tower. Spindle oil, light neutral and intermediate neutral are sent to the Lube Oil Extraction plants as feed stock or to storage. The distillate in excess of the lube oil requirements is sent hot as charge stock to vacuum Distillate Desulphuriser (Plant 13) prior to thermal cracking of these intermediate product. The gas oil is routed to tank 351 and then blended in fuel oil or directly blended with plant - 5HSD

The bottom product from first stage vacuum tower is reheated along with the steam fractionated to yield 500 Neutral and heavy neutral stream. Flash zone vapours of the second stage vacuum tower pass through a demister pad to prevent entrainment of asphaltenes into the heavy neutral stream. The 500 Neutral and heavy neutral stream is cooled and sent to intermediate storage tank as charge to Furfural / NMP Extraction unit.

A part of the second stage vacuum tower bottom, vacuum residuum, is cooled and sent to Bitumen Air Slowing Unit (Plant (7) & Ref-III and the balance is routed to light fuel oil blending. Another part of hot vacuum residue is routed to Tank 350 as PDA feed.

Plant No. 2 - Vapour Recovery Unit

The vapour recovery unit consists of two sections (a) vapour recovery section and (b) mercox treating section. The function of vapour recovery section is to separate gas, LPG, light gasoline and light naphtha from the overhead naphtha of atmospheric tower in plant 1. The mercox treating section is for sweetening of LPG, a mixture of light gasoline and light cracked gasoline for gasoline blending, a mixture of light naphtha or heavy naphtha for blending the light gasoline for hexane feed.

The vapour recovery section is designed to process 75.8 m³/hr. atmospheric tower overhead- from crude unit. This section consists of a stabilizer with LPG stripper and a splitter tower.

The feed to the unit from the stabilizer feed drum in the crude unit is preheated by exchangers and is admitted to the stabilizer column. The stabilizer separates the feed into gas, LPG and C5 + Bottom.



The heat required is obtained from a reboiler by exchanging heat with the bottom pump around the atmospheric tower. LPG is drawn from tray No. 31 or 33 and the light hydrocarbons are stripped in a stripper. The stripped LPG is sent to merox extraction plant to remove mercaptans. The overhead gas is sent partly to fuel gas treating system in the sulphur plant (plant 12) and partly as feed to hydrogen plant after amine treating.

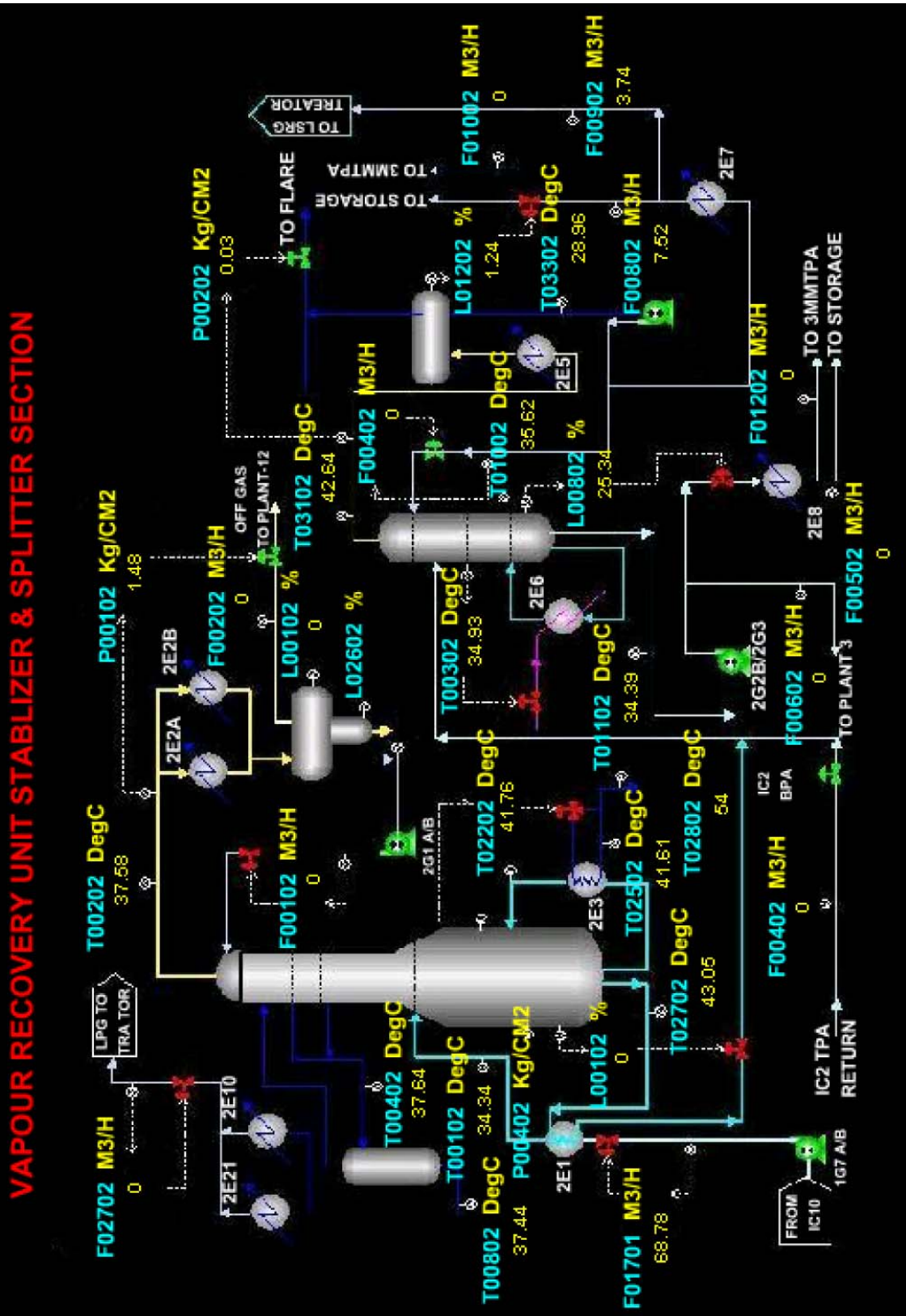
The bottom of the stabilizer is fed to the naphtha splitter to produce light gasoline and light naphtha. The light gasoline is taken overhead and part of this is sweetened in Merox treating section to meet the requirements of gasoline blending and the balance is sent to raw naphtha storage tank. The light naphtha is taken as bottom product. The first part is desulphurised in Unifiner and sent to platformer as feed, the balance is diverted to the raw naphtha storage tanks.

The merox treating facility has three treaters for processing three different streams. The streams processed are (a) LPG, (b) a mixture of light gasoline and light cracked gasoline for motor spirit blending and (c) a mixture of light naphtha or heavy naphtha for blending. Merox treating utilizes a proprietary process developed by Universal Oil Products Company. The treating can be classified into two categories-extraction and sweetening. In the extraction system, the mercaptans are removed from the feed stream whereas in the sweetening system the mercaptans are oxidized to disulfides and are left in the product stream.

The LPG Merox treating is an extraction system designed to process 4.9 M³/hr. (Now 6.5m³/hr. of LPG from Vapour Recovery Section) The feed stream is treated with MEA and passed through a caustic scrubber to remove H₂S from the feed stream. The H₂S free LPG then flows to the extractor where it meets a counter-current flow of Merox solution in a caustic soda medium. The mercaptans in the feed are extracted by the merox solution and the treated LPG is sent to storage. The spent Merox solution is sent to the oxidiser where the extracted mercaptans are oxidised to disulfides. The regenerated Merox solution is then pumped to the extractor. (The extracted disulfides are drained).

The light gasoline Merox treater is designed for a feed rate of 6.8 m³/hr. consisting of a mixture of light gasoline from vapour recovery section and light cracked gasoline from visbreaker fractionator in Plant 6. The Merox solution is regenerated in the common system for LGP and Merox. The treated gasoline is sent to storage and is blended with Reformate from plant 3 to make motor gasoline. The treated LSRG can be routed as Hexane feed.

The Merox treatment of light naphtha is a sweetening process. The merox catalyst is impregnated in a bed of activated charcoal using methanol and made alkaline by circulating caustic soda solution as a preparation to receive the feed stock. This treating unit is designed for a feed rate of 8.0 m³/hr. consisting of light naphtha from vapour recovery section or heavy naphtha sent from plant 1. The treated naphtha is sent to storage for blending purpose. The naphtha feed stream is caustic scrubbed to remove naphthenic acids. Air is then injected to the feed stream and the feed stream is admitted to the top of the solid bed reactor. The





mercaptans are oxidized to disulphides, while passing through the bed and are carried along with the product stream. The sweetened naphtha passes through a casutic settler. Periodically the caustic settler is recirculated through the catalyst bed to remove the absorbed traces of phenols, naphthenic acid and basic nitrogenic acid and basic nitrogen compounds. The caustic when spent attains a brown colour and is discarded.

Plant No. 3 - Unifiner and Platformer

Plant No.3 consists of two inter-dependant sections (1) A Unifiner to remove sulphur and nitrogen compounds and unsaturated olefins in the light naphtha prior to reforming and (2) A platformer to upgrade the low octane light naphtha to a high octane product. The Unifiner uses the hydrogen from platformer to remove the undesirable compounds and supplies the feed to the platformer.

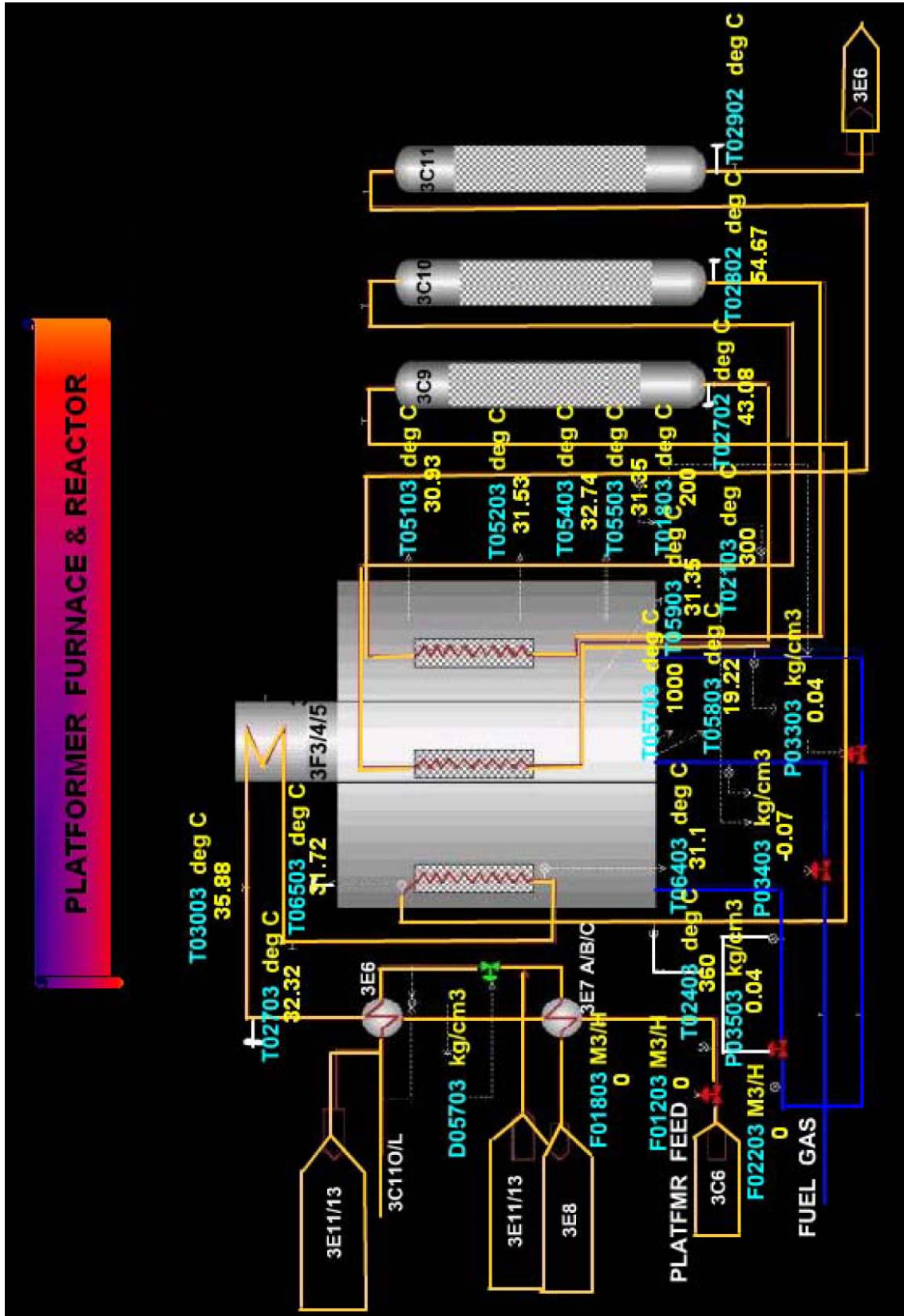
The feed stock for the unifiner is light naphtha from the splitter in the Vapour Recovery Unit. The feed stock is combined with hydrogen and heated to the reaction temperature of 347°C. The vaporized feed is passed through a catalyst filled reactor. In the reactor the organic sulphur compounds are combined with hydrogen to form Hydrogen Sulphide and the Nitrogen compounds are converted to ammonia. The unsaturated olefins are saturated with hydrogen to form naphthenes and paraffins. The reactor effluent is cooled and the ammonia, hydrogen sulphide and excess hydrogen are separated from the product. These are separated and are partially recycled and balance is sent to HSDO desulphurisation unit. The liquid is sent to platformer as feed after stripping dissolved hydrogen sulphide in a stripper.

Over a period of time, the catalyst in the unifiner reactor will be coated with a deposit called coke. It is necessary to burn of the coke to reactivate the catalyst. For this purpose the unit will be shut down and the deposited coke will be burnt by circulating inner gas (N₂) through the reactor and injecting air at a controlled rate. The reactivation is common to all the hydrodesulphurisers and platformer reactors.

The platforming unit converts the low octane naphtha from Unifiner to high octane reformate by conversion of straight chain compounds into cyclic compounds. The reaction is endothermic and therefore the feed stream is reheated after each reactor. The unit consists of three reactors operating in series with heaters before each reactor, a product separator, a debutanizer and hydrogen recycle facilities.

The product from the unifiner is mixed with hydrogen and passed through three sets of heaters and reactors. The reactor effluent from the, final reactor is cooled by heat exchange and is sent to a separator drum. The reaction produces hydrogen which is separated from the hydrocarbons and is partly recycled to the feed stream and the balance is routed to the Unifiner.

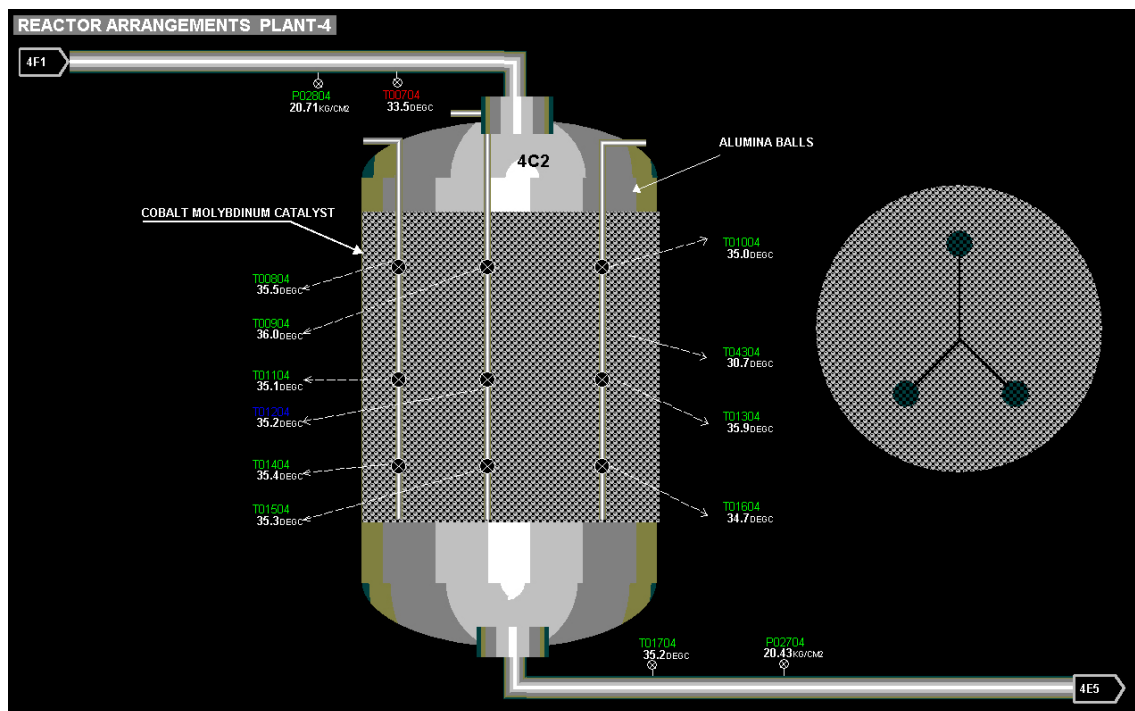
The separated effluent is then sent to a debutanizer where it is supplied as a part of feed gas to hydrogen plant and the bottom product. The reformate is sent to the storage tank. A part of debutanizer Reflux is taken out as LPG and sent to plant 2.



Plant No. 4 - Kerosene Hydrodesulphurisation Unit

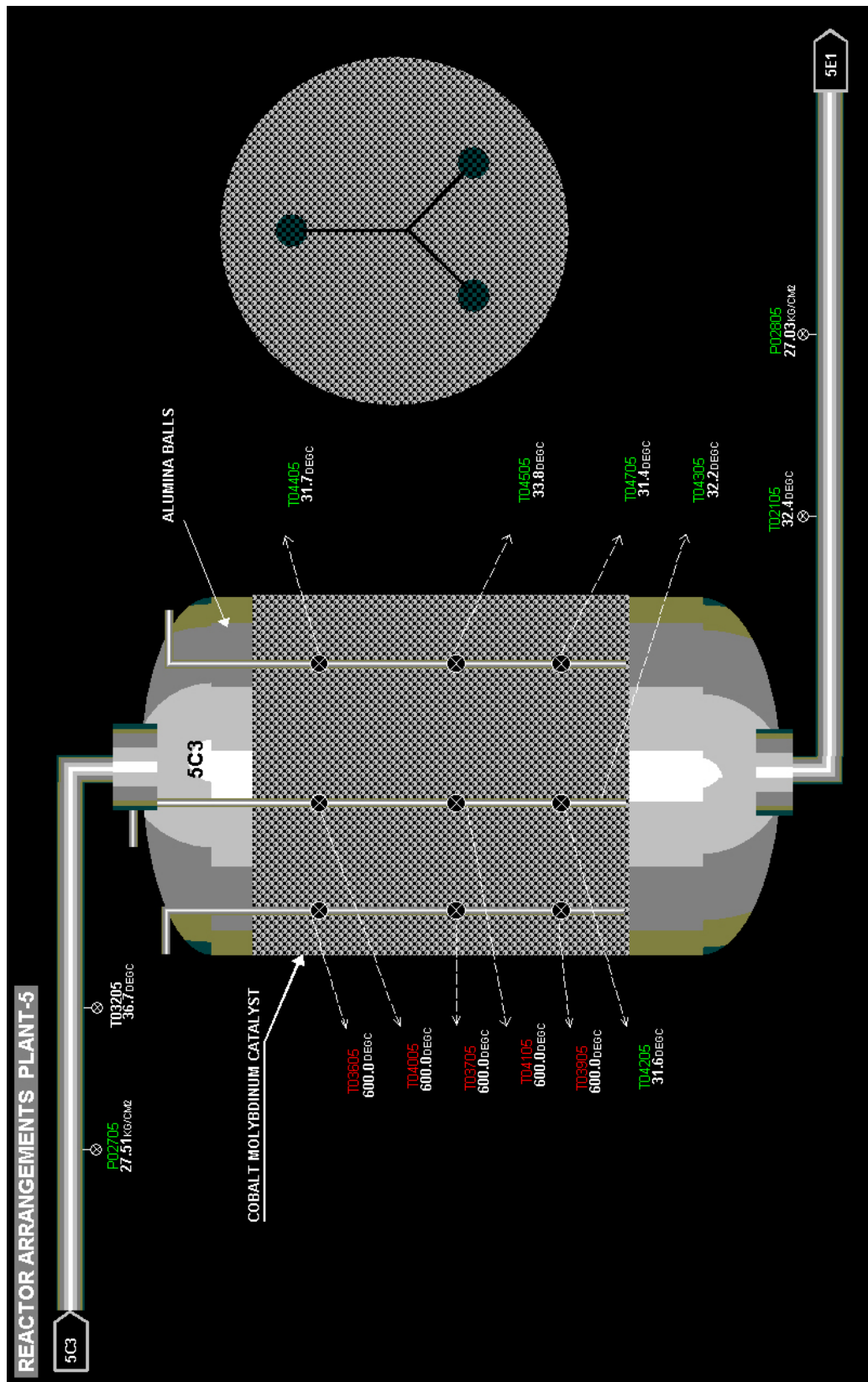
The purpose of the plant is to reduce sulphur content of the raw kerosene (ATF / JPs) by treating with hydrogen. During the treatment some of the aromatic hydrocarbons are converted to cycloparaffins which results in an increase in the smoke point. The plant is designed to process (now 95 m³/hr) raw kerosene from plant 1. The hydrogen rich gas from HSDO desulphuriser meets the hydrogen requirement and the balance is made up from plant 11 reactor, after heating to the required reaction temperature in the charge heater.

After separation of the reaction gases and excess in a two stage separator, the effluent is sent to the stripper. The stripper bottom is the finished product sent to storage after cooling. The hydrogen rich gas from the separator is sent as feed to hydrogen plant or to fuel gas after recovery of the H₂S by amine treating in sulphur plant.



Plant No. 5 - Diesel Oil Hydrodesulphurisation Unit

The function of this plant is to desulphurise (part of) the diesel (approximately 50%) produced in plant 1 by catalytic hydrogenation. The desulphurised diesel and the balance of the raw diesel and heavy naphtha are line blended in this unit. to produce HSD of (35m³/hr) Feed. The hydrogen gas is sent to Vacuum Distillate HDS units. The hydrogen requirement over and above that supplied by these units is met from the hydrogen plant. The feed is mixed with recycle gas and make up hydrogen is heated in a furnace and passed through the reactor. The effluent from the reactor is cooled and the excess hydrogen and other products





of reaction are separated in a stripper. The overhead system of this stripper is common to the stripper in plant 13 also. The desulphurised diesel is yielded from the bottom of the stripper. The hydrogen rich recycle gas from the separator drum is treated with 15% MEA solution to remove H_2S before recycling. A portion of the separator offgas is sent to Plant 4. A liquid from the overhead system of the stripper is sent to IC-22 in plant1 and the vapours to the overhead system of atmospheric tower.

Plant No. 7 - Biturox Plant

The main function of Biturox Plant is to produce high quality air blown bitumen from the feed stock vacuum residue. This high quality bitumen (low pen) will be obtained by air blowing the feed stock by means of Oxidation. It is an exothermic reaction.

Biturox plant feed stock vacuum residue is obtained from Plant - 1 at 230°C. This feed stock normally has a high penetration value (between 150 - 400)

This feed enters the Reactor 7C-1 guiding cylinder (inner vessel) near the bottom. Air is supplied to Reactor 7C-1 by means of two air pipes (4" dia.) entering the Reactor 7C-1 at the top and discharges the air in the bottom of the Reactor 7C-1. The air bubbles and the feed stock mix together at the bottom of the guiding cylinder. Due to the contact of Oxygen and vacuum Residue, the existing aromatic components in the feed oxidizes to asphaltenes. This is an exothermic reaction.

To optimize the reaction, the reactor is equipped with a guiding cylinder inside the reactor, which divides the flow through the reactor, an upstream flow inside the guiding cylinder and down stream flow between the cylinder and reactor shell.

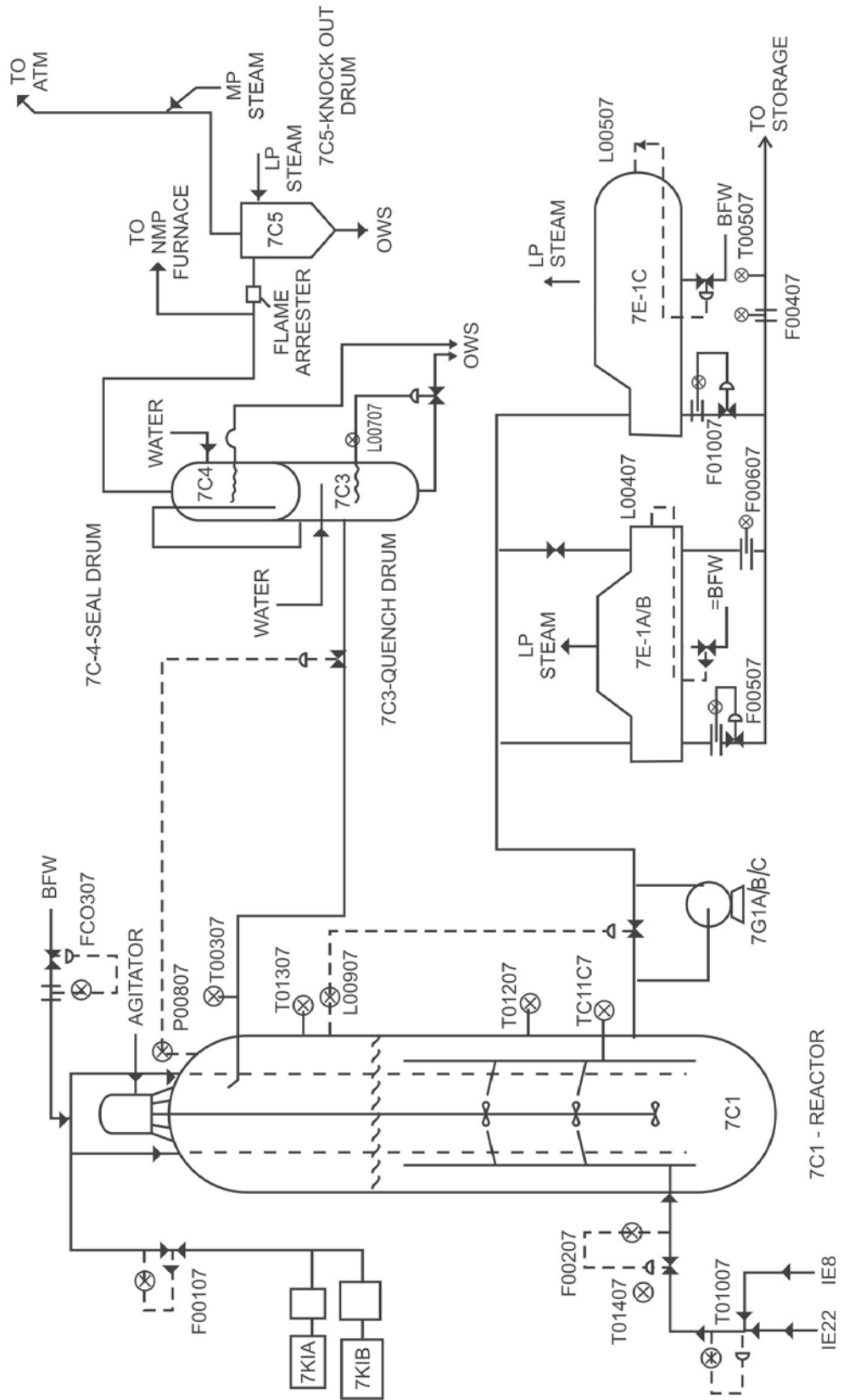
A coalescing device and an agitator is located in the guiding cylinder in three stages. The coalescing device collects the air bubbles and bitumen. The distribution impeller of the agitator will disperse the air bubbles to small bubbles to obtain a larger surface area on air and therefore exposing more reactionable oxygen.

For optimising the reaction, in the reactor, the reactor pressure will be maintained at 2.0 kg/cm². Due to this the residence time required in Reactor is reduced. It will help in higher feed rate. This is maintained by the Reaction off gas. The temperature raises in the Reactor 7C-1 due to the heat evolved by the oxidation reaction. The optimum temperature of 270°C is controlled by injecting a small amount of DM water into the air pipes. The water removes heat from the product and gets vapourised.

The finished high quality bitumen (low penetration value) is pumped out by 7G-1 A/B/C after maintaining the level in the reactor 7C-1 to 7E-1 A/B/C Exchangers and the product is cooled to safe storage temperature (160 - 170 Deg. C.)

The reactor 7C-1 off gas is quenched further in the quench drum 7C-3 by the direct contact of water spray. The condensable hydrocarbons are removed in the

PLANT - 7 GENERAL PROCESS FLOW





quench drum 7C3. Then the off gas passes through water seal drum 7C-4 and flame arrestors to NMP Furnace. There it will be burned completely to avoid environmental pollution.

After commissioning of PDA (Propane Deasphalting Unit - Plant 71), Bitumen is made either by Air blowing of Plant-1 Vacuum, Residue or by blending PDA Pitch from Plant-71 and Extract from Plant - 73. PDA Pitch pen is around 0 - 5. By adding NMP Extract product pen is brought to the requirement. The required pen is generally around 60/70 or 80/100. Pitch & Extract are taken to 7C-1 and blended and Bitumen is produced.

Plant No. 8 - Furfural Extraction Unit

The Furfural Extraction Unit process portion of all vacuum distillates in blocked out operations as the first step in converting these distillates into lubrication oil blending components. The extraction process removes aromatic and oxygenated compounds which have low viscosity index and tend to become unstable. The viscosity index of a component is based on a comparison of viscosity of the reference oil. Viscosity index gives an indication of the reduction in viscosity of the components at higher temperatures in comparison with that of the reference oil.

The components in the feedstock that have low viscosity Index form the smaller percentage of the feed. Furfural has an affinity for the aromatic and oxygenated compounds and therefore, it is used for extracting them from the feed. The extracted aromatics are called extract and the refined stream is termed as raffinate.

The plant is designed to process four feeds stock-spindle oil, light neutral, intermediate neutral and heavy neutral.

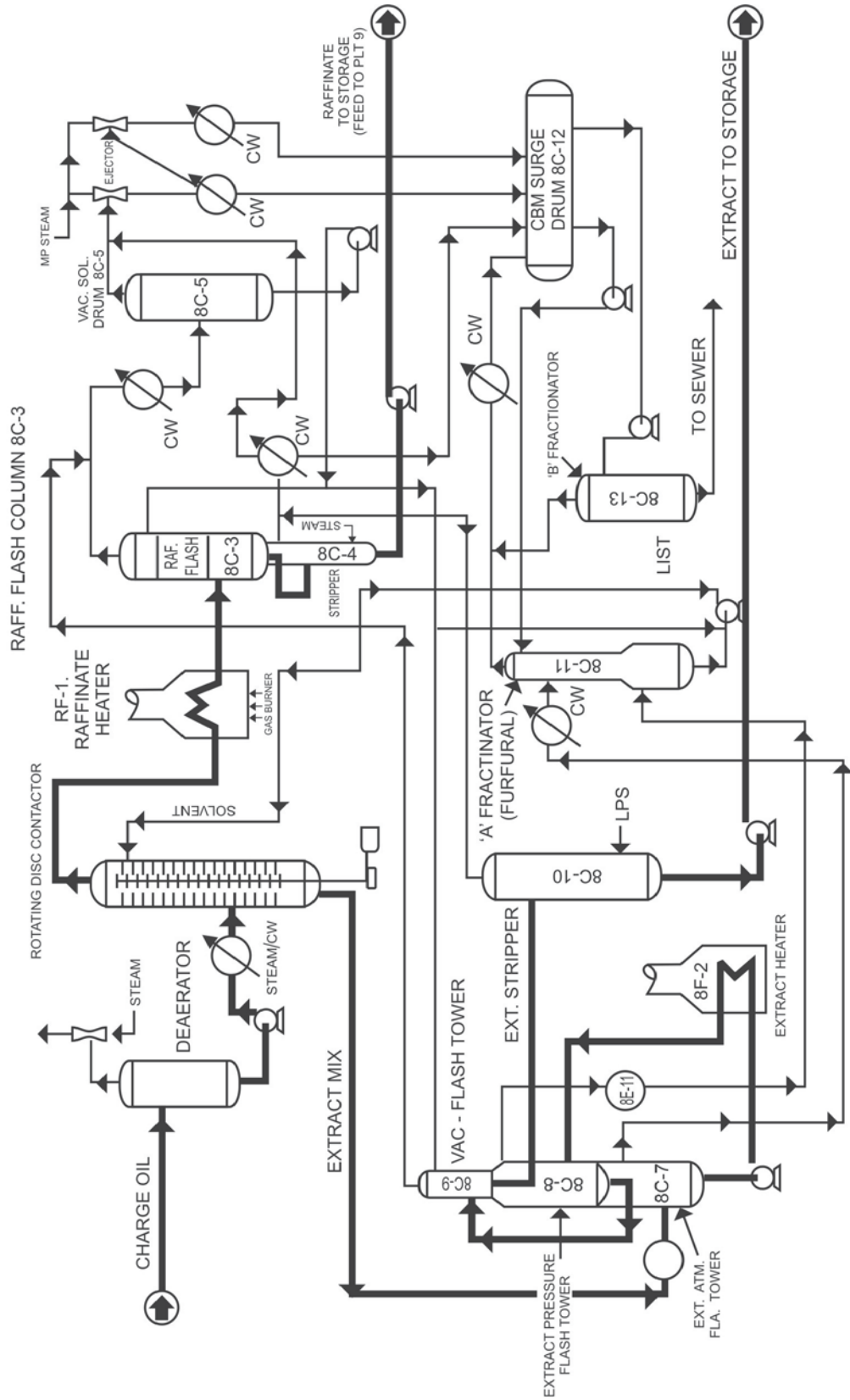
	Stock	Rate of HVI operation
1.	Spindle Oil	33m ³ /hr.
2.	Light neutral	33 m ³ /hr.
3.	Intermediate neutral	36 m ³ /hr.
4.	Heavy neutral	36 m ³ /hr.

The raffinates from this unit are sent as the feed stock to the MEK dewaxing unit through intermediate storage tanks.

For the purpose of discussion the unit may be divided into four sections. They are ; (a) Feed Extraction system, (b) Raffinate system, (c) Extract system, (d) Furfural recovery and drying system.

The air in the feedstock is removed by passing the feed through a deaerator. A de-aeration of the feed stock is necessary to prevent oxidation of the furfural, which will result in furfural losses and cause fouling and corrosion of the equipment. The de-aerated feed is then heated to the required temperature and introduced in the extraction column. The temperature of the feed is maintained

PLANT - 8 FURFURAL EXTRACTION





low enough to minimise the solubility of the paraffinic components in furfural solvent. The extraction is effected in the extraction column known as rotating disc contractor in which the furfural and feed are mixed thoroughly, Furfural is introduced at the top section of the extraction column and the feed at or near the bottom section. The extract mix is drawn from the bottom of the column and is routed to the extract recovery section and raffinate mix is routed to the raffinate recovery section to recover furfural from the respective streams.

The major portion of furfural from the raffinate mix is recovered by heating the mixture in a heater and separating the furfural in the Raffinate vacuum flash tower. The bottom stream of the raffinate flash tower is then steam stripped to recover the residual solvent in raffinate stripper. The solvent free raffinate is then routed to storage. The furfural from the extract mix is recovered in a three storage system operating under different pressures. The solvent recovered from both the systems are segregated into two streams called dry solvent which does not come in contact with steam and wet solvent which comes in contact with steam.

The solvent recovery system consists of two fractionators A and B and the CBM surge drum. The water and furfural mixture from the overhead of the raffinate and extract stripper are separated in the CBM surge drum. The separated furfural is dried in the fractionator A and the furfural from water is recovered in fractionator B. The dry furfural collected in the bottom of the A fractionator is pumped back to the extraction column.

The Raffinate from this unit is the feed stock for the MEK dewaxing units.

Plant No. 9 - MEK Dewaxing Unit

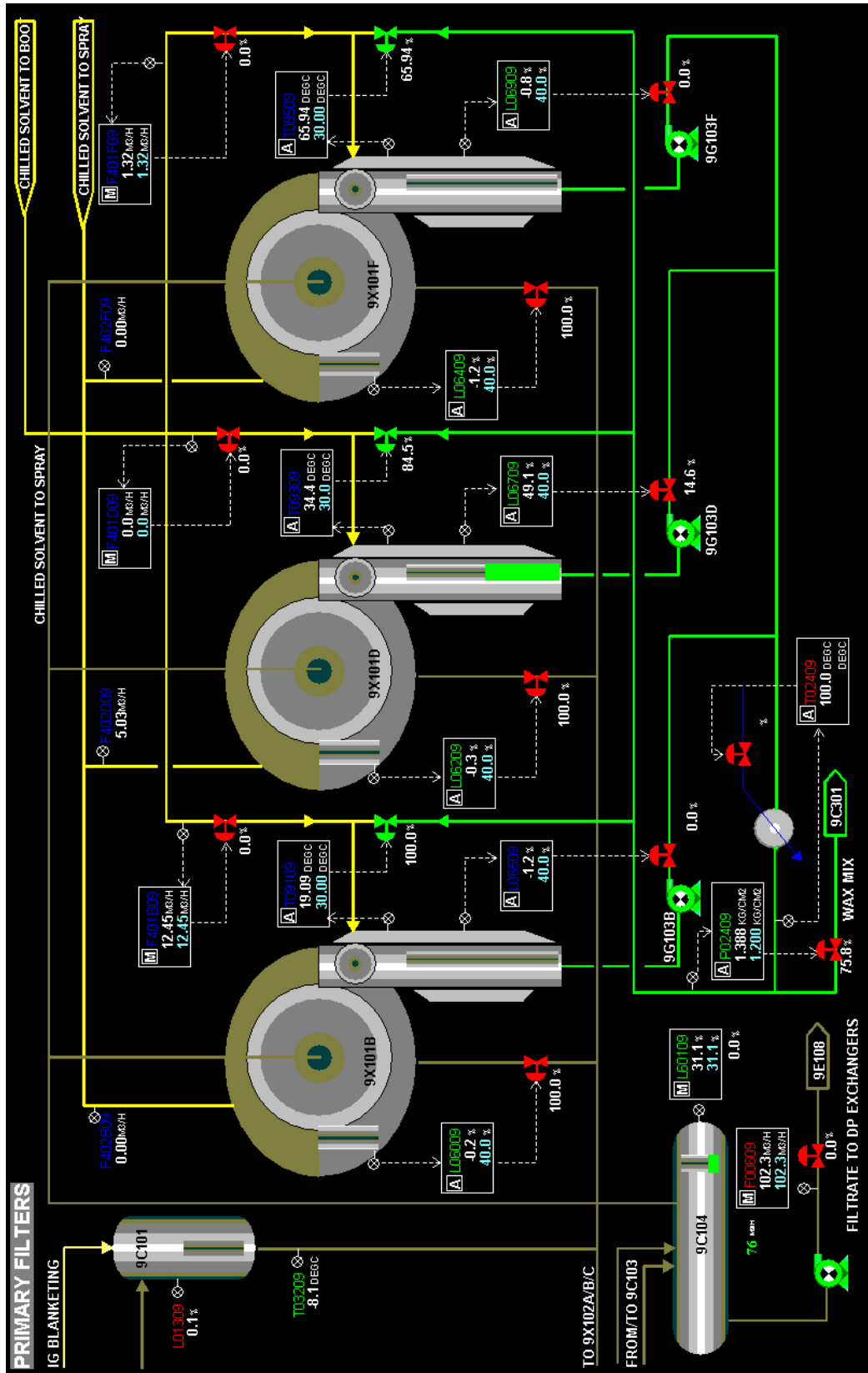
The function of this unit is to improve the pour point of the feed stock by removing the wax from the feed stock. The unit is designed to process 4 grades of furfural raffinates and the BN raffinate from the NMP extraction unit. The dewaxing is carried out on a blocked out operation. The dewaxing operation removes enough of heavy paraffins from the feed stock to lower the pour point of the product.

The dewaxing is accomplished by mixing the waxy charge with a solvent consisting of equal proportion of Methyl Ethyl ketone and Toluene, chilling the mixture to precipitate the wax and then filtering the resultant slurry to separate the wax.

The feed stock to the Dewaxing unit is first heated to a temperature, which is about 60°C above the congealing point to ensure complete solution of the waxy components. The feed is then cooled just upto the cloud point and routed to 5 banks of DIP exchangers / chillers operated in parallel.

Each bank of DP equipment consists of 2 exchangers and 2 chillers in series. The feed is cooled in the exchangers by the primary filtrate and then in the chillers by refrigerant ammonia. The chillers are specially designed to scrape out the wax deposits on the heat transfer surface so as to have efficient heat transfer.

For light stocks upto Inter Neutral, the dilution solvent is injected at 5 point along the IDP equipment for regular growth of the wax crystal and reduction of viscosity





as the mix is cooled. The dilution solvent consists of moist solvent and repulp filtrate mixed in such a ratio so as to achieve a temperature close to the feed-mix temperature at the injection point.

The heavier stocks are processed using temperature shock chilling / double dilution. The first dilution is added after the charge cooler to sharply drop the temperature by about 30°C and the second dilution is towards the end of the DP equipment. This technique helps better crystallization and lowers the pressure drop in the DP equipment.

The chilled mix at a temperature of about 6°C below the desired pour point is fed to the primary filters through a surge drum. There are 6 primary filters operating in parallel. The filter consists of a shell and a cylindrical drum with the filter cloth. By means of vacuum maintained inside the filter drum through a system of internal pipes, the solvent and oil are drawn through the filter cloth leaving a layer of wax on the cloth. The filter drum is continuously rotated by an electric motor and a master valve at the end of the filter drum subjects the filter cloth to vacuum or pressure. Chilled dry solvent is sprayed on the wax to extract maximum oil and is also added to the wax mix in the boot to improve pumpability. The primary wax mix is fed to the repulp filters through a surge drum. The repulping operation helps to leach more oil held in the wax crystals and slack wax containing 10-15% oil can be produced.

The Dewaxed oil (DWO) mix from the primary filters is used to cool the feed in the DP exchangers and then routed to the solvent recovery section.

The repulp filtrate from the repulp filters (Secondary filters) is used in the initial dilution. The wax mix from the repulp filters is routed to the wax recovery circuit. Both the solvent recovery sections are identical and consist of triple - effect flashing for maximum energy optimisation. The three stages are operated at the following conditions

	Temperature (°C)	Pressure (Kg/cm ² A)
LP Flash	103 °C	1.34
MID Flash	142 °C	3.20
HP Flash	221 °C	4.60

The flash tower bottoms is then admitted to a stripper where it is steam stripped to remove the balance of the solvent. The stripped dewaxed oil is sent to the lube oil hydro finisher (plant 10) and the slack wax is routed to wax plant (Plant 14) as feed stock to produce paraffin wax.

The wet solvent from the overhead of the stripper is collected in the solvent decanter, where the water and the solvent are separated. To minimise solvent losses, the water from the decanter is passed through a MEX fractionator where the dissolved solvent is steam stripped and separated. The moist solvent so

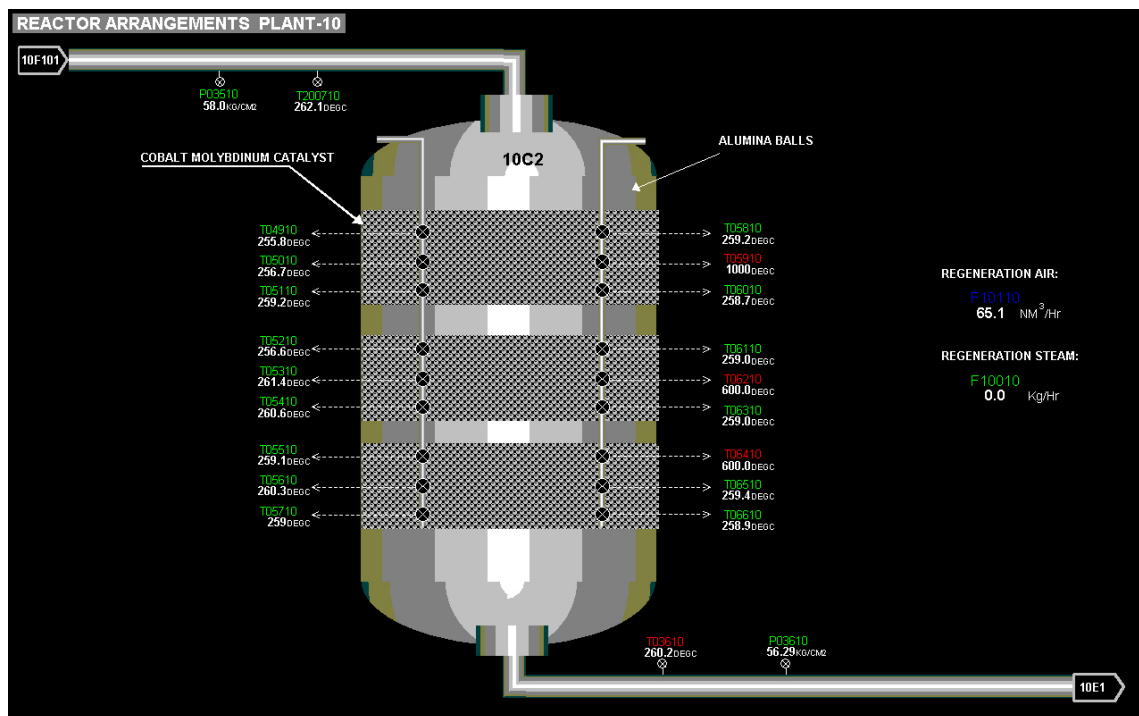
produced along with moist solvent from wax LP flash tower overhead totally containing 1-1.5% water is used for the initial dilution. The dry solvent from other flash columns is used in filter spray, refluxing the flash towers, and as a make up solvent for dilutions.

Plant No. 10 - Lube Oil Hydrofinishing Unit

The lube oil hydrofinisher employs a hydrogenation process to improve colour stability and lengthen the oxidation period of the finished lube stocks. The hydrogenation reduces sulphur, oxygen, nitrogen and undesirable carbon forming compounds without damaging the other properties of the lube oils.

The plant is designed to process all the lube oil stocks from MEK unit. Flash point and odour specification are also attained in the process and Deasphalted Oil on a blocked-out operation. The feed rate for the spindle oil HVI will be 70m³/hr. and for all other stock will be 50m³/hr. The products from this unit are the finished lube oil blending components and are delivered to off-site storage tanks.

The process flow through this unit is similar to the other hydrogen treaters. The feed is mixed with hydrogen, heated in heater and passed through three-bed reactor. Recycle gas is added to the second and third bed to control the temperature. The effluent is cooled and separated from the excess hydrogen and the other gases formed by reaction. The offgas from the separator is MEA treated to remove H₂S and is recycled to the reactor and the feed stream and part of it is sent to plant 5 as makeup gas. The make-up hydrogen for this plant is supplied from Hydrogen Plant (Plant No.11). The liquid from the separator is steam stripped in a vacuum stripper and then dried in a vacuum drier to remove traces of water. The product from vacuum drier is cooled and





then sent to storage. The overhead liquid from the stripper is pumped to 07+water separator in Plant 1.

Plant No. 11 - Hydrogen Unit

The function of plant 11 is to produce enough hydrogen for use in the hydro finishers. The plant converts the light hydrocarbon gas feed into hydrogen by reaction with steam in presence of catalyst at a temperature of 815°C. The reaction proceeds as follows:

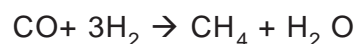
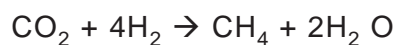


Heavier Hydrocarbons and steam react to form CH_4 , CO and CO_2 and then CH_4 reacts with steam as shown above.

The Hydrogen plant is designed for a feed rate of 1680m³/hr. of hydrocarbon gas not heavier than butane to produce 11,160m³/hr. of hydrogen. The normal feed to the plant consists of all the platformer, stabilizer off-gas plus a mixture of Off-gas from plant 12 HP absorber. During platformer shutdown, all the gas will be supplied by plant 2. The feed gas from plant 4 and plant 2 are combined and MEA treated in Plant 12 to remove H_2S before it is sent to the hydrogen plant.

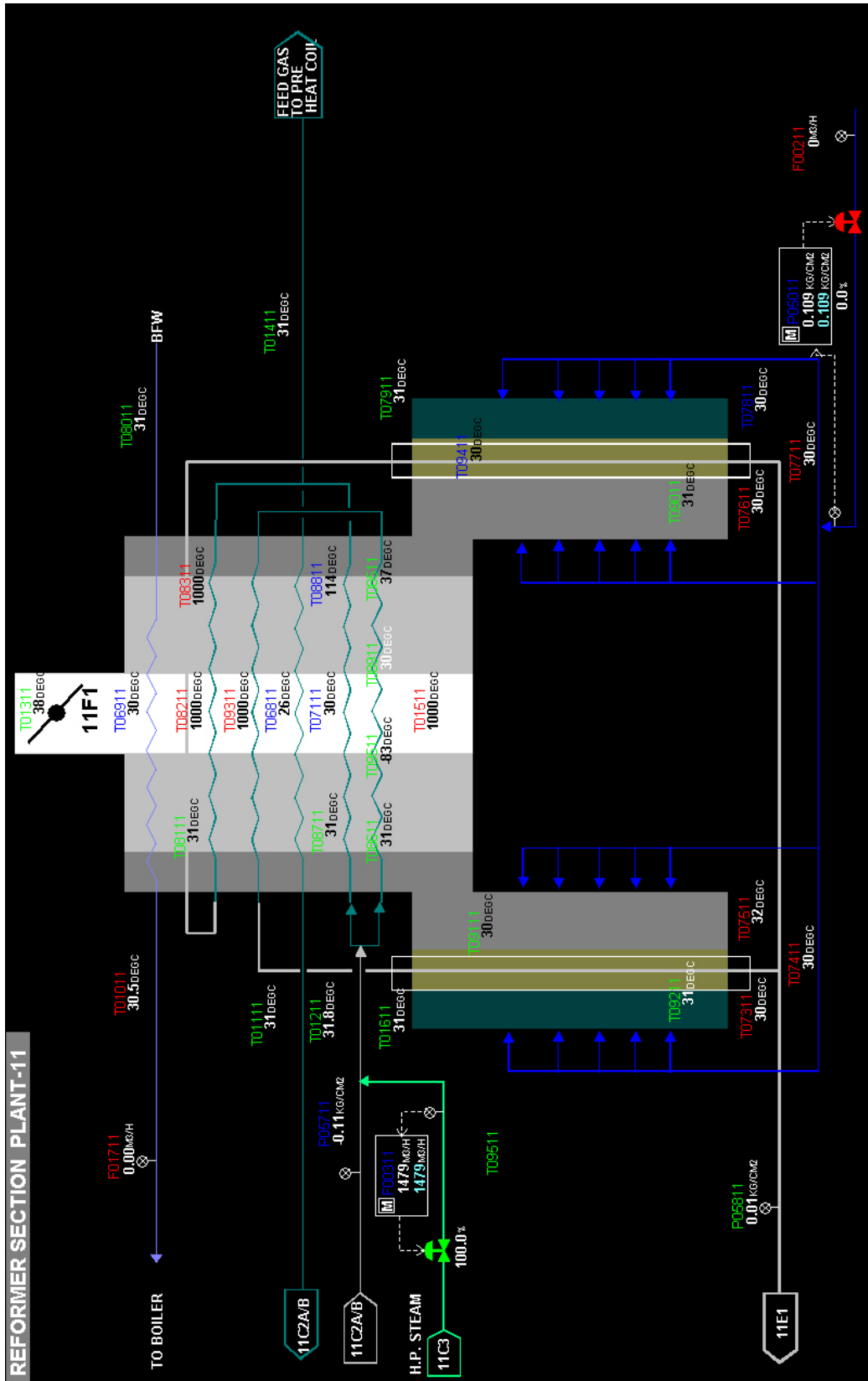
The process can be divided into three sections (a) reforming (b) shift conversion and (c) methanation. The feed gas is desulphurised by passing through two zinc oxide beds. The desulphurised feed is then mixed with sufficient steam to complete the reaction through the shift conversion and passed through the reforming catalysts completed when it leaves the reforming furnace and reaction (2) is partially attained. Therefore, the reforming is followed by a catalytic conversion at lower temperature, which is known as shift conversion. In the shift converter the steam and CO react to form CO_2 and H_2 .

The gas leaving CO_2 absorber contains small amount of carbon monoxide and carbon dioxide, which are poisonous to the catalyst in hydrodesulphurisers, as they form corrosive acids during the processing. Therefore CO and CO_2 are reconverted to methane by a catalytic reaction with hydrogen which is called methanation. The reaction proceeds as follows:



The detrimental reaction takes place over a nickel catalyst at a temperature of 315°C. The methanator effluent gas is hydrogen of 95% purity and is sent to the two-stage compression system. Hydrogen requirements of plants 4 and 5 are met after the first stage compression and that of plant 13 and 10 after second stage compression.

The heat in the reformer effluent is used to produce steam in a waste - heat boiler and this steam is used for the process. Supplementary requirement is obtained from H.P. steam and excess, if any is routed to the MP steam header.





Plant No. 12 - MEA - Gas Treating Units (Mono Ethanol Amine)

This unit treats the sour gases from all the hydro-desulphurisation units as well as the gases from the vapour recovery plant and separates the H_2S and sent it to sulphur recovery unit for producing sulphur.

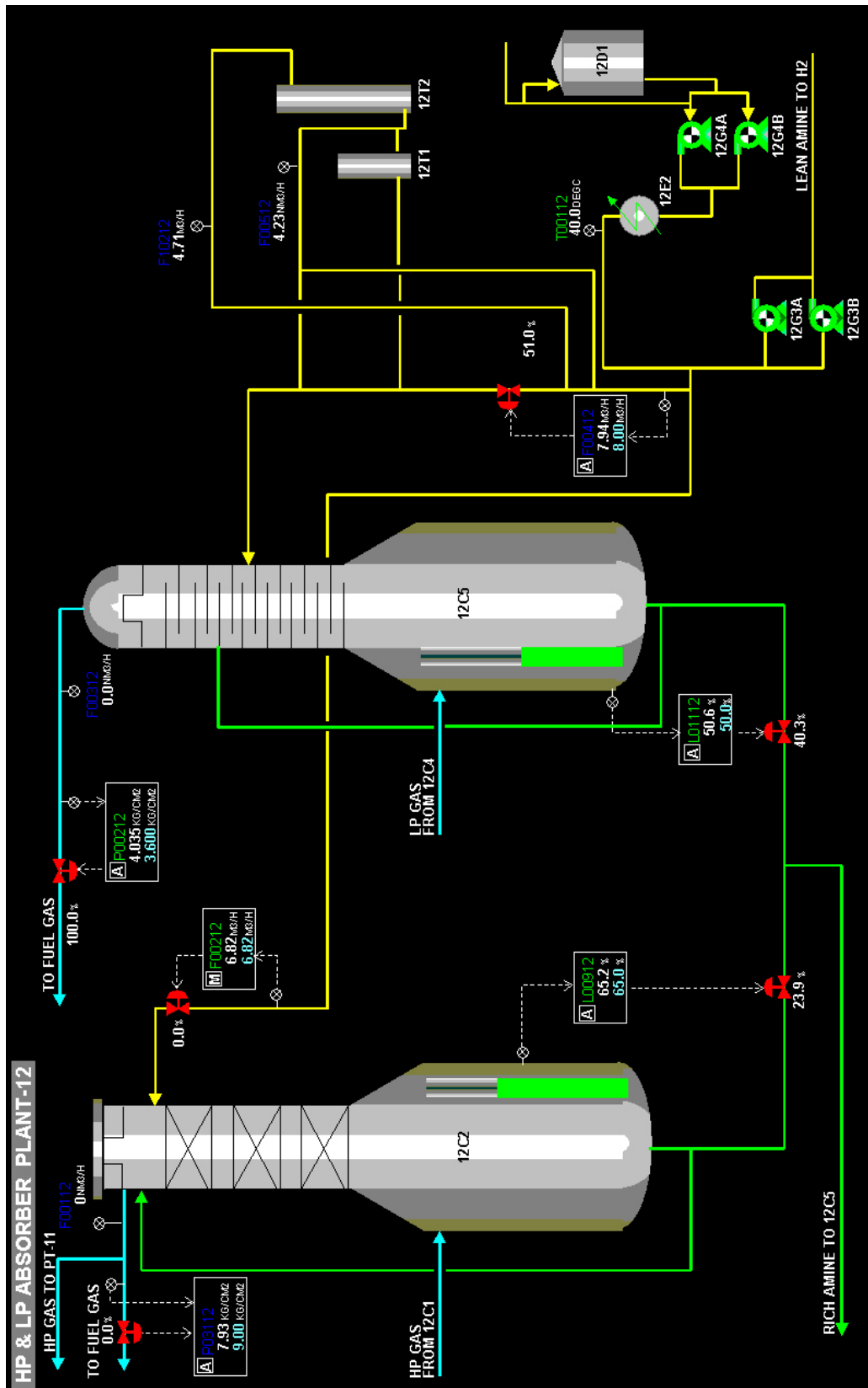
The unit has got two absorbers operating at two different pressures. The H.P. absorber treats the gases from vapour recovery unit and off gases from hydrogen block. After purification the gas is sent to plant 11 at a pressure of 11.0 kg/cm^2 for the production of hydrogen. A 15 wt% Mono Ethanol Amine solution is employed for H_2S removal. In the same manner fuel gas is counter-currently contacted at about 3.5 kg/cm^2 with lean MEA solution in the L.P Absorber and the sweet gas is sent to main fuel gas header.

The rich MEA solution from the absorbers join the rich amine from the absorbers of vapour recover unit, H.S. Diesel oil HDS unit, lube oil hydro finishing unit and vacuum distillate HDS unit. The rich MEA is preheated by exchanger with hot lean MEA solution and stripped in the regenerator

The Regenerator operates at the lowest possible pressure in order to facilitate the removal of H_2S from the rich solution. The stripped MEA solution from the bottom of the Regenerator is cooled and returned to the absorbers. The overhead H_2S gas is cooled in a cooler to condense the water and amine vapours coming along with the H_2S . The condensed weak amine solution is refluxed back to the regenerator top. The pure acid gas is delivered to the sulphur plant at 60°C , 0.8 kg/cm^2 and saturated with water vapour.

Sour water from various plants, rich in H_2S , NH_3 , and other gases is collected in a separator, where oil and gas are separated and the sour water is pressurised to the sour water stripper. The water goes through an exchanger preheated to about 95°C and charge to the stripper, where it is stripped by live steam. The sour off gas is sent to the flare header through a water seal pot and a pressure controller.

The stripped water is sent to the blow down stack after cooling to about 60°C by heat exchange.





Plant No. 13 - Vacuum Distillate Hydro-Desulphurisation Unit

The Vacuum distillate HDS unit processes the vacuum distillates in excess of that needed to meet the lube oil product requirements. The desulphurised product is the feed to the thermal cracker in plant-6 to process Hot Vacuum distillates, spindles, light neutral. Intermediate Neutral and Heavy Neutral can be taken from Plant-1. Similarly cold feed (vac. distillates) from OM & S also can be taken in.

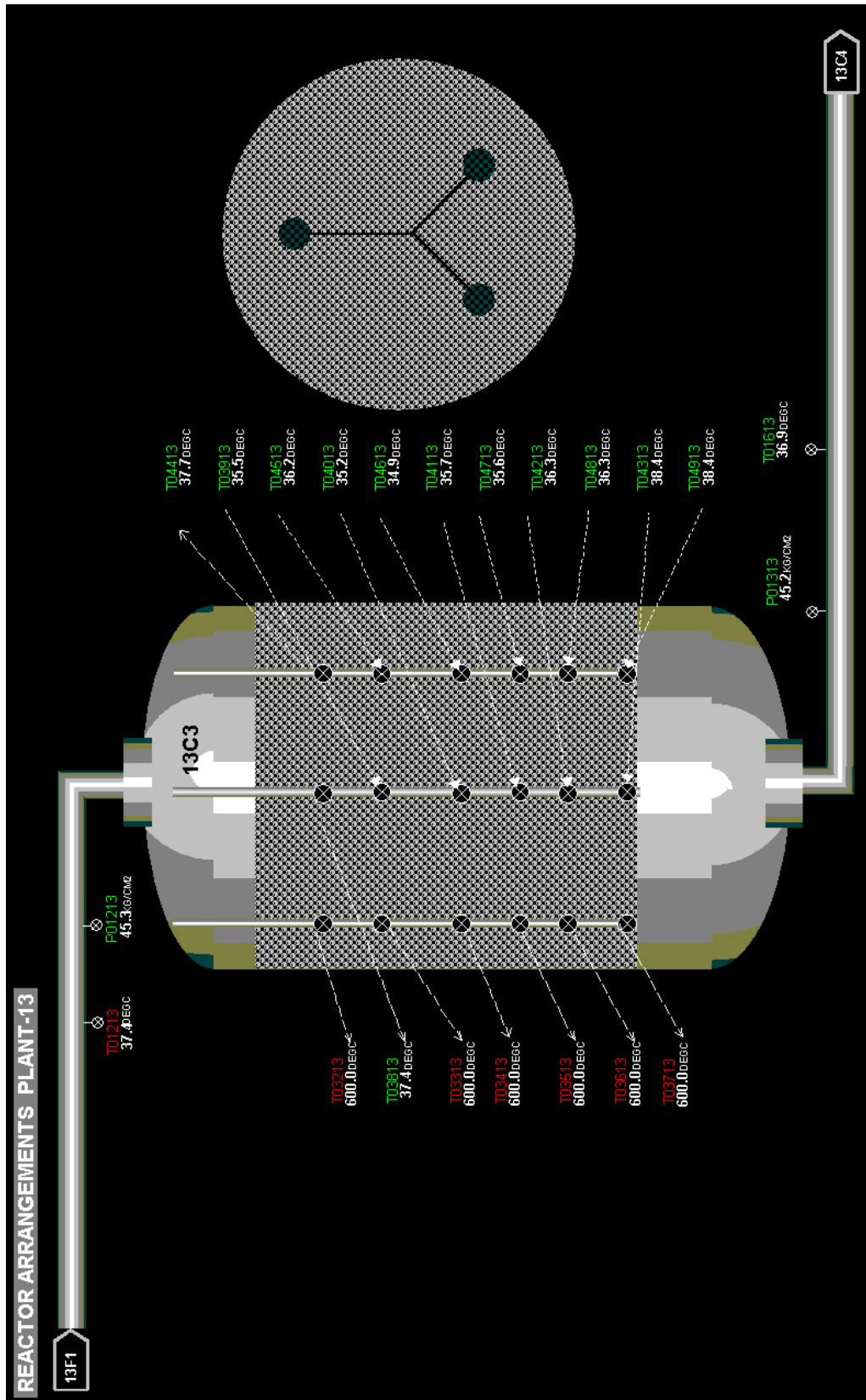
(a)	First stage vacuum tower gas oil from Plant 1	4.3 m ³ /hr.
(b)	Spindle oil distillate from Plant 1	10.8 m ³ /hr.
(c)	Light neutral distillate from Plant 1	8.8 m ³ /hr.
(d)	Intermediate Neutral Distillate from Plant 1	15.95 m ³ /hr.
(e)	Furfural Unit extracts	3.75 m ³ /hr.
	Total	43.6 m³/hr.

The process flow of the vacuum HDS unit is similar to that in other HDS units. The reactor has three beds of catalyst proportioned to give approximately equal rise in temperature. Recycle gas is admitted in between the beds to limit the temperature rise across the bed. The recycle gases are amine treated to remove H₂S. The reactor effluent is steam stripped to remove light hydrocarbons. The stripper overhead vapours are condensed in the common condenser of the HSDO stripper in plant 5. The desulphurised vacuum distillate is fed directly to plant 6 as feed or as called and sent to the visbreaker feed storage tank or Lube oil tanks.

For the past 6 years this unit was operating for improving viscosity index of lube oil to reduce the load on solvent extraction unit by doing hydrogenation operation. I.e., plant will be operated at high severity condition. The VI improvement was 10-12 unit for Heavy Neutral distillates and 12-14 units for Intermediate Neutral distillates.

It was also operated to hydrofinish dewaxed oil i.e. finished Lube service similar to plant 10.

It was also operating on Diesel to remove "Sulphur" whenever CDU II is processing PG. Crude.





Plant No. 14 - Wax Plant

The Paraffin Wax Plant (Plant 14) was envisaged based on the availability of sufficient quantity of Slack Wax from the Lube Dewaxing Unit (Plant 9). The de-Oiling Unit was commissioned in 1984 and the Clay contact Unit in 1986.

The De-Oiling unit and the clay contact unit was provided by M/S. S.Foster Wheeler Energy Corporation, U.S.A and the basic design by Union Oil Company, U.S.A.

The Plant has been designed to produce 20,000 MTPA of various grades of wax. It will be revamped shortly, resulting in the production capacity going upto 30,000 MTPA. A hydrofinishing Unit for decolorising the wax is being considered; this unit would replace the Clay Contact Unit and the capacity of the unit in 40,000 MTPA.

Feedstock and Products

The Plant has been designed to process various grades of Slack Wax from Plant 9. The products included Match Wax (type III), Candle wax (Type II) and Food Grade wax (Type I). Type II has to be decolorised in the HYFI unit to meet the colour specification IV. The various feedstock's that are being processed are follows

Product	Feedstock
Type III Wax	100 % BH HVGO 60% BH HVGO + 40% SPHVI or SPLVI
Type II Wax	100% IN HVI 100 % LN HVI Any proportion of IN/LN HVI IN/LN HVI + Max. 15% IN LVI

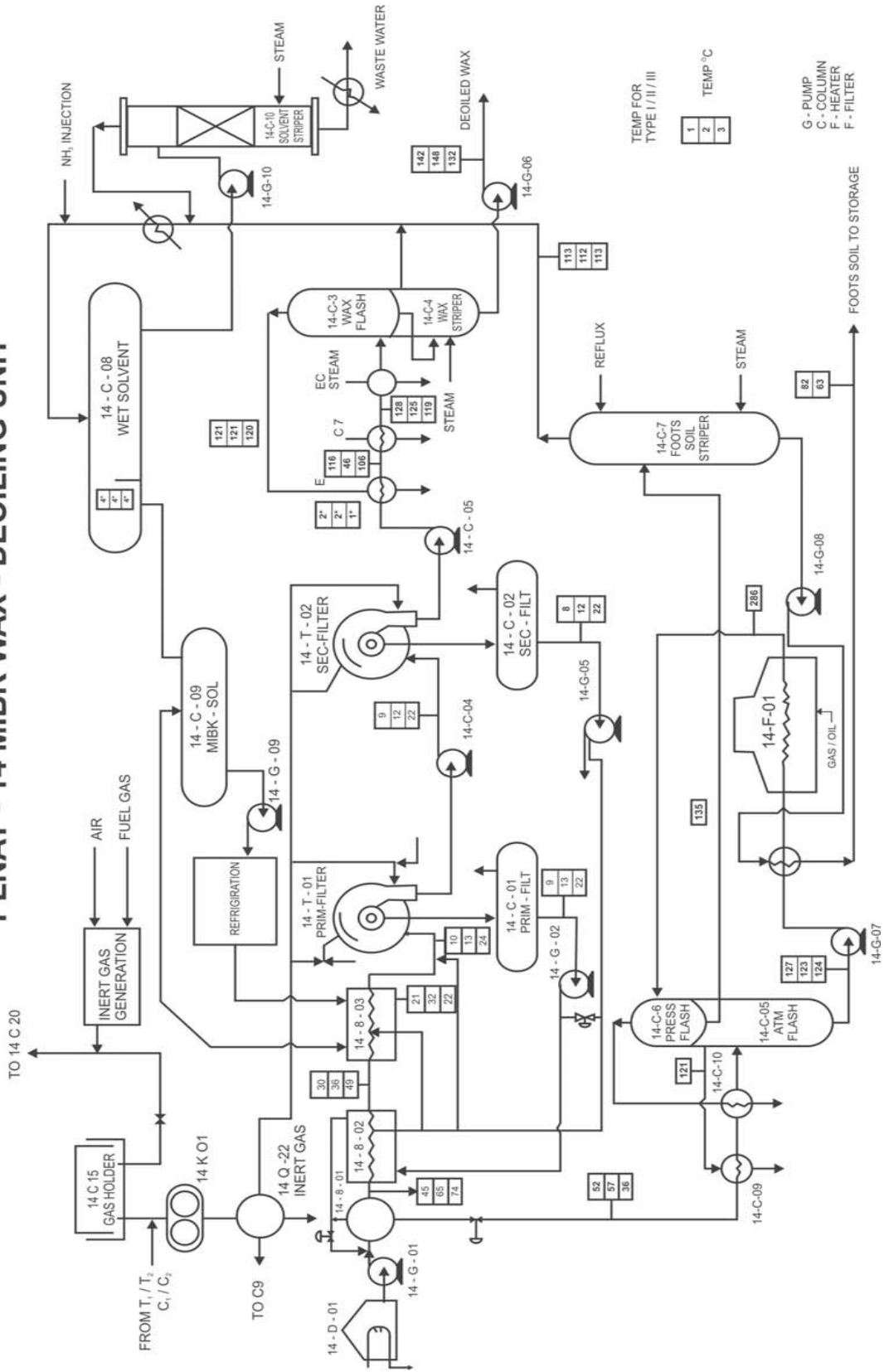
Note: HVI grades are preferred to Type II Wax since the colour bodies are removed to a great extent in the Lube Extraction Unit, Plant 8.

Deoiling Unit

Slack Wax contains hard wax, soft wax and oil. In the De-Oiling Unit, most of the oil and the softwax are removed by extracting with the solvent MIBK (Methyl iso butylketone). The Slack wax is chilled along with the cold filtrate (which is added in increments) in a pre-cooler and two double pipe scrapped surface exchangers. The filtrate which is essentially solvent, is added to keep the wax slurry thin for easy pumping as well as to control the shape of the wax crystals. The solvent is chilled in an ammonia refrigeration unit to 1^o-3^oC. The wax-solvent mix enters the primary filter vat at temperatures between 10 and 13^oC.

The wax get separated from the Fouts oil in the filter by means of a vacuum created by inert gas compressors and gets deposited on the filter surface. It gets exposed to a fine spray of solvent, which reduces the oil content in the wax. The filtrate is used partially as dilution medium; the balance material is sent for solvent recovery. The oil free of solvent is called Fouts Oil and is routed to either FCCU feed tanks (Normally) or to Fuel Oil Pool.

PLNAT - 14 MIBK WAX - DEOILING UNIT



TEMP FOR TYPE I/II/III

1	TEMP °C
2	
3	

- G - PUMP
- C - COLUMN
- F - HEATER
- F - FILTER



The wax gets dislodged from the primary filter onto a scroll from where it is pumped to a secondary filter. The oil content in wax is further reduced by contacting with solvent both in the primary boot and as a spray in the secondary filter. The De-Oiled wax is then sent to the solvent recovery section, from where it is pumped either to the hydrofixing Unit or directly to the product tanks if it is Type III Wax.

HYFI Unit

In the HYFI unit, the Brown Wax (Type II) with a content less than 0.5% from the De-Oiling Unit or from Brown Wax from the tanks is preheated and further heated in the furnace before going to the Reactor. The feed wax gets mixed up with Hydrogen and enters the Reactor. After the reactor, the stream goes to separators and strippers for removal of lighter ends. The product wax after getting improved in colour becomes white wax and goes to the product tank through the product coolers

APV Moulding Unit

For easy disposal of white candle wax (Type II), the wax is formed into slabs of 5 kg each in a Moulding Unit. To facilitate the slabbing process, the wax is solidified in a cooling chamber maintained between 8 and 10°C with the help of an ammonia refrigeration unit. The white wax from the product tanks is pumped to the pre-cooler section where it is cooled to the chamber inlet temperature of 75°C by a tempered water system.

7. REFINERY-II

Refinery II - Over all Process Description

Product from these units are straight away blended with products from Refinery I. Heavy Naphtha from plant 15 is line blended with Diesel in the unit or routed separately to storage. Kerosene is treated in Merox unit if product sulphur conversion is required or it is blended with Diesel in the unit or routed separately to storage or it is blended with kerosene from Refinery I and HSD from plant 15 Atmospheric Tower, is blended again with HSD Product from Refinery 1. Vacuum tower product LVGO and HVGO are fed to fluid Catalytic Cracking Unit. Product like OVHD Gas and LPG from FCCU are treated in Amine and Merox unit before being routed to fuel gas system and storage respectively. Gasoline (High Octane) is treated in Merox treating unit before routed to storage. This Gasoline is blended with straight run gasoline, Cracked Gasoline, and platformate to get 87 Octane Motor Spirit.

CDU-II

General Functions

The Crude Distillation Unit consists of an Electrostatic Desalter, an atmospheric section with a vapour recovery section and vacuum section. The plant is designed to process 3.7 million tonnes/year of crude. The plant produces straight run products as well as feed stocks for other units envisaged in the expansion of the refinery.

Electric Desalter

Crude is preheated to desalting temperature of 125°C by successive heat exchange with heavy naphtha, kerosene, atm. column to pump-around, diesel product and middle pump around.

Sour water from the sour water surge drum 18C31 is pumped and preheated by heat exchange with LGVO (circulating reflux and product) stream from the vacuum section and fed to the sour water stripper 18C 32 and stripped water is added to the crude and the combined stream is emulsified by a mixing valve at the Desalter thus breaking the emulsion of brine and oil phases. The brine is proposed to be sent to the existing closed blow down system or waste water treating section. The crude continues to the atmospheric distillation section via further preheated with atmospheric section, Vacuum section and fuel oil product streams.



Atmospheric Distillation Section

Desalted crude from 15-C-01 is pumped by the crude booster pump 15-G-02 and split into two equal streams. One stream is heated by successive heat exchange with middle pump around, heavy vacuum gas oil, diesel product, and kerosene product and bottom pump around reflux. The other stream is heated with products from the vacuum distillation section and combined with the first stream. The preheated crude is finally heated and vaporised in the crude furnace and introduced into the flash zone of the atmospheric distillation column.

Six stripping trays are provided below the flash zone where reduced crude is steam stripped to remove diesel and lighter constituents. The stripping section vapour together with the vaporised portion of the crude are fractionated on the trays above the flash zone to yield liquid side draw products and as overhead vapour stream, Diesel, Kerosene and heavy naphtha are withdrawn as side draw off products from the atmospheric distillation column and steam stripped in the side stream strippers.

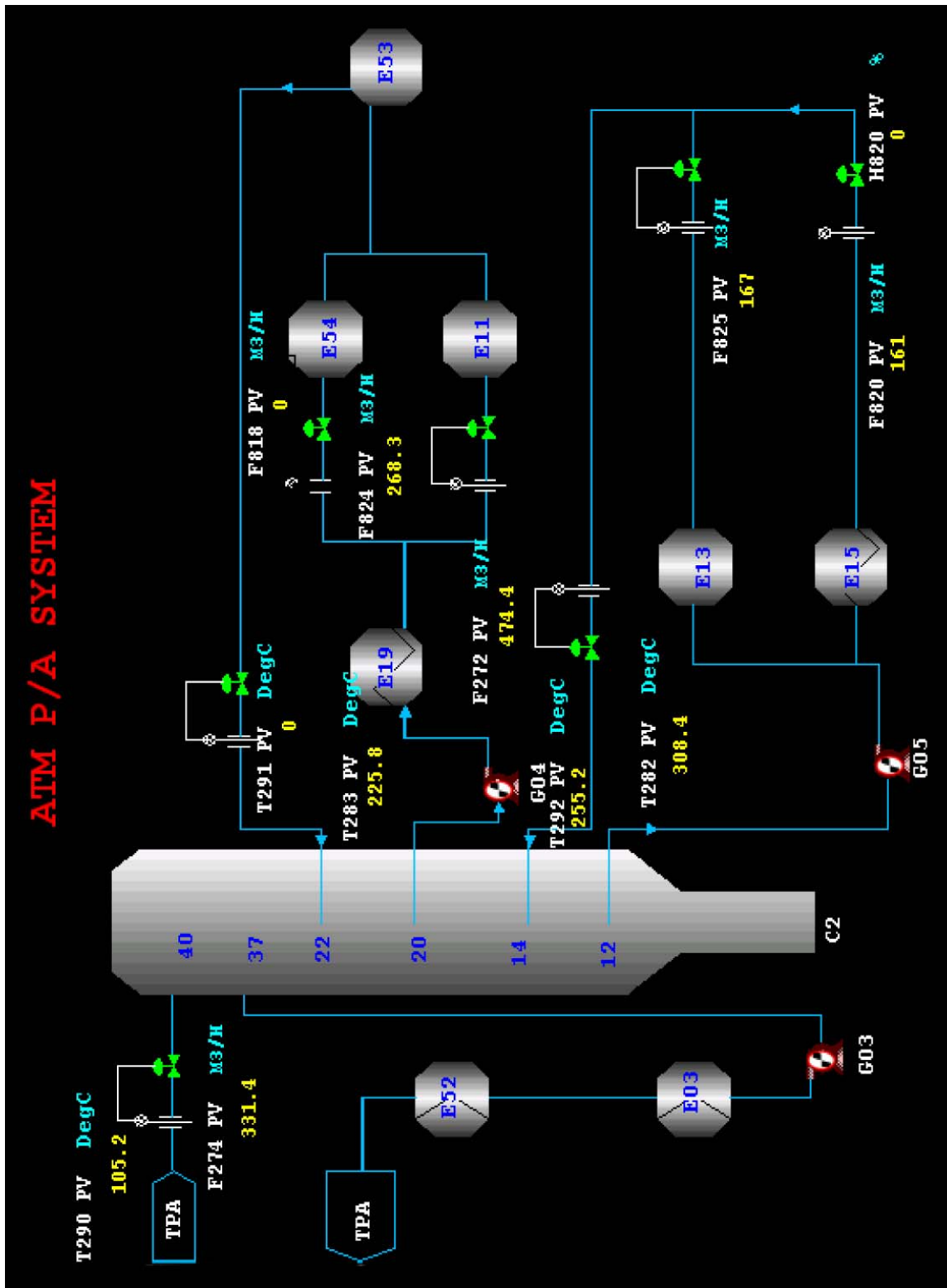
Diesel product exchanges heat with crude oil and is cooled by air cooler and tempered water cooler before being sent to storage. Kerosene product exchanges heat with crude oil and is further cooled with cooling water and sent to storage / merox unit.

Pump Around System

In order to maximise heat recovery and to balance the tower loadings, the heat is removed by way of bottom pump around, middle pump around and top pump around systems. Bottom pump around is withdrawn at the diesel draw off tray and returned to the tower after heat exchange with crude oil. Middle pump around is withdrawn at kerosene draw off and returned to the tower after providing the necessary heat to reboil the stabilizer and preheating crude oil. The top pump around reflux is withdrawn at tray 37 and returned above tray 39 after heat exchange with crude oil. The atmospheric column overhead vapours are totally condensed in overhead condensing system with air condenser followed by water condenser. The condensed product goes to the reflux drum from where, a part is pumped back to the atmospheric tower as reflux while the balance is sent to the naphtha stabilizer 15-C-08.

Stabilizer bottoms preheat the feed naphtha before it enters the stabilizer. Necessary heat to reboil the stabilizer is provided by the middle pump around via the stabilizer reboiler. The overhead vapours from the stabilizer are condensed in overhead condenser against cooling water.

A part of the condensed product goes to the stabilizer as reflux and the balance is sent to the LPG / ATU / Merox / Storage. Stabilized naphtha from the bottom of stabilizer is used to preheat stabilizer feed and is cooled in a water cooler before going to storage.





Vacuum Distillation Section

Hot reduced crude from atmospheric column is mixed with slop recycle, heated and vaporised in the vacuum furnace and introduced into the flash zone of the vacuum column.

The liquid portion of the feed drops into the bottom section of the tower and is withdrawn as vacuum residue. The vaporised portion rises up the tower and is fractionated into three side stream products.

Slop distillate cut (530°C-550°C) is withdrawn as the first side draws product along with the recycle, which is pumped, back into the inlet of vacuum furnace.

The slop cut is mixed with vacuum residue and sent to the F.O. Pool. The slop cut helps to achieve the quality of the FCCU Feed. The vapours rising from the flash zone passes through a demister pad to ensure removal of entrained asphaltenes.

The hydrocarbon vapour is condensed in the HVGO and LVGO sections by circulating reflux and internal reflux to the flash zone. The circulating reflux is used to preheat crude and then returned to the top of the HVGO section.

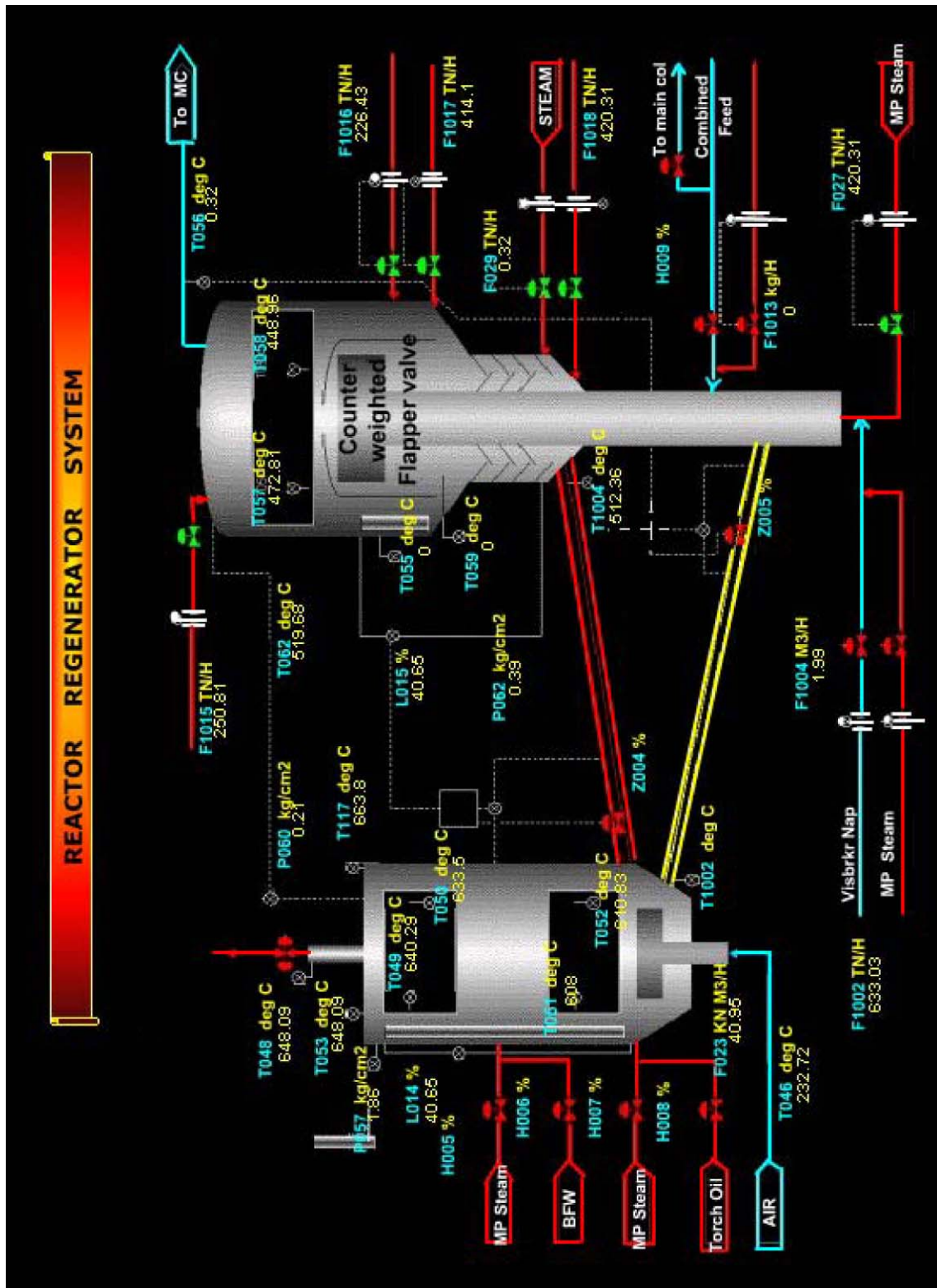
LVGO is the third side stream along with the circulating reflux and internal reflux to the HVGO packing. Circulating, reflux is returned to the top of the LVGO packing after exchanging heat with crude and desalter water and being further cooled in water cooler.

Vacuum is maintained by a three-stage ejector system with surface condensers. The vacuum column overhead vapour flows through the first stage, ejector. The discharge from the first stage goes via 15E43 condenser to the 2nd stage ejector. The vapours from the second stage go to the unit inter condenser and the uncondensed vapours are sent to the third stage. The discharge of the third stage goes to the after condenser and the non-condensibles are vented to the atmosphere. Condensate is routed to the hot well from which it is pumped to the sour water surge drum 18C31. Any oil, which is carried over along with the tower overheads enters the hot well along with the steam condensate and is pumped to the slop tanks.

The Vacuum Residue exchanges heat with crude oil and then it is sent to the fuel oil pool after being cooled with tempered water.

Plant No. 16 - FCCU

The Fluid catalytic cracking unit produces more valuable hydrocarbons including LPG, Gasoline and diesel blend stock. The cracking reaction takes place at a lower pressure and temperature than the thermal cracking processes. The process employs synthetic silica-alumina catalyst in the form of micro-spherical particles, which behave like a fluid when aerated with a vapour.





Catalyst Section

This section consists mainly of the reactor and Regenerator. The feed to the unit along with recycle streams is preheated to a temperature of 365-370°C (in bottoms feed preheat exchanger and a natural draft furnace) enters the riser where it comes in contact with hot regenerated catalyst (at a temp. of 640-660°C). The hot catalyst vaporises the feed and the cracking reaction takes place in the riser. This vapourisation fluidises the catalyst up the riser to the disengaging T-section at the top of riser. The cracked hydrocarbons in vapour form exit from the Reactor through a cyclone (which collects entrained catalyst and returns it to the reactor through the dip leg) to the fractionator section.

The spent catalyst (with coke deposited on it due to the cracking reaction) passes through the reactor stripper, where hydrocarbons are removed by means of steam stripped and sent to the regenerator where the coke is burned off by air, which is compressed by a high capacity Air blower. The regenerated catalyst flows back to the riser where it meets the feed, thus completing the cycle. The hot flue gas (680-720°C) from the regenerator consisting of small percentages of CO and CO₂ flows to a Co boiler where the heat is utilised to produce high-pressure steam.

Fractionation Section

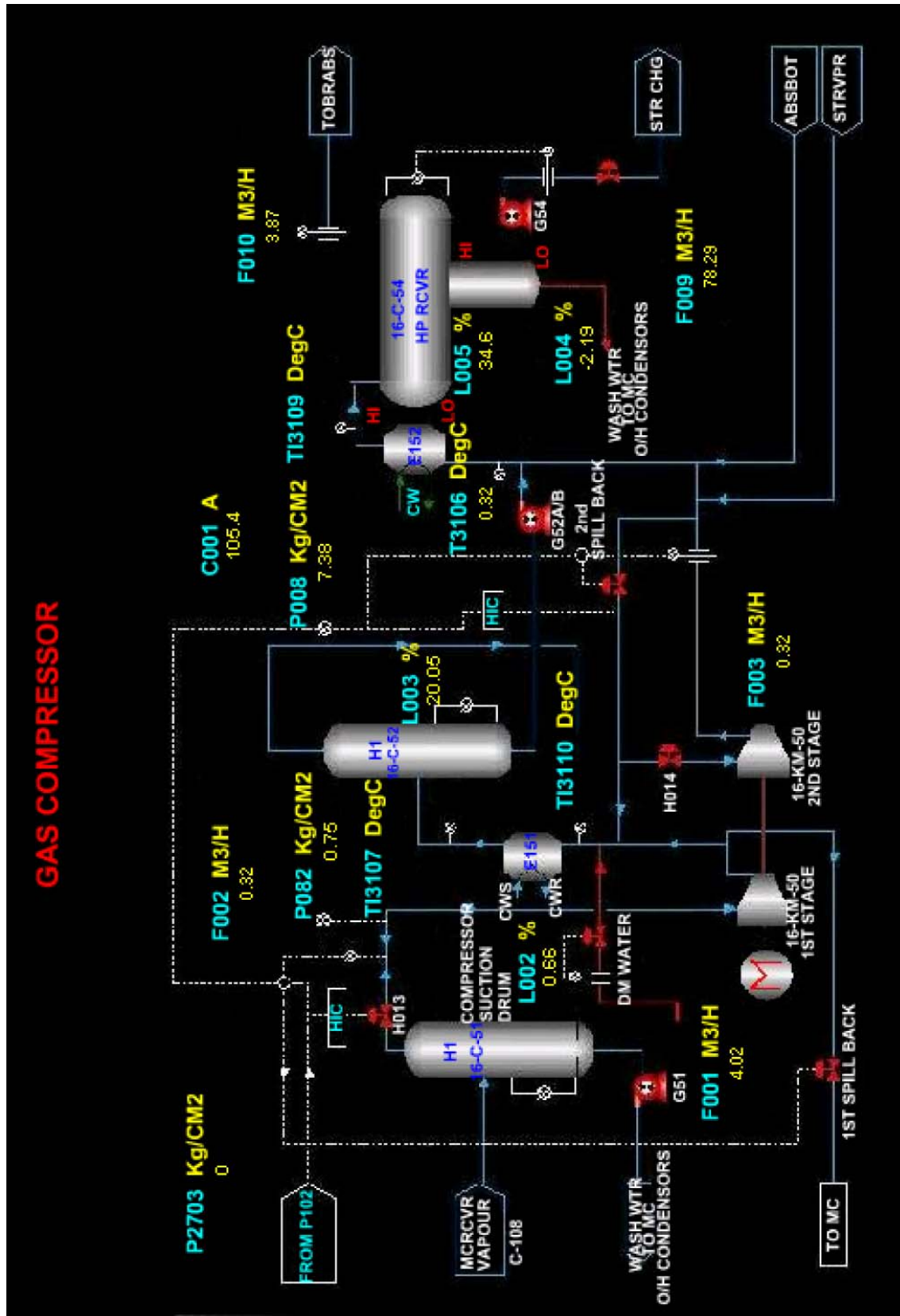
In the main column gas, LPG and gasoline are removed overhead as vapour. Unconverted products such as LCO and HCO are withdrawn as side stream liquid products, stripped and sent to diesel storage.

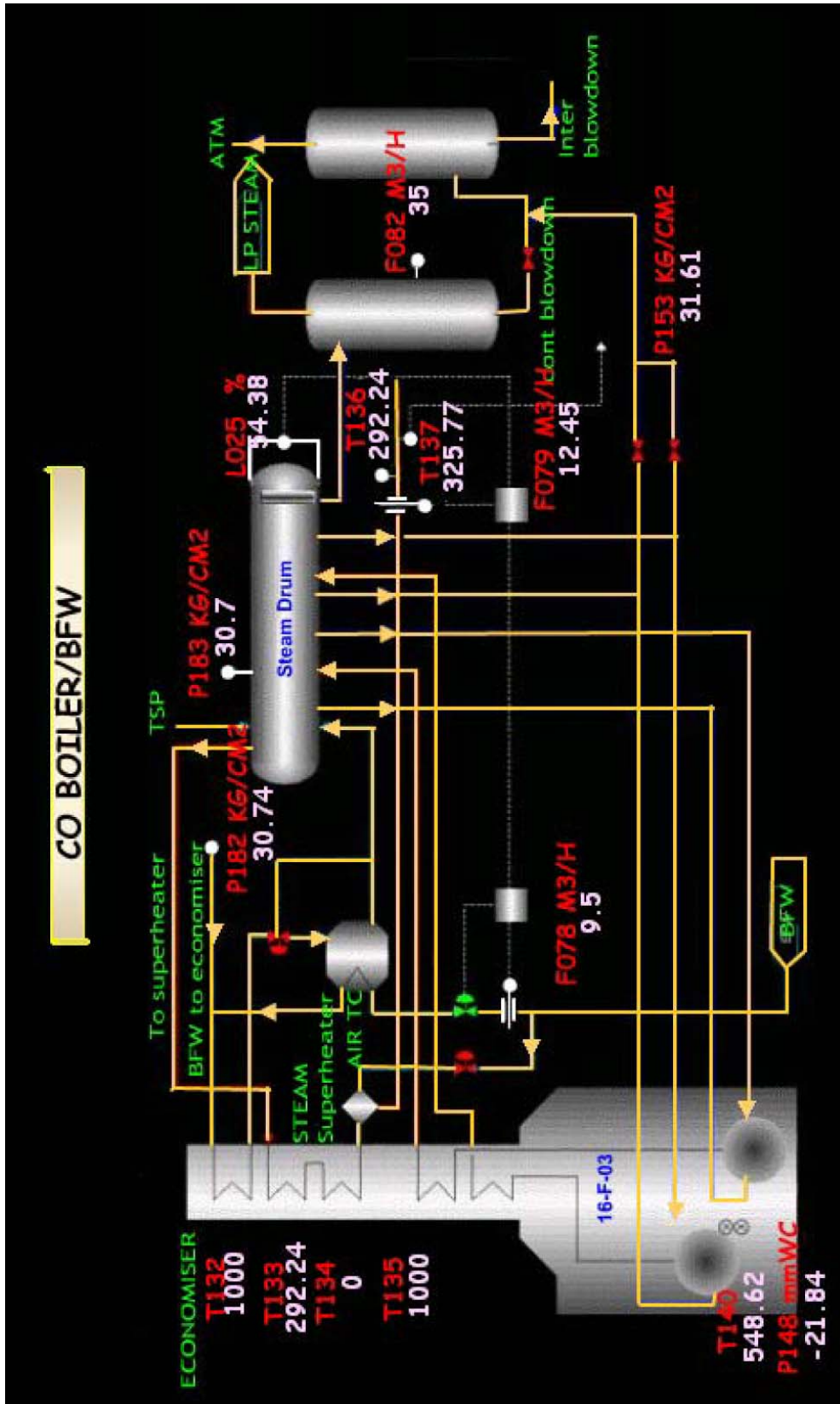
Overhead vapour from the top of the main column passes through condensers into the overheads receiver where unstabilised gasoline is separated from lighter products. Vapour from the top of the receiver is compressed by the wet Gas compressor, cooled and directed to the bottom of the primary absorber via the stripper charge drum.

Unstabilised gasoline from the receiver is pumped to the top of the primary absorber. Much of the C³S and heavier components in the wet gas are absorbed in the unstabilised gasoline.

Vapour, from the top of the primary absorber passes to the sponge absorber (where the remaining C³ and heavier components are removed from the vapours by absorption into cooled HCO. The dry gas from the top of the sponge absorber is directed to the Amine Treating Unit where hydrogen sulphide is removed from there and the dry gas passes to the refinery fuel gas system.

Unstabilised gasoline from the bottom of the primary absorber first has some of the light components removed in the stripper and then proceeds to the debutaniser where C³ and C⁴ are removed overhead as LPG. The LPG is amine and merox treated (to remove H₂S and reduce the mercaptan level respectively) before being sent to LPG pool or as feed stock to the propylene recovery Unit. The Debutanised gasoline is Merox treated and sent to gasoline pool.





Main column bottom is pumped to the slurry settler where entrained catalyst from the reactor settles and is sent back along with feed as recycle. Clarified oil (CLO) from the top of the slurry settler is cooled and pumped to Fuel oil / LSHS Pool.

Plant No. 17 - Merox Treating Unit

The MEROX (Mercaptan Oxidation) process is for the chemical treatment of petroleum distillates to remove mercaptans or to convert mercaptans to disulphides. The former is known as extraction where reduction in sulphur content takes place and the latter is known as 'sweetening' where there is no such reduction in sulphur content. Mercaptans impart obnoxious odor, corrosiveness and make the product Doctor positive and are not desirable for sales. Under proper operating conditions and depending on the results desired, distillates upto kerosene range can be successfully treated.

The process is based on the ability of the catalyst composed of iron group metal chelates (cobalt phthlecyanin sulphonates) to promote the oxidation of mercaptans to disulphides using air as source of oxygen in an alkaline medium. The overall reaction is, $4\text{RSH} + \text{O}_2 \rightarrow 2\text{RSSR} + 2\text{H}_2\text{O}$

The reaction proceeds at an economically practical rate at normal temperatures for refinery rundown streams.

EXTRACTION process is adopted for both straight run LPG and Cracked LPG from FCCU where a sweetening process is employed for cracked gasoline and kerosene.

LPG after amine treatment, for hydrogen Sulphide removal, is bubbled through Caustic Solution in a caustic Scrubber vessel where any slipped H_2S is removed and passes through liquid-to-liquid extractor where counter current contacting takes place between LPG and merox caustic solution. Substantially mercaptan-free LPG goes to caustic settler and then through sand filter to remove traces of caustic and finally goes to rundown sphere under back pressure control.

The Mercaptan rich merox caustic solution from both extractors is heated to 45-60°C in a steam heater and then sent to an oxidizer vessel where air is injected to promote oxidation of mercaptans to disulphide in presence of merox catalyst. The oxidised merox caustic solution is decanted and the regenerated merox caustic solution is pumped back to absorbers for further treating.

Extraction is not employed for straight run LPG as its initial Mercaptan level is low and meets odour NO_2 requirement. 15°Be caustic is used for caustic scrubber as well as merox caustic solution preparation. Whenever caustic strength comes down to 5 to 6%, spent caustic is pumped out and fresh caustic is charged. Merox catalyst consumption is in the order of 2 bottles per month.

Cracked gasoline from FCCU is mixed with light caustic (3°Be) and air and reaction takes place in a reactor with activated Charcoal bed impregnated with merox catalyst. The oxidised disulphide molecules goes to rundown tank under backpressure control Cracked gasoline sweetening unit also called "MINALK".



Kerosene is mixed with small amount of light caustic to neutralize any naphthenic acid present and dehydrated in an electrostatic coalescer where water is separated. The dehydrated kerosene is mixed with air and conversion of Mercaptan to disulphide takes place in the keromerox reactor containing activated charcoal impregnated with merox catalyst. The sweet kerosene from reactor needs extensive post treatment to meet stringent ATF specification. It passes to caustic settler (caustic removal), water washer (traces of caustic and water soluble impurity removal), Salt filter (water removal), clay filter (organic impurity removal) and then goes to rundown tank under backpressure control.

Unlike cracked gasoline reactor, keroreactor bed is saturated with strong caustic of quite large volume intermittently. Whenever the reaction shows decline in efficiency, reactors are water washed to restore the efficiency. The reacting bed is impregnated with merox catalyst once in 10 years.

Plant No. 18 - FCC off Gases - Saturated and Cracked LPG Amine Treater

Process Design Specifications

Introduction

The FCC off gas and LPG Amine Treating Unit are designed to process FCC off gases and cracked LPG from GCU and saturated LPG from CDU. FCC off gases and cracked LPG units are designed for Bombay high and Iranian Heavy Crudes whereas the saturated LPG unit is designed for Basrah crude. The design flow rates for all the cases are tabulated below:

	Unit	Flow rate kg/hr.		
		BH	IH	BASRAH
(a)	FCC off gases	3123.00	3789.00	
(b)	Cracked LPG	9180.00	7828.00	-
(c)	Saturated LPG	6379.00	-	8114.00

The unit consists of three Diethanolamine (DEA) absorbers and one regenerator. Hydrogen Sulphide from sour streams is absorbed in the absorbers. The H₂S rich amine solution is stripped off hydrogen sulphide in amine regenerator.

FCC of Gases

Sour FCC off gas is charged to the amine treating unit from GCU at a pressure of 12.5 kg/cm² abs and 38°C. Sour gases enter the DEA absorber (18-C.01) at the bottom of the column and flow upwards. H₂S free FCC off gases leave the absorber at the top and are sent to the Fuel gas system. The DEA absorber (18-C-01) system is a 20 valve trays column. Lean DEA enters the absorber (18-C-01) on the top tray of the column and descends down by making a counter current contact with sour gases stream.

Sour LPG Streams

Saturated LPG and cracked LPG are charged to the amine treating unit from GCU at a pressure of 19.0 kg/cm² abs. and 38°C respectively. Sour LPG streams enter the DEA absorbers through distributors at the bottom of the respective columns and flow upwards, H₂S free LPG streams leave the Respective absorbers at the top and are sent to Merox units for further processing. The DEA absorbers (18-C-02 and 18-C-03) are sieve tray towers with 10 trays each.

Lean DEA enters the absorbers (18-C-02 and 18-C-03) on the top of the respective columns and descends down thereby making a counter current contact with the respective streams. Sufficient tray spacing has been provided for proper settling for DEA and disengagement from LPG on each tray. At the bottom of the tower sufficient residence time has been given to ensure complete separation of DEA from LPG.

The absorption is essentially isothermal. The rich DEA flows out of the absorbers (18-C-01, 18-C-02 and 18-C-03) at the bottom under its own pressure. The 3 DEA streams are sent to a flash column (18-C-04) where the pressure is brought down to 3.0 kg/cm² abs. The hydrocarbons absorbed by the DEA, escape. Some H₂S also gets liberated. A slipstream of DEA making counter current contact with the liberated gases over a rasching ring packing again absorbs the liberated H₂S. Four blind trays are provided for sufficient liquid residence time in the flash column.

The rich DEA is heated from 44°C to about 96°C by exchanging heat in 18-E-01 A/B with lean DEA before being sent to the DEA Regenerator (18-C-05).

DEA Regenerator (18-C-05)

DEA Regenerator (18-C-05) is a plate tower. 23 trays are provided. The first 20 trays are valve trays and the remaining baffle trays. The combined rich DEA stream enters the tower at the 20th tray and descends down.

Reflux water enters the column at the 23rd tray and descends down. This prevents DEA losses into the overhead and ensures complete removal of H₂S. The reboiled vapours from the bottom of the tower counter currently contact the rich DEA and strip it off H₂S. The reboiler (18-E-04) is kettle type and is steam heated. The overhead vapours from the regenerator are condensed in the condenser 18-E-03. The vapours are H₂S and water. Most of the water is condensed and the free H₂S is sent to sulphur recovery unit. To maintain the DEA concentration at 25% wt, some make up water is added in the reflux drum from where it will be pumped back to the regenerator by the reflux pump along with the reflux water. The lean DEA from regenerator bottom at 121°C is passed through 18-E-01 A/B and pumped through the lean DEA cooler (18-E-2) to the DEA absorbers at 38°C. A small slip stream of lean DEA is passed through charcoal filter 18-T-01 and Cartridge filter 18-T-02, 18-G-02 back to the suction of the pump 18-G-03 A/B. This filtering is required to remove periodical amine degradation products and scales due to corrosion. Corrosion inhibitor and Antifoam is added for trouble free operation of the unit. A storage tank is provided in the unit for storing DEA inventory. A sump is



also given for collecting DEA from all plant equipment. This will help to minimize DEA losses and also facilitate making of DEA solution for the plant.

Process Description

The unit has been designed to process FCC off gases cracked LPG and saturated LPG. The design is done for two cases namely Bombay High Crude and Iranian Heavy Crude for FCC off gases and cracked LPG. Design of the saturated LPG unit is done for Basrah Crude.

Diethanolamine (DEA) has been chosen as the absorbent since the LPG from FCC is likely to contain carbonyl sulphides and carbon disulphides. These compounds are highly reactive with mono ethanol amine (MEA) and degrade it. DEA, on the other hand, is less reactive with these compounds and hence is well suited as absorbent for this service.

Design Basis for Equipment

DEA Absorbers

The DEA Absorbers are designed for removing H_2S from sour streams. H_2S concentration in these sweet FCC off gases will be 1%. The maximum allowable H_2S in the treated LPG streams will be 100 ppm wt. Absorbers are operated at the bottom pressures of 12.5 kg/cm² abs., 19.0 kg/cm² abs and 19.2 kg/cm² respectively.

Circulation rate of lean DEA taken for design is one with a basis of 25% by wt. aqueous solution of DEA.

DEA Regenerator

The DEA Regenerator is designed to remove maximum H_2S from DEA. 20 valve trays are provided. 3 baffle plates are provided above the feed point to ensure complete removal of H_2S and prevent DEA loss into the overhead.

Special Design Considerations

To fight basic operating problems of amine system such as corrosion and foaming, following facilities have been provided.

- (a) Corrosion Inhibitor Injection: Injection facilities for corrosion inhibitor have been provided in overhead line of regenerator.
- (b) Antifoaming Agent Injection: To minimise foaming problem, injection of antifoaming agent has been provided with the Regenerator.
- (c) Filters.

Charcoal and Cartridge filters have been provided to remove fine particles particularly iron sulphide. In addition charcoal filter will remove the hydrocarbons, some of the degradation products and reaction products to improve amine solution quality.

Sour Water Stripper Unit - Process Design Specifications

Introduction

Sour water stripping unit is designed to strip primarily hydrogen sulphide (H_2S) from Sour Water stream emanating from FCC and CDU/VDU units. The unit is designed for a flow of $35m^3/hr$ of sour water.

The Stripper system shall be of reflux type. Apart from H_2S , significant quantity of other contaminants in the sour water viz. Ammonia (NH_3), Phenols and Cyanides are also stripped. However the design of the unit is based on H_2S removal only and the removal of other contaminants shall be taken as incidental.

The stripper-off-gases are routed to Crude Furnace/FCC Furnace/Flare. The stripped Water shall be pumped to the desalter unit partly and rest to WWTP.

Process Description

Sour water from FCC, CDU, VDU units enter the surge drum (18-C-31). Surge drum is a horizontal vessel and is provided with baffle plates, which divide the drum into three compartments. Sour water enters at the middle compartments where in phased separation takes place. Water the heavier phase, underflows into third compartment. Oil, the lighter phase, overflow from the top of the baffle to the first compartment from where it is drained periodically to OWS by operating the block valve. In addition a liquid seal is also provided to drain off in case the level goes beyond operating level. This compartment is provided with level gauge (18-LG-303) to facilitate periodic draining. The third compartment is provided with level gauge (18-LG-301) and high and low level alarms (18-LG-302) respectively. The flow control valve (18-FIC-301) / F-50 on the sour water feed line to the stripper is cascaded with the level controller on the surge drum. The vent on the surge drum is connected to exit gas line from the reflux drum to avoid escape of H_2S to atmosphere, which separates from the sour water in surge drum. But this line would be closed when sour gas would be routed to flare. Then the other vent should be opened, to vent the flashed H_2S to the atmosphere. Surge drum would then be operated under atmosphere pressure.

Service water (DM water) connection to surge drum is for the start up and also to meet the turndown ratio of the sour water, stripping unit. A pressure gauge (18-PG-301) is provided to keep a check on pressure inside the drum. Stripper feed pump (19-GG-31A & B) pumps the sour water from surge drum (18-C-31) to the stripping column (18-C-32) through heat exchangers (15-E-27A, B, C). The feed sour water is heated from $42^\circ C$ to $101^\circ C$ in the tube side of the exchangers (15-E-27A, B, C). Flow controller (18-FIC-301) F501, cascaded with level controller in surge drum, controls the flow of sour water feed to the stripper.

Sour water stripper (18-C-32) is a vertical column containing 20 number single pass valve trays. Normally the column operates at a pressure of 1.6 kg/cm^2 abs and temperature of $112^\circ C$ at top and at a pressure of 1.8 kg/cm^2 abs and



temperature of 115°C at bottom. When the sour gas is routed to flare, then column operates at a pressure of 2.1 kg/cm² abs and temp of 120°C at the top and at a pressure of 2.3 kg/cm² abs and temp of 124°C at the bottom. L.P. Steam at 3.5 kg/cm² abs for stripping, as well as for heating, is introduced at the bottom of the column controlled by a flow controller (18-FIC-302) F 502. A safety valve (18-PSV-301), a pressure gauge (18-PG-305) and a temperature indicator (18-TI-302) T 502 are provided at the top of the column. A level gauge (18-LG-304) with high low level alarms (18-LAH-305) L501 respectively, pressure gauge (18-PG-306), temperature gauge (18-TG-302) and temperature recorder (18-TR-303) T 503 are provided at the column bottom. Two sample draws off connections are provided at the 17th and 9th tray to study the performance of the stripper. This shall be an intermittent operation and the sample shall be drawn at the operating platforms by controlling the flow by a globe valve.

The sample connection is also provided at the discharge header of the pumps (18-G-31 A & B).

The overhead vapour from the top of the column passes to the reflux drum (18-C-33) 112°C, 95°C exchanger (18-E-31). Overhead vapour is cooled from 112°C to 95°C in the air-cooled exchanger where the major portion of water vapour condenses. A temperature indicator controller (18-TIC-301) T505 controls the airflow through cooler.

A temperature indicator (18-TI-304) T 504 is also provided at the outlet of the cooler. The condensed portion of the stripper overhead vapour from the cooler is separated at the vertical reflux drum operating normally at a pressure of 1.45 kg/cm² abs and a temperature of 95°C. When the sour gas would be routed to flare the operating pressure would be 1.95 kg/cm² abs. A level gauge (18-LG-306) and high low level alarms, (18-LAH-307) L 503, (18-LAL-307) L 503, are provided at the reflux drum bottom. The pressure in the reflux drum (18-C-33) and the stripping column (18-C-32) are controlled by the pressure controller (18-PG-307) and temp. Gauge (18-C-33) and the stripping column (18-C-32) are controlled by the pressure controller (18-PG-307) and temp. Gauge (18-TG-303) is provided at the top of the reflux drum. The exit gases from the reflux drum are sent to crude furnace. FCC furnace/Flare. Sour gas is to be sent to flare only when both the furnaces are not operating. It is envisaged that this would be a rare operation. At that time pressure in the reflux drum is increased to 1.95 kg/cm² abs. by the pressure control valve.

The condensate from the reflux drum (18-C-33) is pumped to the sour water feed line to the stripper by pumps (18-G-33 A&B). A flow controller (18-FIC-303) F 503 cascaded controls the flow of reflux stream with the level control at the reflux bottom. The liquid level at the stripper bottom is maintained by a level controller (18-LIC-301) L 501 which controls the flow of stripped water by a control valve (18-LV-301) located at the stripped water line.

The stripped water from bottom of the column and at a temp of 115°C is pumped to required pressure by pumps 18-G-32 A&B and sent to desalter at a maximum

flow rate of 25m³/hr. Rest is mixed to sour water coming from desalter. This is controlled by flow controller (18-FIC-304) F504 and control valve (18-FV-304).

Mixed sour water is cooled to 50°C by exchanging heat with cooling water in a heat exchanger (18-E-32A & B). One is kept as a spare. Cooled sour water is sent to WWTP.

Plant No. 19 - Propylene Recovery Unit

Plant - 19 consist of two sections namely

- A. Propylene Recovery unit
- B. PB/MEK Feed Preparation unit (Poly Butene-PB)

The purpose of propylene recovery unit is to recover TPA of 20% ISO-butane purity poly butane feed stock (PBFS) and TPA of 70% CIS-Transbutane Purity Methyl

Ethyl Ketone feed stock (MEKFS) from C4 stream, which comes out of propylene recovery unit.

Polybutene feed Stock is used as raw material in making polybutanes by M/s KSCL and BL and balance is returned to CPCL after separating ISO-butane.

MEKFS is used as raw material in making MEK by M/s CETEX petrochemicals.

The function of the plant is to recover Propylene from cracked LPG. Cracked LPG, one of the products of FCCU is basically a mixture of Propane, Propylene, Butane and Butylene. The unit first separates the stream into propane, propylene, mixture and then further separates the stream into propane and propylene. The aim is to make 17,000 TPA of 95% purity propylene.

Brief Description of the Process Flow

Cracked LPG from the FCCU after Merox Treating is received in the caustic settler 19-C-03 where entrained caustic is allowed to settle. Then the feed is passed through a sand filter to further remove any entrained material. From here under regulation of pressure controller 19-PIC-103 (17.3 kg) the LPG enters the feed surge drum 19-C-05. The drained caustic from 19-C-03 and the draining from 19-C-04 are routed to LPG Merox Unit for disposal there.

The LPG from the surge drum 19-C-05 is pumped by the pumps 19-G-1A/B through heat exchanger 19-E-01 to the 26th tray of the splitter 19-C-01. 19-C-01 has 50 trays. In the heat exchanger 19-E-01 the feed is exchanging heat with hot 19-C-01. 19-C-01 bottom then goes to pumps 19-G-8A/B which pumps the bottoms, under level controller LIC 103 which maintain 19-C-01 bottom level, to cooler 19-E-06 and then routed to LPG storage. FRC 101-flow controller controls the feed to 19-C-01. There is a reboiler 19-E-03, which is heated by LP steam to maintain 19-C-01 bottom temperature at the desired level (94°C). The O/H vapours, of 19-C-01 are routed to cooler 19-E-02 and the condensed liquid goes to 19-C-06-



reflux vessel. Pressure controller PRC - 102 on the H/C outlet of Condenser 19-E-02 maintains 19-C-01 pressure at the required level (15.5kg). Also a vapour line from 19-C-06 goes to the feed surge drum 19-C-05 under PIC - 101B control to maintain the required pressure on 19-C-05. There is a vapour line from 19-C-05 to Fuel gas header to release the excess pressure to fuel gas 10-C-05 pressure is maintained by PIC 101B & PIC - 101A.

The liquid collected in the reflux vessel 19-C-06 is pumped by Reflux pump 19-G-2A/B to the top of 19G-01 under FRC - 103 to maintain tower top temp. (42°C) as needed. Excess is routed to the Surge Drum 19-C-13 under FRC - 201 control (in cascade control with LIC 102 maintained level in reflux vessel 19C-06).

The propane-Propylene rich fraction collected in 19-C-13 is pumped by the pumps 19-G-7A/B to the splitter 19-C-02 under FRC - 205. It is also a cascade control with LIC-205 maintaining level in 19-C-13. The feed to 19-C-02 can enter on the 47th, 55th or 63rd trays. The splitter 19-C-02 has 90 trays. The bottoms are routed to a reboiler 19-E-05 for maintaining the desired temp. at the bottom of the tower (54°C). The re-boiler is heated by LP steam.

The bottom of 19-C-02 go to cooler 19-E-07 and then routed to the LPG storage under LIC-201 control. The splitter 19-C-02 bottom is maintained at 54°C and top is held at 40°. The overhead vapour rich in propylene is routed to [pressure is maintained by PIC-201 on] the H.C. outlet of 19-E-04 at (16.2kg) the desired level. A vapour line from 10-C-07 goes to 19-C-13-surge vessel to maintain the surge drum pressure by means.

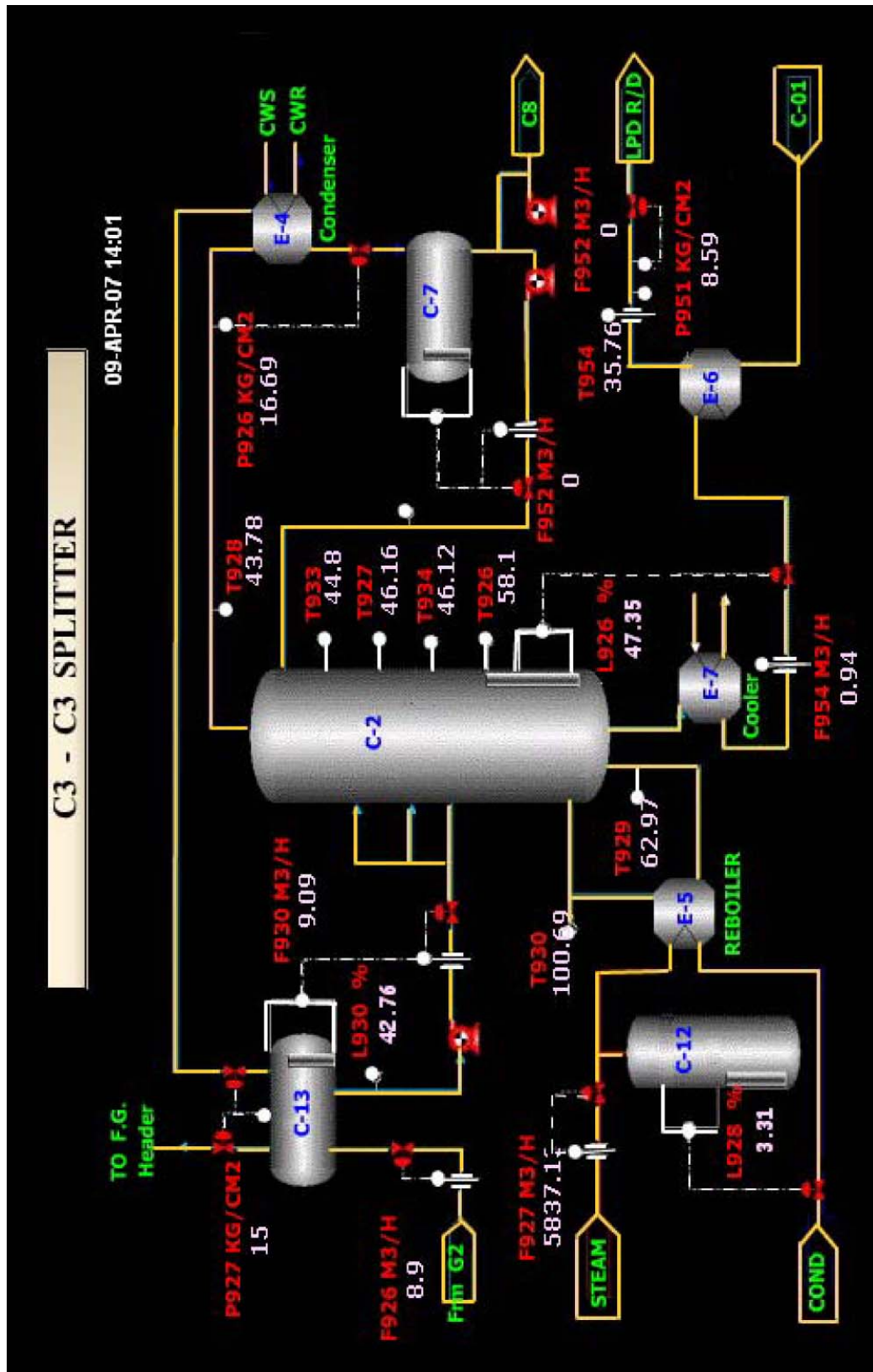
PV-203, controlled by PIC-202, excess pressure in the vessel is routed to fuel gas under 191PV-202.

The propylene collected in 19-C-07 is refluxed to the top of 19-C-02 by pumps 19-G-03. The reflux flow is controlled by FRC - 203 along with LIC-202 which maintain level in 19-C-07.

Excess propylene level in 19-C-07 is refluxed to the top of 19-C-02 by pumps 19-G-03. The reflux flow is controlled by FRC - 203 along with LIC-202 which maintains level in 19-C-07.

Pumps 19-G-04 to the carbonyl sulphide settler pump excess propylene level in 19-C-07. Enroute it mixes with caustic & MEA solutions kept circulating by 19-G-05. A mixing valve HIC-201 ensures that good mixing takes place between the chemical and propylene stream. Impurities like carbonyl sulphide, mercaptan and hydrogen sulphide are removed and settle down in the carbonyl sulphide settler 19-C-08 from where they are periodically released through the blow down. As and when needed, fresh caustic and MEA are added to the circulating chemical stream by pump 19-G-06.

The propylene coming out from the carbonyl sulphide drum 19-C-08 goes to the water wash vessel 19-C-09 where it is bubbled through DM water to remove left over traces of chemicals. The bottom of 19-C-09 is routed periodically to the blow down to remove accumulating sediments.





The propylene coming out of the water wash vessel is sent to the Coalescer 19-X-01 to remove traces of water. The water collected at the bottom is sent to the blow down. The final product propylene is routed to the propylene spheres under PRC-302, which maintain a backpressure on the chemicals treating section.

A product purity analyser ARC-201 is provided on the 19-G-04 discharged to monitor the quality of propylene. There are provisions to route the product propylene back to the feed surge drum 19-C-05 or 19-C-13 in case it is not on spec.

Brief Process Description

This description is to be read in conjunction with the Process Flow Diagram and Piping and instrumentation Diagrams.

The C4 feed stream obtained from Propylene Recovery Unit is received in a feed surge drum 19-C-33. This C4 feed stream is pumped by 19-G-32A/B under level / flow cascade control to upper section (tray No. 65) of BB Fractionator 19-C-31. A provision has been made to pump this stream to LPG pool in case of very high level in feed surge drum resulting due to shutdown of the BB Fractionator or in case of high flow rate of C4 feed stream from the Propylene Recovery Unit.

Pressure in Feed Surge Vessel 19-C-33 is controlled with the help of split range pressure controller at 6.1 kg/sq.cm (A). In case of over pressure, vapours from 19-C-33 are diverted to the fuel gas header and in case of under pressure overhead vapours from BB Fractionator 19-C-33.

In BB Fractionator 19-C-31, N-Butane rich and Butane / Isobutylene rich streams are separated. The Butane / Isobutylene stream go in vapour phase to BB overhead condenser 19-E-31 where they are condensed and collected as distillate in BB Distillate Drum 19-C-34. Part of this distillate is pumped by 19-G-33A/B as reflux under level/flow cascade control to top tray temperature of the BB Fractionator 19-C-31 and the balance distillate (PB Feed) which is also the feedstock for Polybutenes Plant is pumped out to the Battery Limit of Polybutene Plant using the same pumps 19-G-33A/B under flow controller through a totaliser.

Since the PB feed quantity has to increase in proportion to C4 feed stream throughout, the flow controller on PB feed line is cascaded with flow controller on C4 feed stream through a ratio relay.

The N-Butane stream containing certain heavies in C5 range is drawn off from column 19-C-31 bottom section in vapour phase and sent to Butane Side Rectifier 19-C-32.

In column 19-C-32 the heavies are stripped off from n-butane stream, which go in vapour phase to over head Butane condenser 19-E-32 where they are condensed and collected as distillate in Butane Drum 19-C-35. The condensation rate and thereby Butane Side Rectifier 19-C-32 pressure is controlled by regulating the distillate withdrawal rate based on 19-C-35 level. Part of this distillate is pumped

out by 19-G-34A/B as reflux to 19-C-32 via flow control and the balance distillate (MEK feed) is pumped out to intermediate butane storage bullets using same pumps. 20G 704/705 further transferred batch wise by 20G 501A/B to Battery Limit of the MEK plant through a flow totaliser after necessary quality control checks.

Butane Side Rectifier 19-C-32 bottom is fed to BB Reboiler 19-E-33.

BB Fractionator 19-C-31 bottoms, which are mainly C5s, are pumped out by 19-G-31 A/B to MOGAS POOL under column bottom level controller.

On Stream Analysers for both MEK feed and PB feed continuously monitor the quality, in case the material is off grade with respect to any of the components, the product is diverted automatically to LPG Pool directly in case of PB feed and recycled back to 19-C-33 in case of MEK feed.

BB Fractionator 19-C-31 is operated at about 7.7 kg/sq. cm (A) bottom pressure and 7.2 kg/sq.cm (A) top pressure, BB Fractionator 19-C-31 top pressure is controlled with the help of split and range pressure controller at 7.2 kg/sq.cm (A) located on the overhead vapour line of the BB Fractionator. The top temperature is about 57°C and the bottom temperature varies from about 82°C to. 89°C for the range of operations.

The heat required for the distillation in column 19-C-31 and a vertical thermosiphon reboiler 19-E-33 at the bottom, heated with low-pressure stream 4.5kg/sq.cm (A) supplies 19-C-32. Controlling the stream flow rate to the reboiler controls the heat input.

In order to maintain the desired composition of MEK feed stream, the 11th tray temperature is controlled at about 70°C by a temperature controller. This is achieved by controlling the reflux ratio to column 19-C-31 which in turn is indirectly controlled by varying the ratio of C4 feed stream to PB feed quantity. Temperature controller's signal is governing for ratio relay.

Plant No. 20 - Oil Movement & Storage

Oil Movements and Storage division of Chennai Petroleum Corporation Limited plays an important role in the operation of the refinery. It coordinates not only with all the sections of the refinery but with external agencies like IOC, BPC HPC and neighboring industries for the movement of our products.



General

The main function of this section is

1. Crude receipt from tankers and preparing them for unit feed.
2. Receiving of products from various units either in finished or semi finished conditions.
3. Blending of products to the required specification.
4. Supplying of intermediate products like LUBE BASE stocks, FCC feed stocks for further process in secondary units.
5. Dispatch of products to various TERMINALS of IOC etc.,
6. Supply of LPG & BITUMEN for cylinder filling and drum filling respectively.

Apart from these operations, OM & S has to take care of

1. Sewer system
2. Flare System
3. Slop System
4. Effluent Water Treatment System.

Detailed Description of OM & S Functions

Crude Receipt & Preparation

Chennai Petroleum Corporation Limited consists of two refining sections, Refinery I & Refinery II. Refinery I commissioned in 1969 process Persian Gulf (PG) crude and Refinery II commissioned in 1984, processes indigenous Bombay High (BH) crude and imported PG crude

The Crude tankers bringing either imported PG crude or BH crude berths at Bharathi Docks 1 & 3 at Madras Port Trust. Crude is discharged into CPCL storage tanks Via 30" pipeline running underground for about 13 kilometers between CPCL & Port Trust. Crude surveyors nominated by CPCL, takes care of unloading formalities at jetty. At CPCL end necessary calculations are done by taking dips in crude tanks before & after the receipt of crude by the operating staff along with the crude surveyors and final accounting done by oil accounts section.

Since crude is pumped from off-shore drilling, there is every possibility of water being carried along with crude and it has to be removed before feeding to process units. After giving proper setting time, water is drained out and tank will be kept ready for feeding.

Products Receipt

During the refining process CPCL produces various products, some of which are primary products and some are secondary products. They are

1. Liquefied Petroleum Gas (LPG). Stored in Bullets & Spheres.
2. Light Aromatic Naptha (LAN)
3. High Aromatic Naptha (HAN). These products are stored in floating Roof tanks
4. Superior Kerosene (SK)
5. Aviation Turbine Fuel (ATF)
6. High Speed Diesel (HSD)
7. Fuel Oil (FO) & Low Sulphur Heavy Stock (LSHS). These products are stored in cone roof tanks.
8. Lube Base Stocks
9. Bitumen

The secondary products are:

Hexane, Sulphur, Wax, CBFS and Sofo oil etc.,

Some of the products like SK. ATF.LAN.HAN.LPG.BITUMEN and HEXANE are collected directly from units in storage tanks and after proper sampling and getting certification from quality control lab, dispatched through marketing.

Products like HSD, MS, FO are not independent products and their components from various units are to be blended to make ON-SPEC products.

Lube Base Stocks (Distillates) are received from Refinery I Vacuum section and then rerouted to various process units before making them as Finished Lube Products. Those units are:

1. Extraction Units: Furfural extraction (Plant 8) & NMP Extraction (Plant 73)
2. Dewaxing Unit (Plant 9)
3. Lube Hydro Finished Unit (Plant 10)

To utilize excess vacuum distillates from Refinery I and Heavy Vacuum Gas Oil from Refinery II, they are stored in tank 353 in OM & S and given as cold feed to FCC unit to get more valuable products like Cr. Gasoline Cr. LPG TCO & CLO.



Product Blending

The components of Motor Spirit (MS) are reformat, Tr. Gasolene and Cr. Gasolene. HAN is also added to certain amount. The main critical test for MS is octane test. Depending upon the result TEL (Tetra Ethyl Lead) & Dye addition will be done.

The components for Diesel blending are:

1. Diesel R/D from unit 1 & 15
2. TCO from FCC unit
3. SK & LVGO from plant 15 and
4. Heavy Naptha from plant 1 & 15

All these components are received through a blending header and collected in storage tanks.

Fuel oil, also, is a blended product with components like HFO (vacuum residuum and reduced crude) wax, extract and foots oil. When the viscosity of the material is above 180 cst, a calculated amount of high flash diesel is added. The tank will be circulated and sampled to get ON-SPEC FUEL OIL.

Despatch of Products

The certified products like MS, SK, ATF, FO, NAPHTHA (LAN) and HAN are transferred through pipeline to IOC terminals, BPC & HPC terminals and for shipping also as per IOC's requirements. Normally HAN (High Aromatic Naptha) is given for export market only.

LPG is filled in cylinders and in bulk carriers.

BITUMEN is filled in drums and in road trucks.

As per Government's directive, CPCL is producing UNLEADED PETROL for the vehicles using catalytic converters.

We are aiming for the production of HSD (Diesel) with 0.2% Sulphur content as per the norms given by the Petroleum Ministry for the CPCL. CPCL is going to put up a DIESEL HYDRO-DESULPHURISATION UNIT during the next few years and production will be through around 2000.

Some of the neighboring industries were also receiving our products.

They are:

- | | | |
|---------------------------|---|---------------------------|
| Tamil Nadu Petro Products | - | SK, Fuel Oil |
| Madras Fertilisers | - | LPG, Fuel Oil Naptha |
| Balmer & Lawrie | - | Propylene |
| Cetex | - | MEK feed stock (Butylene) |

These transfers are done by pipeline and tank measurements will be witnessed by their representatives

Sewer System

During refinery operation, there is every possibility of oil getting drained into sewer due to draining and through any equipment for maintenance, during sampling, pump gland leaks etc., These oil and water from units are collected through a under ground sewer system in Sewer Basin (for Ref I) and in OWS (Ref II).

In the Sewer basin, oil & water are separated. The oil is pumped to dry slop tank and water pumped to API separator. Traces of oil that is being carried along with water is separated and skimmed by hand operated skimmers. The skimmed oil is pumped back to slop tanks for further processing. Water is taken to effluent treatment plant for treating to MINAS-Standards. From effluents treatment plant water is pumped to OXIDATION POND or to GUARD POND, which serves as water reservoir for fire fighting system.

From OWS, also, oil and water are separated. Oil pumped to slop tank and water is taken to ETP II for further treatment to MINAS Standard.

Flare System: A Flare system is a means for safe disposal of flammable, corrosive vapour discharged from process units to less objectionable compounds by combustion. Flaring is the only method for safe disposal of Hydrocarbons heavier than air by burning.

There are two flare stacks one on the north side of the refinery for Ref II and Sulphur Plants and the other one on the south for Ref.I and Lube Expansion Projects.

Ref.II flare consists of knock out pot, a seal pot and Molecular Seal at the top of the stack.

Ref.I & LEB flare consists not only a knockout drum & seal drum, but also a Gas Seal provision instead of Molecular Seal at the top of the Stack.

A FLAME GENERATOR provision is given at the ground level where Air & Gas were mixed in proper proportion and ignited. The flame travels to the top to the flare tip and ignites the pilot's gas. Water level is maintained in the SEAL POT to avoid any flash back.

The storage tanks are classified into three categories.

1. Cone-roof tanks for low volatile products like FO, LUBE & ASPHALT.
2. Floating-Roof tanks for high volatile like products like MS, NAPHTHA, SK, HSD Etc.
3. Pressure vessels for products which are stored under pressure like LPG. Propane, etc.,



Since, each drop, all saved and accounted helps to the profitability of the refinery, OIL MOVEMENTS & STORAGE section plays an important role in this organization.

UTILITIES SYSTEM

Utilities are the common requirements that are necessary for the refining of crude oil. These common items that are necessary for the proper operation of the refinery are required in such quantities that, it is economical to supply them from a central source rather than provide separate facilities for individual plant. The items that come under utilities are steam, electricity, cooling water, boiler feed water, fuels and compressed air facilities.

Water supply to the refinery comes from the wells located at 14 to 20 km. away from the Refinery. These wells are operated by the Tamil Nadu State Water Supply Department. Adequate facilities to ensure uninterrupted water supply are provided at the site. We have three water reservoirs of capacity 6.6 million gallons, 2.5 million gallons and 0.1 million gallons.

Boiler Feed Water Treating, Steam and Power Generation

A schematic representation of the treated water system and steam is shown in the accompanying fig. To prevent scale formation in the tubes of the steam generating equipment, the feed water must be treated. Salts of silica, magnesium, calcium and iron in the water form scales. Oxygen, carbon-di-oxide and hydrogen sulphide are corrosive gases. The raw water from the fresh water pond containing hardness of about 210 ppm is first softened in a cold lime softener to about 115 ppm. Water is then passed through a set of cationic softeners. The ion exchange softeners are filled with resins. The cationic softener removes calcium, magnesium and sodium ions by exchanging place with Hydrogen ion. The bed is regenerated periodically by dilute hydrochloric acid. The anionic softener removes sulphate, chlorate and silica ions by replacing the hydrogen in the anionic resin. The bed is regenerated with a weak solution of sodium hydroxide.

The demineralised water is used as feed water to the main boilers and waste heat boilers in the units.

The steam to the units is supplied by means of common headers running through the plants and to the tank farm. There are three systems of steam supply (a) the high pressure steam under a pressure of 31.5 kg per Sq. cm (b) the medium pressure steam at a pressure of 10.5 kg. per sq. cm (c) the low pressure steam of 3.5 kg. per sq.cm. at a pressure of.

Fuel System

The fuel supply for the heaters, in the process plants and boilers comes from the fuel gas system and the fuel oil system. The fuel gas is primarily produced from the vapour recovery unit and the desulphurisers. The fuel oil is supplied from a tank of 790 cubic meters capacity by means of a pump. The pump discharges

into a header that runs to all the heaters and boilers to maintain a steady pressure and an even flow a circulation line returns part of the fuel oil back to the tank. The fuel oil tank is filled with the visbreaker tar from Plant 6.

Fire Water System

Water for fire fighting requirement is supplied from the oxidation basin of the effluent water from the API separator. The system has one low-pressure pump and two pumps of higher capacity and greater discharge pressure. Normally the smaller pump will be kept running to maintain the firewater header under pressure and also to supply minor requirements from the header. For fire fighting, the higher capacity pumps can be started remotely from the control room. The fire water lines are run around the process units and throughout the refinery and is provided with hydrants and monitors at suitable locations.

Drinking Water

The drinking water is served through a 2" line from the discharge of the raw water pumps at the fresh water pond. The water is properly chlorinated and filtered and served by a separate header running to places where needed.

Compressed Air Facilities

The compressed air required for the operation of the instruments and for driving the pneumatic tools is supplied by two compressors. (Totally 5 compressors are available). Normally 2 compressors are required for meeting the consumption. The air supplied to the instruments is dried through air driers to remove moisture. The air driers are filled with desiccants to absorb the moisture and regenerated periodically. A back pressure controller is provided in the service air line to preferentially supply the instrument air requirement, in case, the total air requirement is higher than the input.



CHENNAI PETROLEUM CORPORATION LIMITED

8. LUBE EXPANSION BLOCK

I. Introduction

Purpose of this expansion block is to recover 40% oil present in vacuum residue

There are 3 process plants and 3 utilities

Plant - 71 Propane deasphalting Unit (PDAU)

Plant - 72 Propane Recovery Unit (PRU)

Plant - 73 Normal - Methyl pyrrolidone N-methyl-e-pyrrolidone)

Utilities

Plant - 81 Cooling tower III

Plant - 82 Inert gas compressor system

Plant - 84 Instrument air compressor system

Plant No. 71 - Propane Deasphalting Unit

Feed : Crude I Vacuum residue (150 pef)

Feed Rate : 40-50 m³/hr.

Product
DAO (De Asphalted oil)
15 m³/hr

Asphalt-35 m³/hr

Solvent used : Propane

Feed Solvent ratio : 1:5.5

PDA unit is divided into the following section

1. Feed & Solvent section
2. Extraction section
3. DAO section
4. Asphalt Section
5. Propane Recovery Section



It (PDA) produces De-Asphalted oil (DAO) from VR obtained from crude unit vacuum section.

Capacity of the Unit : 20 percent of crude processed (Except Indian Crude)

Capital Cost :

Selection of Solvent : Based on selectivity of the solvent as well as requirement

Alternate solvents available

1. Ethane
2. Butane
3. Pentane
4. Hexane
5. Ether

Suitable for our requirements

1. Ethane
2. Propane
3. Butane

Why Propane is Selected?

- Compared to butane, the extraction of oils is good
- Compared to ethane, the system operating pressures are low
- Availability of propane in St. LPG.

Due to these reasons propane is selected as a solvent. Purpose of the Unit to extract the heavy oil present in vacuum Residue, for the purpose of manufacturing LOBS.

Specification of Products

De Asphalted oil	Viscosity	32 cst
	Flash Point	310°C
	CCR	2.5
	Asphalt (Pitch Pen	o

Allowable loss of solvent 500 Kg/hr.

Process Description

The Vacuum Residue received from IC 19 is fed to extractor, where it is mixed with propane. Due to solubility and settling, heavy oil present in the vacuum residue mixes with the propane and is taken out from the extractor top as DAO. The settled asphalt with some amount of propane is taken out from the extractor bottom as Asphalt mix. To induce the extraction process, the temperatures of the extractor is maintained by steam coils and propane temperature.

Recovery of propane from DAO & Asphalt Mix.

Asphalt Section

To recover the propane in Asphalt mix, the mix is heated at furnace upto 230°C. Then the asphalt mix is fed to FLASH DRUM, where propane is flashed due to high temperature and difference in pressure. Then the Asphalt with traces of propane goes to Asphalt stripper, where stripping steam strips propane. The bottom of the Asphalt stripper goes as product PITCH with pen of 0 to 10.

The top of Asphalt flash drum is condensed and collected at propane surge drum. To utilize the heat in the vapour, it pre heats the DAO mix fed to HP flash Tower.

The top of Asphalt stripper goes along with vapours from DAO stripper top to compressor suction, through a condenser and knock out drum.

DAO Mix System

The DAO mix from extractor top is heated by the overhead vapours of DAO, MP Flash Drum and goes to DAO LP FLASH DRUM.

In DAO LP Flash drum, the propane in the mix is flashed by high temperature and low pressure. 50% of propane in the mix is recovered from this column. From the drum bottom, the DAO mix is pumped to HP Flash Drum through DAO mix propane Vapour Exchanger and DAO mix / LP steam Heater at 145°C temperature.

The DAO mix is flashed by higher temperature and the flashing is controlled by the top pressure in DAO mix HP Flash tower. Again propane is stripped by vapour from Reboiler Return Stream.

30% of propane is recovered from this stage of flashing.

The bottom of the DAO mix HP, Flash Drum, the DAO mix goes after flash drum where the propane is flashed under much low pressure than earlier stages. 18% of propane is recovered from this stage. To recover the remaining 2% of propane in DAO mix, the DAO mix goes to DAO stripper, where the propane is stripped by MP steam. The bottom of DAO stripper goes is as product after cooled down by heating the DAO mix.

Propane System

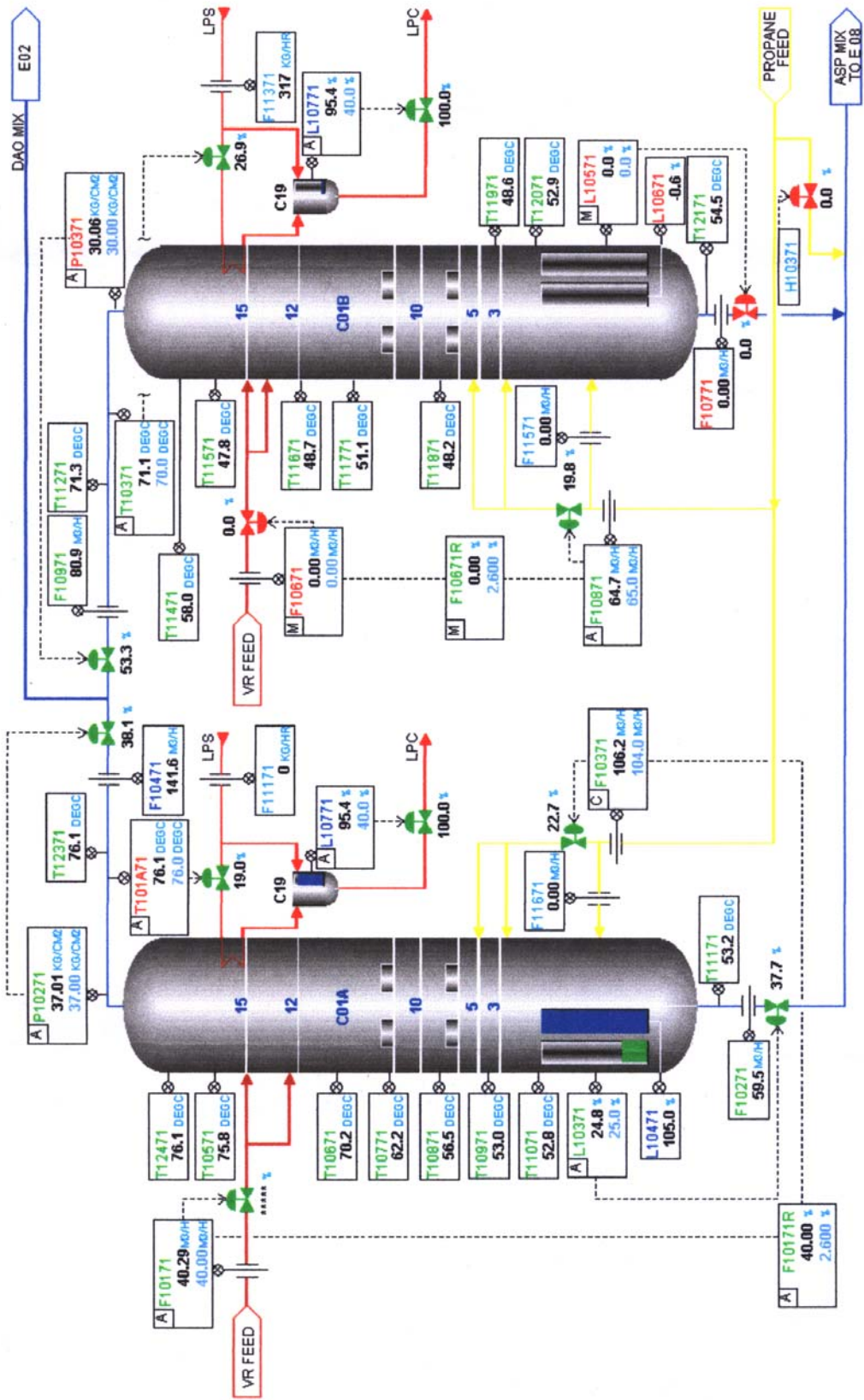
Propane from flash drum overheads are condensed by condensers and get collected at propane surge drum, from where it is taken for recirculation.

The propane and water vapours from stripper overheads are cooled down to condense the water vapours. The condensed water vapours are knocked out in knock out drum and propane vapour goes to compressor suction. In the compressor, the propane is compressed and then condensed in the condenser.

The condensed propane goes to propane surge drum through the coalescer to separate water from propane.



Plant - 71 - PDA - EXTRACTOR SYSTEM



Highlights of the Unit

1. Handling both the lightest component and heaviest component of crude oil.
2. Using only HT motors (except for DAO rundown and auxilliary purposes)
3. Only unit having helical coil arrangement furnace.
4. Special trays like Loure type used in this unit.

Concluding Part

The product DAO can also be used as feed to FCCU. In case of using DAO for FCCU feed, the CCR value may be allowed upto 10 and DAO yield may go upto 50 to 60% instead of 30%.

Plant No. 72 - Propane Recovery Unit

Erection done by	:	SPIC SMO
Process design & Detail Engineering	:	Engineers India Ltd.,
Purpose of the Unit	:	To separate Propane from straight run liquified petroleum gases (SR LPG).

Process Description

SRLPG from MREP is taken to an accumulator, from the accumulator it is pumped to depropaniser through pre heater.

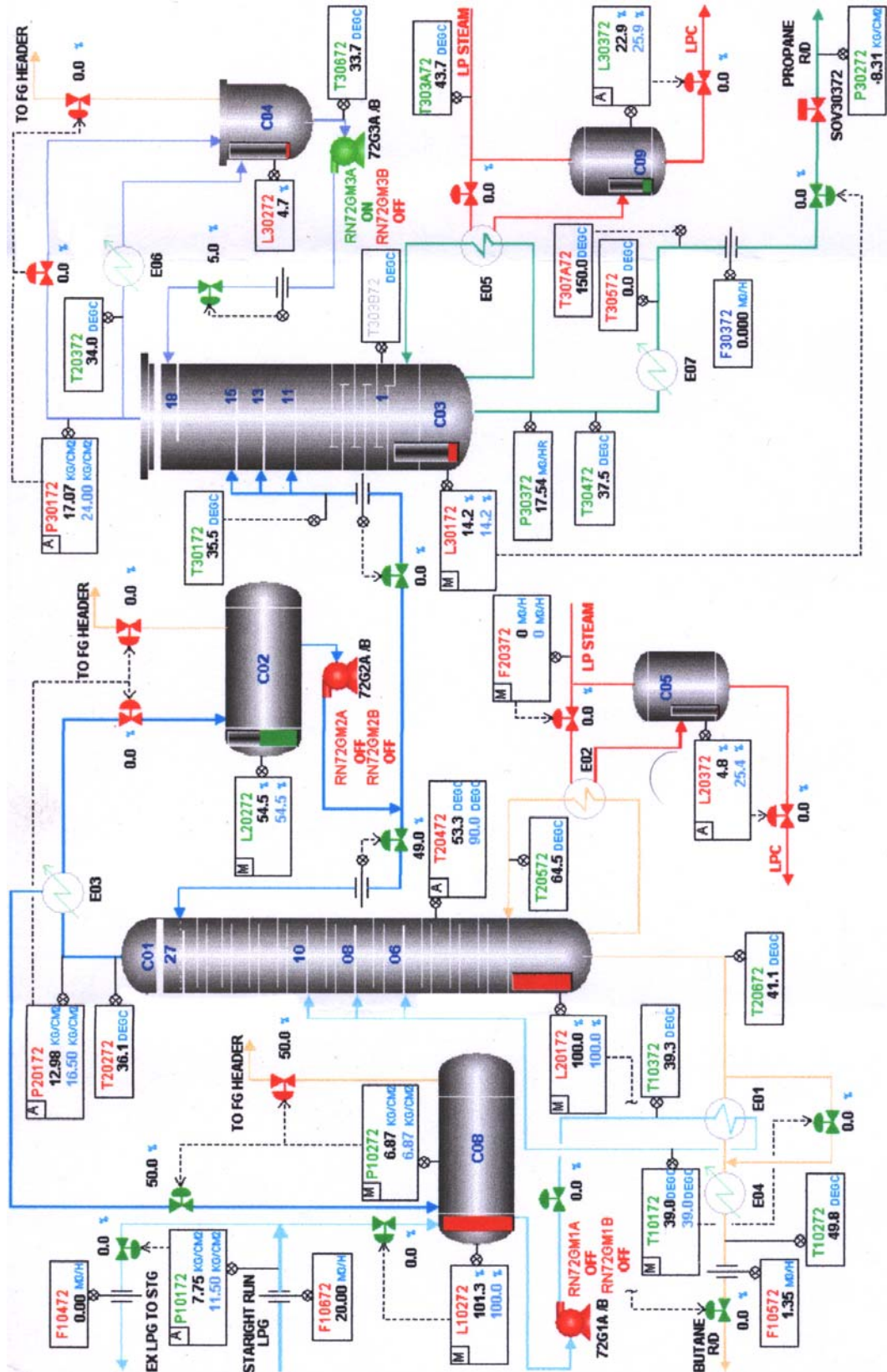
In depropaniser, the propane and ethane are separated by simple distillation, with reboiler stripping. The propane and ethane from the top is condensed and collected at an accumulator. The bottom of Depropaniser goes to storage (LPG) through exchanger & Cooler. The purity of the propane + ethane is controlled by reflux from propane + Ethane the liquid is pumped to De-Ethanizer.

In De-Ethanizer, the same process in Depropaniser separates the ethane. The ethane vapour from top is condensed and collected at an accumulator for the purpose of Reflux to control the purity of propane and excess ethane goes to Fuel gas header. From the bottom of De-Ethanizer, the product propane goes to sphere through cooler.

Product Specification	:	Propane	:	95%
		Butane + Ethane	:	5%



Plant - 72 - PRU - OVERVIEW



Name of the Unit: Instrument Air System

Unit Number	:	84
Erection done by	:	Lloyds Steel
Capacity	:	1200 Nm ³ /hr @ 7.0 kg/cm ²
Purpose of the unit	:	To compress the atmospheric air and dry it, to make it useful for actuating instruments.

Process Description

Air from the atmosphere is compressed and stored in storage after cooled down to atmospheric temperature.

The condensed moisture is drained from storage.

Compressed air from storage then goes to drier. In Drier the air is heated and used for Regenerating the Drier and then goes through condenser. The moisture from Regeneration is condensed and drained from cooler. In drier the moisture remaining in the air is absorbed by Activated Alumina Balls and Dry Air leaves the drier to header. After 6 Hrs. of drying, the Drier goes to heating mode. Heating model will be for a period of 6 Hrs. Then it goes to cooling mode and changed over to drying after 2 Hrs. Sequential change over are done by Programmable Logic Controllers.

Name of the Unit	:	Cooling Tower III
Unit Number	:	81
Erection done by	:	M/s. Baharpur Cooling Towers & Bridge & Roof Ltd
Process Design & Detail Engineering	:	Engineers India Ltd.,
Capacity	:	2700 NM ³ /Hr in each cell cooling range + 12 ^o C

Purpose of the Unit

To supply cooling water requirements to MEK dewaxing unit (Plant 9), propane de asphaltting unit (Plant 71), propane Recovery unit (Plant 72), NMP extraction unit it (Plant 73), Nitrogen unit (Plant 82) and Instrument Air unit (Plant 84)

Process Description

The circulating water from pump is discharged to units and returned to suction through units, Cooling tower decks cooling tower, bay and sump is treated with phosphate to prevent the system from corrosion.



To control the microbiological matters, chlorine is charged to the system continuously.

The loss of water due to evaporation, spills and drift is made by raw water.

Name of the Unit	:	Nitrogen Unit
Unit Number	:	82
Erection done by	:	Kinetics Technology India Limited
Capacity	:	600 Nm ³ /hr.
Purpose of the unit	:	To produce nitrogen for refineries inert gas requirement
Process description	:	

Drying of Air

Air from the atmosphere is compressed to 8.0 ksc and cooled. The condensed moisture is drained from KOD. The moisture less air goes to drier filled with the Alumina balls (Activated). Every 5 min. once, the air drier is changed over to spare one and regenerated by dry air.

Adsorption of Oxygen

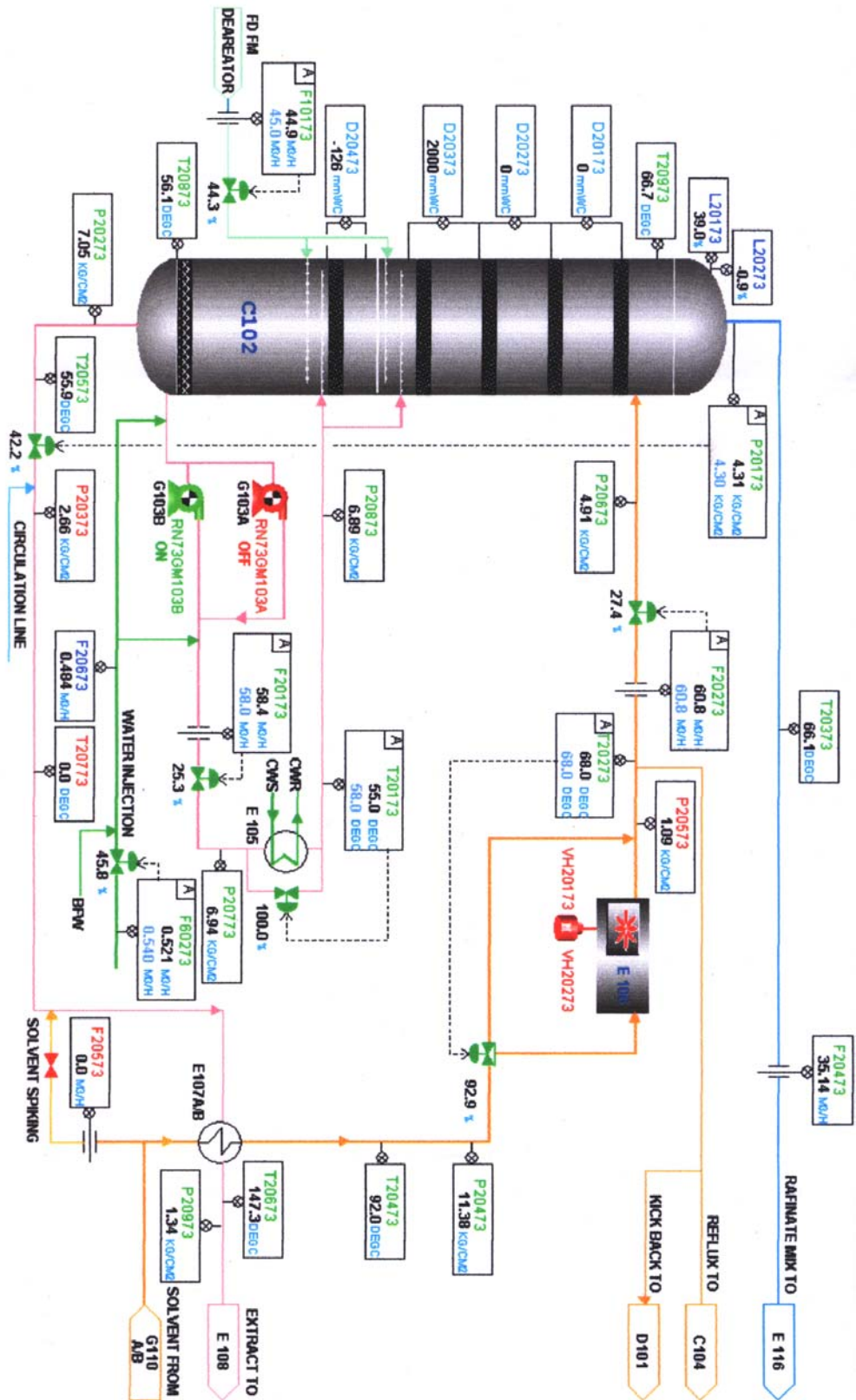
The dry air from drier passes through the CARBON MOLECULAR SIEVES, (CMS), where the oxygen molecules are trapped in the CMS and NITROGEN goes out of ADSORBER. Every 1 min once, the ADSORBER is change over to spare one and regenerated by Depressing the ADSORBER. From ADSORBER OUTLET the NITROGEN GOES TO REFINARY HEADER.

SEQUENTIAL changes are made by "Programmable Logic Controllers"

Plant - 73 - NMP Extraction Unit

Name of the Unit	:	NMP EXTRACTION UNIT
Unit Number	:	73
Erection done by	:	BRIDGE AND ROOF (EIL)
Detail Engineering	:	ENGINEERS INDIA LTD
Process Design	:	TEXACO INC. USA.
Unit started on	:	19th MAY 1994
Capacity	:	170,00 MT PER YEAR
Solvent	:	N-METHYL PYROLIDONE
Purpose of the unit	:	To process the available distillate and upgrade it to meet the requirements and demands of HVI grade products.

Plant - 73 NMP - NMPEU EXTRACTION SECTION





HOW VI of the distillate is improved?

By extracting AROMATICS from the distillates

What will be the base VI of Distillate & Rundown Product?

VI of Distillate is from +55 to +60

VI of products is from +90 to + 105

What are the other solvents available for Extraction?

Furfural and Phenol.

Why NMP is selected?

Is thermal stability?

What Feeds can be processed in NMPEU?

Inter Neutral, Heavy Neutral, Bright Neutral and Heavy Vacuum Gas Oil.

Process Description

Deaerator System

In this section, the feed is prepared by removing oxygen (dissolved) in the feed to avoid oxidizing solvent NMP.

Extraction System

In this section, the feed is treated with NMP solvent to remove the AROMATICS from the feed in the Extraction Column.

Raffinate Recovery System

In this section, the raffinate mix from the Extractor is Pre-heated by the rundown Raffinate and goes to furnace. In the furnace the Raffinate mix is heated up to 270°C and leaves to Raffinate mix vacuum flash tower.

In Raffinate Vacuum Flash Tower, the Solvent in the Raffinate mix is flashed and Raffinate mix with traces of solvent goes to raffinate Vacuum stripper through a "U Loop". In Raffinate Vacuum stripper, the solvent in the Raffinate is stripped by super heated LP steam stripper bottom is pumped to storage through Raffinate mix/Raffinate Exchanger and Raffinate cooler.

Extract Recovery System

In this section, Extract mix from Extractor bottom is pre-heated and the solvent in the Extract mix is flashed in a low-pressure flash tower.

20% of solvent from the Extract mix is recovered in low-pressure flash tower.

From low-pressure flash tower bottom the extract mix goes to medium pressure flash Tower through exchanger condenser. In medium pressure flash tower the solvent in Extract mix is flashed and the extract mix with reduced solvent content goes to furnace.

30% of solvent from the Extract mix is recovered in Medium pressure flash tower.

In Furnace the Extract mix is heated upto 290°C and then goes to High Pressure Flash Tower. In High Pressure Flash Tower, the solvent in Extract mix is partially vaporised by temperature and the Extract mix with reduced solvent content goes to Extract Vacuum Flash

Tower from the bottom of the Tower.

35% of solvent from the Extract mix is recovered in High Pressure flash tower.

In Extract vacuum Flash tower, the Extract mix from High Pressure Flash Tower is flashed under vacuum and bottom of the Extract vacuum Flash Tower goes to Extract Vacuum stripper through 'U' loop (with Exchanger).

10 to 12% of solvent from the Extract mix is recovered in Extract Vacuum Flash Tower.

In Extract Vacuum stripper the remaining solvent is stripped of by Low Pressure super heated Steam and from the bottom Extract goes to storage through feed/ Extract exchanger and cooler.

Plant No. 74 - Hexane Plant

Introduction

Hexane Plant is designed to produce 25000 MT of Food grade Hexane - per annum.

Food Grade Hexane is used as a solvent in various applications. Some of the important areas of application are as follows:

1. Used as a solvent for edible oil extraction from oil seeds and cakes like cotton seed cake, ground nuts cake, linseed cake, rapseed cake, soybean and rice husk.
2. Used as a reaction medium for various polymerisation reactions.
3. Used as a component of quick drying rubber cement and of certain two solvent system adhesives in which it is used to control viscosity and to reduce drying time.
4. Used to prepare certain lacquers and printing inks where a quick drying diluent is required in the solvent system.

The Hexane is essentially a 63-70°C cut naphtha but has stringent specifications. The ISI specification of Food Grade Hexane is given in the write up.



Due to the stringent aromatic specifications, Middle East Crudes are ideal to produce this product. This is due to lower aromatic content of naphtha resulting in higher yields and lower operating cost. Bombay High Naphtha could also be used to produce hexane but yields are low and operating costs are higher.

The Process

The food grade hexane could be produced by the following processing schemes.

1. Conventional distillation followed by two stage oleum treating.
2. Conventional distillation followed by liquid-liquid extraction using sulfolane as a solvent.

The earlier scheme involves handling of oleum, which is highly hazardous and toxic. It also presents corrosion and pollution problems giving rise to hazardous effluents. Hence the process presents operation problems and is unsafe.

The second scheme involves extraction of aromatics with a solvent "Sulfolane" which can be recycled back after flashing in a column. The concentration of aromatics in the hexane product is also considerably less in the later scheme. Indigenous technology developed by M/s EIL in collaboration with M/s. IIP is available for Aromatics Extraction using sulfalone solvent.

Further alternate schemes like absorption process with activated carbon or silica gel after conventional distillation are also found to be unattractive due to economic consideration like higher quantitative requirement of activated carbon and silica gel. Also monitoring of aromatic content in Food Grade Hexane will pose problems.

The Process Description: (Refer to attached schematics)

There are two sections

1. Production of raw hexane in fractionation section
2. Extraction section

The feed to the plant is light straight run gasoline fraction produced in vapour recovery unit. The overheads from crude unit are fed to a stabiliser and the stabiliser bottoms IBP-130°C cut fed to the splitter. In the splitter, we split it into two fractions, namely IBP-90°C cut and 90⁰-130⁰C. The IBP-90°C cut is called LSRG and is the feed to hexane unit.

The LSRG is treated for sulphur removal first in a caustic scrubber and then in a mercox extractor in a conventional mercox system. The mercox treated LSRG is fed to the Hexane Plant.

The feed is pumped into a feed surge drum from where it is sent to a splitter 'I'. This has a reboiler with MP steam as heating medium. In this splitter IBP-63°C cut is removed as an overhead product and is sent to storage into naphtha / gasoline pool as necessary. The bottoms from splitter -I" which is a 63-90°C cut

is routed to splitter-II which has a reboiler with HP steam as heating medium. Here the 64-70°C cut which is called raw hexane is removed as a top product. The bottoms, with 70-90°C cut is routed to naphtha gasoline pool as necessary after necessary cooling.

The 63-70°C, which is raw hexane, is sent to extraction section where aromatics are extracted with "Sulfolane" solvent.

The Second section of the plant is called "Extraction section". The raw hexane is pumped to the bottom of the extraction tower and meets the descending solvent sulfolane. The column contains 40 Nos. Sieve trays, which provide contact surface for liquid extraction. The sulfolane, which has affinity or solubility for aromatics, is taken into solution as extract and exits the tower at bottom. The top stream from the extraction tower, which is hexane, lean in aromatics, is removed as raffinate.

The raffinate is routed to a water wash column where traces of sulfolane is removed by water and is pumped to storage as Food Grade Hexane from where it is sent to loading. The specifications of Food Grade Hexane is given below



Requirements for Hexane, Food Grade

Sl.No.	Characteristics	Requirement Appendix	Method of Test Refer to	(P :) of IS: 1448*
1	2	3	4	5
i)	Distillation:			P: 18 Method B
	a) Initial boiling point, °C, Min.	63		
	b) Dry point, °C, Max.	70		
	c) Temperature range of final 10 Percent, deg C, Max	2		
ii)	Composition:			
	a) Aromatics, percent by volume, max,	1.0	-	P: 63
	b) Saturates, percent by volume, Min.	98.5	-	P: 23
iii)	Density at 25.0°C, Max	0.687 A	-	
iv)	Colour (Saybolt), Min.	+30	-	P: 14
v)	Sulphur content, ppm, Max.	75	B	-
vi)	Corrosion, copper strip, 3 hours at 50°C, Max. 1Method C	1	-	P: 15
vii)	Doctor test	Negative	-	P: 19
viii)	Lead, g/l, Max.	0.0005	C	
ix)	Phosphates ppm Max.	20		P:54
x)	Chlorides (as Cl), ppm, Max.	20	D	
XI)	Bromine number, Max.	1		P: 44
xii)	Non/Volatile residue, g/100 ml, Max.	0.001	E	-
xiii)	Reaction of non-volatile residue	To pass the test		F -

(* Methods of test for petroleum and its products)

The aromatics rich solvent sulfolane is flashed in a solvent recovery column under vacuum after heat exchange. The aromatics in the solvent is flashed off and is condensed in the condenser and routed to storage into gasoline pool. The bottom from solvent recovery column, which is sulfolane lean in aromatics, is recycled back to the extract column.

Water from water wash column is fed partly at the bottom of solvent recovery column after heating in an exchanger and partly to the top of the column as reflux.

A small slipstream of recovered sulfolane from the bottom of solvent recovery column is routed to a solvent regenerator where amine is added to remove degraded solvent periodically. Here the degraded solvent is removed from the

bottom of the regenerator and purified solvent from top of the regenerator. The purified solvent is routed to solvent recovery column bottom. To make up for sulfolane solvent losses, solvent is periodically pumped into the solvent recovery column from storage.

In order to minimise solvent losses from the system in the event of safety valve discharge, a vent tank, is provided to knockout entrained solvent. This solvent along with drain of solvent-bearing equipment and lines is routed to the solvent sump from where it is pumped back into the system.

Hexane Storage and Loading System

The Hexane product from the unit meeting food grade specifications is routed to 2 Nos. storage tanks of 1000 KI capacity each where it is stored. The food grade hexane is loaded into tankers by loading pumps. Two Nos. truck loading points are planned in the loading gantry.

Necessary facilities for filling the food grade hexane in drums are also being installed to meet some customer requirement.

CPCL is the first refinery to use liquid-liquid extraction process for hexane production. M/s. IIP Dehra Dun and EIL, New Delhi has jointly developed this. The HPCL, Bombay uses extractive distillation.

Plant No. 75 - Sulphur Recovery Unit

The purpose of this Plant is to recover Sulphur as much as possible from feed gas (H_2S) from Plant-12 consisting of 88% H_2S .

Feed gas from Plant-12 comes to feed drum (75C1) where water to liquid hydro carbon are recombined and passed to main chamber (75F-1) where limited oxygen is supplied to burn. Here thermal conversion at $1150^\circ C$ takes place.

When acid gas is burned at $115^\circ C$. (it is an exothermic reaction) in 75F-1 and passed to waste heat boiler (75E-1), Sulphur Vapours from 75F-1 are condensed in 75E-1 and drained to sulphur pit. MP steam is produced in 75E-1.

The remaining unburned gas from 75E-1 through a demister pad is heated upto $290^\circ C$. in Line Burner-I (75F-1) and sent to Catalytic convertor - A where Alumina based Catalyst is used. Sulphur is further recovered and sent to condenser - A from where sulphur is drained to pit. The balance gas from condenser-A is heated again in Line Burner-II (75F-2) and passed to converter - B at $205^\circ C$. Sulphur is recovered further and condensed in condensor-B and drained to pit

The gases from the condenser-B are passed through a coaliser where entrained sulphur is recovered and drained to pit. The gases from coaliser are heated in Incinerator Burner (75F-4) and go to Catalytic Incinerator reactor (75C-6) where the residual H_2S is converted to SO_2 and let out in the vent stack 75X-2.



The Sulphur plant should be on line always to reduce pollution of atmosphere by SO₂ and, energy conservation by recovery of sulphur and production of steam in waste heat boilers.

Plant No. 76 - Naphtha reformer

Design and Objective of the Plant

The unit was designed to supply the make up hydrogen required for the diesel hydro desulphurisation plant. The design capacity of the unit is 22500 Nm³/hr of hydrogen (99.9 vol%) based on naphtha feed. The naphtha feed containing a sulphur content of 1000ppm wt. is desulphurised in the naphtha predesulphurisation section to 10ppm.wt max. before usage in the reformer section with an intermediate storage outside the units battery limit. The sweet naphtha from the storage area is returned to the battery limit or used directly from the predesulfurisation section R/D. The sweet naphtha is again desulphurised to 0.1ppm wt. max before fed in to the reformer section. The turndown for the hydrogen plant will be about 35% of the design capacity of 7875 Nm³ hydrogen.

The production of hydrogen based on steam reforming of naphtha and purification by pressure swing adsorption, consists of the following major steps and systems:

- Naphtha pre-desulphurisation
- Naphtha vaporization and final desulphurisation
- Steam-naphtha reforming
- HT shift conversion
- Process gas heat recovery and cooling
- Pressure Swing Adsorption (PSA)
- Steam system
- Fuel system
- Effluent system

Through Put Details and Yield Pattern

Maximum Reformer feed rate	7112 kg /hr
Minimum Reformer feed rate (35 %)	2489.2 kg/hr
Maximum Product Hydrogen	22488 Nm ³ / hr
Minimum Product Hydrogen	7875 Nm ³ / hr

Feed and Product Specifications

Feed Specifications

Liquid Feeds :

Type	Design	ALT.1	ALT.2	ALT.3
Source of crude	Arabmix (75% light & 25% heavy)			
Feedstock type	HPCL(V) naphtha	LSRN	LAN	LSRG
Specific Gravity (15/15)	0.73	0.7292	0.6915	0.6734
ASTM Distillation (D) 86°C				
IBP	45	95.0	46.0	40
30 vol.% over	77	107.0	71.0	60
50 vol% over	92	112.0	86.0	71
70 vol% over	108	117.0	101.0	85
90 vol% over	125	125.0	123.0	106
FBP	160	141.0	141.0	118
Pone Analysis (wt.vol%) Method	Vol%	Vol%	Vol%	Vol%
Total paraffins	54-76	73.0	56-75	86.8
Naphthenes	19-27	17.0	18-28	8.7
Aromatics	< 10	10.0	10.0	2.5
Sulphur Content (wt.ppm)	1000	1000	1000	1000
Chlorides (wt.ppm)	4	4	4	4
C/H Ratio (wt.)	5.7			
RVP psi	6.0-11.0			



Operating conditions:	Pressure (kg/cm ² g)	Temperature(°C)	Flow kg/h)
Minimum		-	
Normal	7.0	40	
Maximum		-	
Mechanical design	13.0	70	
Nitrogen (wt. ppm)	4		
Arsenic (wt. ppb)	10		
Lead (wt. ppb)	100		
Nickel (wt. ppb)	100		
Vanadium (wt. ppb)	100		
Copper (wt.ppb)	20		

Specifications of wild naphtha

Components	Kg/mol/hr
H ₂ S	< 1.00 ppm
Cut 40-136	3.57
Cut 136-142	4.16
Cut 142-145	3.61
Cut 145-147	3.32
Cut 147-149	3.06
Cut 149-150	1.44
Cut 150-201	2.28
Cut 201-226	0.05
Organic sulphur	< 10 ppm
Total (kg/mol/hr)	21.49
Total (kg/hr)	2651.0

Final boiling point: 184°C

Product Specifications

Gaseous Products

Type		Design
Composition		(vol%)
Hydrogen		99.9
Methane		Balance
Nitrogen	max. ppm V	< 50
Carbon Monoxide/Carbon Dioxide	max. ppm V	< 20
Chlorides	max. ppm V	Nil
Water	max. ppm V	< 50
Total		100.0

Operating Conditions:

	Pressure (kg/cm ² g)	Temperature (°C)	Flow (Nm ³ /h)
Minimum	-	-	7875
Normal	22.0	40	22500
Maximum	-	-	-
Mechanical design	26.0	80	

**Catalyst / Adsorbents Details**

	Specification						Service
	App. To Eq. E.O.R.	P over Catalyst bar	Volume m ³	Bulk Density kg/m ³	Size mm	Vessel/ Reactor Item No.	
HR-306 C1-2	-	2.0	3.2	780	1.2	76C-01	Hydro-desulfurisation
ICI 41-6	-	0.2	4.7	720	3	76C-11	Hydro-desulfurisation
ICI 32-4	-	0.1	2 x2.1	1160	2.8 – 4.75	76C-12A/B	Desulfurisation
ICI 59-3	-	0.1	2 x1.7	900	2 – 4.75	76C-12A/B	Dechlorination
ICI 46-3	-13	1.2	4.6	900	17 x 14 x 4	76F-11	Reforming
ICI 46-6	-13	1.2	4.6	850	17 x 14 x 4	76F-11	Reforming
ICI 71-5	24	0.2	11.8	1240	9 x 4.7	76C-13	CO-shift
PSA	-	0.7				76X-12	H ₂ purification

Brief Process Description**A. Naphtha Pre-Desulphurisation Unit**

The sour naphtha (1000 ppm wt.) is pumped and mixed with the recycle hydrogen gas before entering the reactor feed preheat exchangers. The mixed feed is vapourised against the reactor effluent and super heated in the Naphtha super heater to the reaction temperature.

The super heated naphtha–recycle gas mixture is fed to Hydro–Desulphuriser-I, where hydrogenation of sulphur and chloride compounds takes place. The reactor effluent is cooled in the sour naphtha vapouriser and naphtha condenser. The condensed naphtha is separated from the recycle gas and fed to the naphtha stripper. The naphtha containing dissolved H₂S is stripped (heat is supplied by a steam heated reboiler). The overhead gases containing H₂S is cooled and the condensed overhead liquid is fed as reflux to the stripper. The H₂S rich gas is sent to the amine treating section. The hot stripped naphtha (containing 10 ppm wt. Sulphur) is cooled against the stripper feed and by cooling water and sent to storage.

B. Reformer Unit

Sweet naphtha (sulphur- 10 ppm wt.) mixed with recycle hydrogen is vapourised in the naphtha vapouriser by HT shift Reactor process gas effluent. The mixture

is superheated in the convection coil and sent to Hydro- desulphuriser –II , where sulphur compounds are converted to H_2S . The organic chlorine converted in the CoMox reactor is absorbed in the Chloride guard and the H_2S is absorbed in the ZnO beds.

The desulphurised gas is mixed with superheated process steam in the appropriate ratio and further heated in the mixed feed super heater, then distributed over the catalyst tubes in the radiant section of Reformer, where hydrocarbons are converted to hydrogen, carbon monoxide and carbon dioxide in the presence of steam over the nickel based catalyst.

The reformer effluent is cooled in the Process gas Bolier, there by generating steam. Most of the carbon monoxide reacts with steam and gets converted to hydrogen plus carbon dioxide over an iron oxide/chromium oxide catalyst in the HT shift convertor. The outlet gas stream is cooled by vapourising the naphtha feed and in BFW Pre-heater, further cooled by pre-heating DM water. The condensate formed is separated in the Process condensate separator –I, then water cooled and the condensate is separated in the Process condensate separator –II. The cooled process gas is sent to Pressure Swing Adsorption Unit.

C. Pressure Swing Adsorption Unit (PSA)

In the PSA unit, hydrogen is recovered from the process gas by adsorption of methane, carbon monoxide, carbon dioxide and water vapour on molecular sieves and activated carbon based adsorbents.

Under the high pressure of the feed , the adsorbent attracts the impurities and as a consequence a pure hydrogen product stream exits from the adsorber. Subsequently the adsorbent is regenerated by bringing the adsorber down to the lowest pressure. The adsorbent releases the impurities which are disposed off as purge gas.

Plant No. 77 - Diesel Hydro Desulphurisation

Design and Objective of the Plant

The unit was designed to desulphurise by catalytic hydrogenation of diesel oil from various origins- straight run or cracked products with a sulphur content ranging from 1.86%wt. using hydrogen from Hydrogen unit (Plant 76).

The feed is a mixture of products containing:

Unsaturated components (diolefins, olefins)

Aromatics

Sulphur compounds

Nitrogen compounds



In addition to the deep desulfurisation, the diolefins and olefins will be saturated and a denitrification will occur. The choice of catalysts and operating conditions is made in order to avoid an important hydrogenation of the aromatics.

Now, owing to the addition of a second reactor in series, the unit is able to produce treated diesel oil with a maximum sulphur content of 500 ppm wt. max.

THROUGH PUT DETAILS AND YIELD PATTERN.

Maximum feed rate	263.8 (for 0.853 density) m ³ /hr
Minimum reactor feed	160 m ³ /hr
Product yield	98.81 %

Feed Specifications

Feed Stock Components

Characteristics		GO PT 1 PG	GO PT 15 PG	LVGO PT 15 PG	SPO blend PG/BH	LCO FCCU PG	HCO FCCU PG	Blended Feed Stock
From		Persian gulf Direct	Persian gulf Direct	Persian gulf Direct	Blend direct	Persian gulf Direct	Persian gulf Direct	
Flow rate	T/y (10 ³) T/h	680 85	384 48	168 21	144 18	136 17	288 36	1800 225
Properties Sp. Gravity	-	0.8532	0.8572	0.8929	0.9016	0.8055	0.9205	0.869
Total Sulphur	% wt	1.5	1.5	2.6	2.1	0.4	3.3	186
Nitrogen	Ppm wt.	(300)	(300)	(300)	(400)	(700)	(700)	402
Bromine No.	g/100g	<2	<2	<2	<2	46	22	8
Metals	Ppm wt							<1
Cetane index	ASTM D976	52.6	52.0	44.9	45.0	22.3	31.9	48.8
Flash Point °C								(36)
Aniline Point	°C	75.5	74.5	71.0	72.0	(28.5)	(28.5)	

Diesel Product

	Diesel Product			
	Case 1 SOR	Case 1 EOR	Case 2 SOR	Case 2 EOR
Flow rate (kg/hr)	220376	219195	219363	217424
Sp.Gr	0.852	0.852	0.848	0.848
ASTM D86 50% (°C)	306	308	308	309
90% (°C)	378	378	378	378
Sulphur (wt.ppm)	2000 max	2000 max	500 max	500 max
Water content (wt.ppm)	<135	<135	<135	<135
Nitrogen (wt.ppm)	285 max	285 max	185 max	185 max
Flash Point (°C)	At least identical to feed			
Cetane Index (ASTM D976)	52.9	52.9	54.1	54.1
Bromine number (g / 100g)	<1	<1	<1	<1
Pour point (°C)	Same as feed			
Colour	Same as feed			

**Stabilised Naphtha:**

	Stabilised Naphtha Product			
	Case 1 SOR	Case 1 EOR	Case 2 SOR	Case 2 EOR
Flow rate (kg/hr)	1864	2651	2574	3755
Sp.Gr	0.763	0.766	0.758	0.763
Sulphur (wt.ppm)	<10	<10	<10	<10
H ₂ S content (wt.ppm)	<10	<10	<10	<10
Nitrogen (wt.ppm)	<5	<5	<5	<5
Cetane Index (ASTM D976)	156	159	154	163

Rich amine to Regeneration Unit:

	Rich Amine			
	Case 1 SOR	Case 1 EOR	Case 2 SOR	Case 2 EOR
Composition				
H ₂	0.0	0.0	0.0	0.0
H ₂ S	2.6	2.6	2.6	2.6
H ₂ O	73.0	73.0	73.0	73.0
DEA	24.4	24.4	24.4	24.4
HC	24.4	24.4	24.4	24.4
Flow rate (kg / hr)	166038	165335	177442	177482

Catalysts Specifications**1. HR 945**

HR 945 is a NiMo type catalyst to be used in front of hydrotreatment catalysts to protect them against deactivation by unsaturated compounds generally contained in cracked stocks.

HR 945 special design limits the polymerization of olefins and diolefins and thus, the coke formation, even at low hydrogen partial pressure. The resulting advantage is longer cycle operation. It can be used in combination with any HR series catalysts.

Typical properties:

Nickel and molybdenum oxides on very high purity alumina Spheres

Diameter	2 to 4 mm
Surface area	140 m ² /g
Total pore volume	0.4 cm ³ /g
Tapped bulk density	0.88 kg/lit

2. HR-348

HR-348 is a NiMo type catalyst used for the hydrodesulfurization, dearomatization and hydrodenitrication of hydrocarbon cuts including gasolines, naphthas, kerosenses, gas-oils and vacuum gas-oils.

By its specific design, HR-348 presents a very high hydro desulfurization activity and stability which makes it attractive for deep desulfurization. HR-348 can be used in association with NiMo type catalysts where specific objectives are required.

Typical properties:

Nickel and molybdenum oxides on very high purity alumina

Cylindrical extrudes :

Diameter	1.2 mm
Nickel (NiO)	3.3 wt %
Molybdenum (MoO ₃)	16.5 wt %
Total pore volume	0.42 cm ³ /g
Stock loading density	0.72 kg/lit
Dense loading density	0.82kg/lit
Bulk crushing strength	1.49 Mpa

Brief Process Description

The function of the High Speed Diesel hydro de sulphurizer (DHDS) is to desulphurize by catalytic hydrogenation of the raw diesel oil to produce a diesel product meeting a 500 ppm max, sulphur specification.

The total raw diesel oil product is received from the OM&S tanks and cracked feed from FCC unit. Makeup hydrogen to DHDS plant is fed from the Steam-Naphtha catalytic reformer unit (Plant 76) to satisfy consumption requirements. The raw diesel oil feed is combined with makeup plus recycle H₂, the mixed charge



is exchanged against reactor effluent, and then heated to the required reaction temperature in the Charge heater. Reaction is carried out in a Quenched multi bed reactors, down flow type, reactor effluent is exchanged first against feed. Then with stripper feed and is finally cooled by air fin coolers, trim coolers and put to the cold separator. The separator gas is treated for H₂S removal by absorption in 25% DEA solution, then gas goes to the suction KOD of 77K2 for recycle to mix with feed. The cold separator liquid which goes as stripper feed is preheated by heat exchange against stripper bottom product and sent to the stripper 77C14. The stripping medium is M.P superheated steam from the convection section of heater 77F1. The overhead from stripper and from the stabilizer are joined. The combined stream is cooled and partially condensed in 77EM9A/B and 77E10 sent to the OVHD accumulator where sour water, liquid hydrocarbon by product, and stripper off gas are separated. A part of stripper reflux is going as a feed to the naphtha stabilizer where the stabilizer feed is reboiled against the stripper bottom product in a reboiler and cooled in a cooler then sent to storage. The High Speed Diesel Oil product is stripped essentially to the flash point atleast identical to the feed diesel. Entrained water is removed in the coalescer 77C17 and in the dryer system 77C18 to meet a product specification of less than 135 wt.ppm and the finished product goes to storage.

Plant No. 78 - DHDS-Sulphur Recovery Unit

The plant has been designed to convert all sulphur compounds present in the acid gas feed into elemental liquid sulphur.

The nominal (design) plant capacity is 86.7 MTPD of recovered sulphur.

Each Train of the SRU has been designed for a capacity of 52 MTPD of recovered sulphur.

The turndown on feed flow for each Train is 30 % with design feed composition.

The turndown on H₂S content at design feed gas rate is 50 % of H₂S in feed. Balance to be adjusted with CO₂.

The guaranteed sulphur recovery efficiency is 99 %.

The on-stream factor is 8000 hours/year or 330 days/year.

The H₂S content in the flue gas leaving the incinerator is less than 10-PPM vol.

Design Basis

Feeds and Effluents Characteristics:

Acid gas from Amine Regeneration Unit (ARU)

Composition

- H ₂ S	3831.9	kg/h
- H ₂ O	117.2	kg/h
- H ₂	1.5	kg/h
- C ₂ H ₆	36.4	kg/h
Mass flow at design:	3987	kg/h
Molar flow at design:	121.17	kmol/h
Molecular weight:	32.9	kg/kmol
Temperature at BL:	45	°C
Pressure at BL:	0.8	kg/cm ² g

Sour gas from Sour Water Stripping Unit (SWS)

Composition

- H ₂ S	42.7	kg/h
- H ₂ O	1.8	kg/h
Mass flow at design:	44.5	kg/h
Molar flow at design:	1.356	kmol/h
Molecular weight:	33.82	kg/kmol
Temperature at BL:	84	°C
Pressure at BL:	0.8	kg/cm ² g

NH₃ Rich gas from Sour Water Stripping Unit (SWS)

Composition

- H ₂ S	2.2	kg/h
- NH ₃	22.5	kg/h
- H ₂ O	13.9	kg/h
Mass flow at design:	38.6	kg/h
Molar flow at design:	2.161	kmol/h
Molecular weight:	17.86	kg/kmol
Temperature at B.L.:	90	°C
Pressure at B.L.:	0.8	kg/cm ² g
Sulphur product		
Colour:	Bright yellow (in solid state)	
Purity:	99.9% wt. Dry basis	
H ₂ S content:	10-ppm wt. (in solid sulphur product)	

Incinerator Flue Gas

**Composition**

- SO ₂	0.822	kmol/h
- H ₂ O	225,985	kmol/h
- O ₂	14.840	kmol/h
- N ₂	471.851	kmol/h
- CO ₂	22.612	kmol/h
- H ₂ S	10	ppmv max
- O ₂	2 vol.% min	
Molar flow at design:	786.108	kmol/h
Mass flow at design:	18812	kg/h
Molecular weight:	25.45	kg/kmol
Temperature:	774	°C (at Incinerator outlet)

General Process Description

The process design of Sulphur Recovery Unit (SRU) is based on the MCRC (Maximum Clause Recovery Concept) technology, which is licensed by M/s DELTA HUDSON ENGINEERING LIMITED. It is a combination of Clause process and the extension of Clause reaction up to the temperature at which the product sulphur starts condensing on the catalyst itself. Extension of Claus reaction up to sulphur dew point enhances sulphur recoveries beyond 99%. As sulphur condensation on the catalyst lead to its activity reduction, hence regeneration of such portion of the catalyst bed is required.

The SRU consists of two parallel trains with number of common facilities. The Design capacity of SRU is 86.7 T/d of product sulphur.

Clause Section

Each Train of the SRU consists of one thermal reactor (main combustion chamber) and four catalytic converters. The first catalytic converter is a conventional Claus Converter while the last three are MCRC converters that alternate between a sub-dew point mode and a regeneration mode. With such a four-converter MCRC configuration, sulphur recovery higher than 99 % is achievable. The salient feature of the MCRC process is that regeneration takes place on line.

The acid gas from Amine Regeneration Unit (ARU), H₂S-rich gas from the 1st stage Sour Water Stripping Unit (SWS) and NH₃-rich gas from the 2nd stage SW Stripping Unit are fed to the SRU to convert H₂S contained in the feed gas to elemental sulphur.

The acid gas is preheated to 89°C using LP Steam. The preheated Acid Gas is fed in to the MCC furnace in each Train, which is already heated to 1100°C with Fuel Gas or vaporized LPG. Air flow to MCRC is adjusted to get H₂S to SO₂ ratio at 2:1 and to be maintained

The major part of heat generated in the furnace is recovered by producing MP steam in the Waste Heat Boiler (WHB). The vapours leaving the waste heat boiler is further cooled to 191°C in Sulphur Condenser-1 to remove elemental sulphur from the gas mixture producing LP Steam. The gas from condenser is reheated in Line Burner using a slip stream of ARU gas from KO Drum as fuel. The preheated vapours from the Line Burner at 273°C further flows to the 1st Claus converter where additional conversion to sulphur takes place. The reaction gases from the converter is cooled in a Reheat Gas Exchanger and Sulphur Condenser 2. The produced sulphur condenses and flows to sulphur pit via sulphur lock.

MCRC Section

In the MCRC Section there are three catalytic stages along with respective Sulphur Condensers. Operating conditions in two of the three MCRC reactors are aimed in such way that the adsorption of produced sulphur takes place on part of the catalyst present in the reactor. Such adsorption of sulphur on the catalyst is achieved by maintaining temperature in the corresponding reactors lower than the sulphur dew point. Removal of sulphur from product gases of Claus reaction by the way of adsorption on catalyst to increases the sulphur conversion by moving Claus reaction in forward direction. Additionally lower reaction temperature also helps thermodynamic equilibrium to shift towards higher sulphur equilibrium concentrations. Thus overall higher sulphur conversions are easily achieved by reducing the operating temperature in the catalytic reactors. However deposition of sulphur on active site of catalyst prohibits its further activity. To regenerate the activity of such catalyst sites, sulphur present on such site needs to be desorbed. Desorption of sulphur is carried out by operating the reactors at temperature higher than sulphur vaporization temperature. Need of operating sulphur loaded catalyst at higher temperature is met by operating one of the three MCRC reactors at any given time under regeneration mode.

Each MCRC reactor operates in sequence under the following operating modes:

- Regeneration mode

- Sub dew point mode-1

- Sub dew point mode-2

As mentioned above, MCRC Section includes the three sub-dew point sulphur converters. These converters alternate between a sub-dew point mode of operation and a regeneration mode. For the purpose of this discussion, the converter operating in the regeneration mode is said to be in the sulphur converter II position, and the converters operating in the sub-dew point mode are said to be in the No. III and No. IV positions.

The reheated gas from the Claus section enters the No. II position sulphur converter and regenerates the catalyst bed by vaporizing sulphur which was previously adsorbed onto the catalyst when this converter occupied the No. III and IV positions. Claus conversion continues in this converter even while it is



regenerating. The exit gas is cooled to remove elemental sulphur and flows directly (without reheat) to the No. III positions sulphur condenser

That is operating in sub-dew point mode. The gas mixture from converter flows to condenser and the balance gas from condenser directly flow to No. IV position sulphur converter where additional sulphur is produced and adsorbed onto the catalyst.

The adsorbed sulphur onto the catalyst is removed from same converter in the next cycle. Approximately every 24 hours one of the three MCRC converters is changed from sub-dew point mode to regeneration mode and another one is changed from regeneration mode to sub-dew point mode.

The cycle time may be changed depending on the loading of sulphur onto the catalyst bed during actual operation.

Thermal Incinerator

In thermal incinerator the combustible components in the process gas from the last condenser of MCRC section and vent gas from sulphur pit are thermally oxidized at high temperature. Thermal Incinerator is common for two-train sulphur recovery. There are two tail gas streams from two trains and one vent gas stream from sulphur pit; those are oxidized in incinerator.

The thermal Incinerator converts almost all the H_2S and NH_3 in the tail gas so that the H_2S in stack gases has concentration lower than 10 ppm (volume). The exit gas temperature must be kept at $750^{\circ}C$

Ratio controller controls the proper ratio of air to fuel. Oxygen analyser controls the oxygen content of flue gases. Excess air Operation is essential for complete incineration of process gases. Oxygen content of stack gases is set at 2 % vol. The flue gases are vented to atmosphere through the vent stack. Shutdown of thermal incinerator due to any reason will activate the shut down of SRU.

Sulphur Storage

Sulphur produced is routed to R/D line through specially designed sulphur lock and collected in the sulphur pit. Sulphur pit is provided with degassing facility and LP steam heating coil to keep the sulphur in molten condition. 78 G5A/B sulphur pump pumps the product sulphur to pellatisation unit where the molten sulphur is pellatised and stored in silos through bucket conveyor. Sulphur yard is also provided to produce lump sulphur by pumping the molten sulphur to yard by cooling with cooling water.

9. REFINERY-III

Refinery –III consists of the following major units

- CDU/VDU
- Visbreaker Unit
- Catalytic Reforming Unit
- Once Through Hydrocracker Unit
- Sulphur Recovery Unit

The CDU/VDU unit has the design capacity to process 3.0 MMTPA of crude oil. The design feed stocks for the unit are Bombay high (BH) and Arab mix (AM) (50:50 light and heavy) crude. The unit is designed based on 8000 on stream hours per annum.

As part of the expansion, the Shell Soaker Visbreaker Unit of 1.15 MMTPA capacity is installed for residue upgradation.

The Shell Soaker Visbreaker Unit is intended to process vacuum residue (from Refinery I, II and III) and propane de-asphalt pitch. The primary objectives of the unit are to reduce the production of residual fuel oil by reducing both the quantity and viscosity of residual oils and to increase the yields of net distillates.

Naphtha Hydrotreating Process

The purpose of the "Naphtha Hydrotreater" process is to produce a clean hydrotreated reformer feedstock sufficiently low in contaminants such as sulphur, nitrogen, water, halogens, diolefins, olefins, arsenic and metals so as not to affect the performance of the downstream catalytic reaction sections of the Reforming unit and very low in benzene precursors to meet the specifications of 1 vol % of benzene in reformate.

Catalytic Reforming Unit

The "Reforming process" is a catalytic process to convert low octane naphtha's into higher octane reformate products for gasoline blending. Naphtha feeds to this process include straight run naphtha direct from crude distillation or naphtha boiling range products from other processes such as hydrocrackers, cokers etc. A valuable by-product from this process is the hydrogen released from the aromatic producing reactions. This hydrogen is necessary to support the upstream hydrotreating unit which is necessary to prepare the naphtha feed to be reformed and other hydrogen consumers within the refinery complex.



Plant No. 201 - CDU/VDU

The CDU/VDU unit has the design capacity to process 3.0 MMTPA of crude oil. The design feed stocks for the unit are Bombay high (BH) and Arab mix (AM) (50:50 light and heavy) crude. The unit is designed based on 8000 on stream hours per annum.

The CDU is designed to produce Off gas, Liquefied Petroleum Gas (LPG), Light Naphtha, Heavy Naphtha, Kerosene, Reformer feed Naphtha, Diesel and Atmospheric residue.

The VDU is designed to process atmospheric residue from CDU and to produce Vacuum Diesel, Light Vacuum Gas Oil (LVGO), Heavy Vacuum Gas Oil (HVGO) and Vacuum Residue (VR). CDU/VDU are designed to be operated in conjunction and independent operation of either of these units is not considered.

The CDU also comprises the Naphtha stabiliser and Naphtha splitter sections.

Fuel gas from CDU is routed to the Amine Treating unit. LPG from CDU is routed to the LPG Amine Treating Unit. Light naphtha (LSRG) from Naphtha splitter can be routed to Naphtha pool or to Hydrogen/ GT feed tanks. Provision has also been given in the unit to route hot LSRG directly to Hydrogen unit. LSRN from Naphtha splitter can be routed hot to the Catalytic Reformer unit. Cold LSRN can be routed to CRU/ GT unit feed tanks or to Naphtha pool. Provision has also been given in the unit to route stabilized Naphtha directly to Naphtha storage or Hydrogen / GT unit feed tanks in case of shut down of Naphtha splitter. Blending of heavy Naphtha to Diesel pool is done in the OSBL at Diesel blending header. Kerosene is routed to the Kerosene Merox unit. Flexibility has also been provided to route Kerosene to Diesel blending / DHDS feed tank.

Diesel can be routed to blending / DHDS feed tanks. Various components of Diesel pool within unit battery limit include Gas oil draw from Atmospheric column, EGO product (second gas oil draw) from Atmospheric column, Vacuum diesel and Slop oil from hot well.

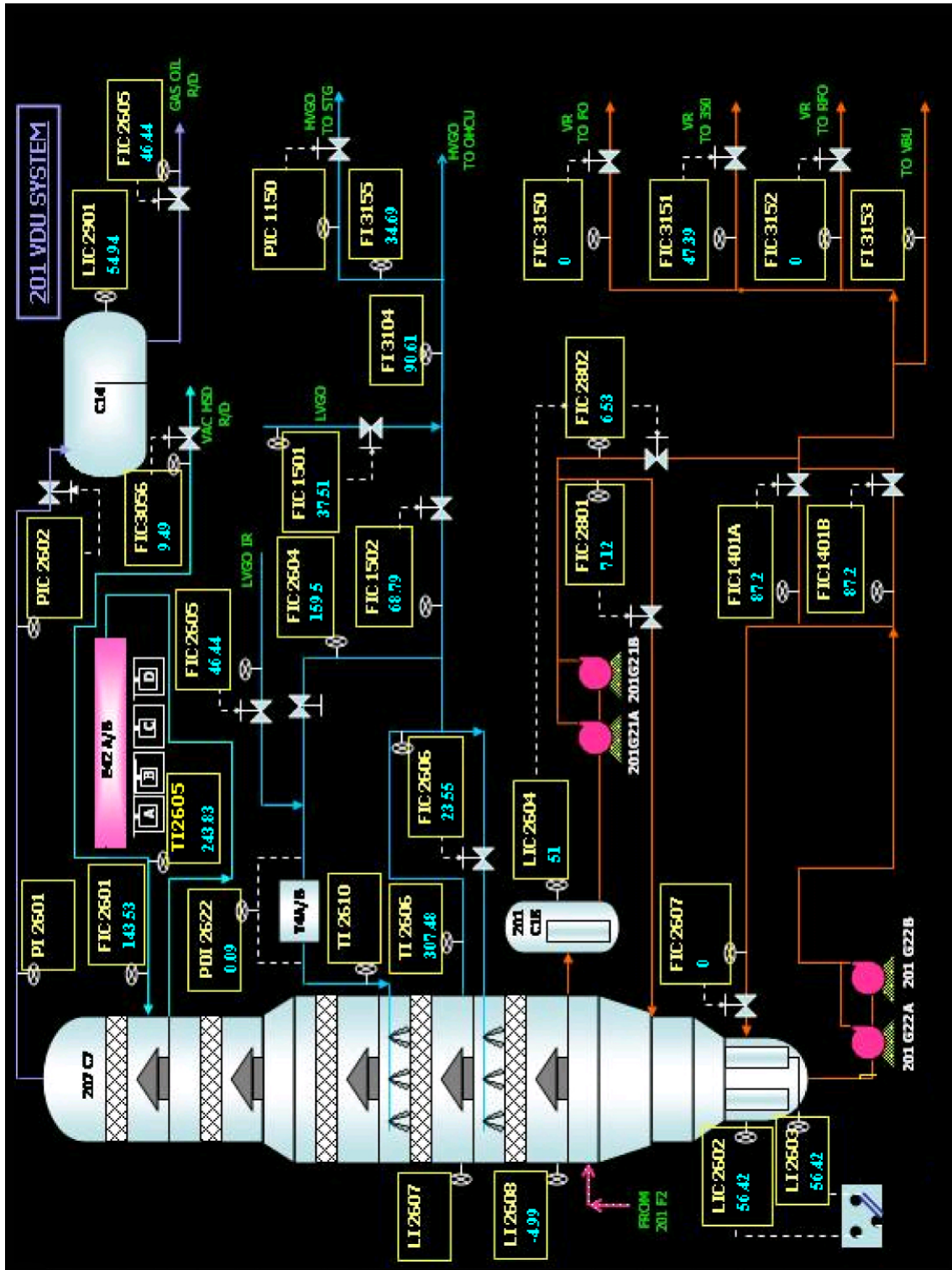
Hot vacuum residue (VR) is normally routed to Visbreaker unit. Provision has been given to route cold VR to VR storage (VBU feed tanks) or to Internal fuel oil. Cold VR can also be routed to Fuel oil storage after addition of cutter stock within unit battery limit (if required).

Hot VGO can be directly routed to Hydrocracker unit. Cold VGO can either be routed to Hydrocracker feed tanks or to Tank-353. The Extra Gas Oil product can also be routed along with VGO.

The units are designed for a turndown capacity of 50%.

Plant No. 202 - LPG Merox Unit

The Merox block of Chennai Petroleum Corporation Limited, Refinery III Expansion project consists of two different units to take care of two different feedstock's



namely Straight Run LPG (SR.LPG) and Kerosene. Both units are designed to handle feed stocks based on crude oil of 50% Arab mix and 50% Bombay high blend.

The Straight Run LPG from Crude distillation unit (CDU) of 3MMTPA is pretreated in Amine system to remove H_2S and treated subsequently in Saturated LPG Merox unit for Mercaptan removal and the final product is sent to storage.

Plant No. 203 - Kerosene Merox Unit

Kerosene Merox unit has been designed to treat Kerosene from CDU. The UOP Merox Process is an efficient and economical catalytic process developed for the chemical treatment of Petroleum distillates for removal of sulphur present as mercaptans (Merox extraction) or Conversion of Mercaptan sulphurs to a less objectionable form (Merox sweetening).

The name "Merox" is an acronym derived from Mercaptan Oxidation. The process relies on a special catalyst to accelerate the oxidation of mercaptans to disulfide at economical product rundown temperature. The saturated LPG unit is an extraction process and the Kerosene Merox unit is a sweetening process. Product Kerosene is sent to storage.

Plant No. 204 - Visbreaker Unit

As part of the 3MMTPA refinery expansion, the Shell Soaker Visbreaker Unit of 1.15 MMTPA capacity was installed for residue up gradation.

The Shell Soaker Visbreaker Unit is intended to process vacuum residue (from Refinery I, II and III) and deasphalted pitch. The primary objectives of the unit are to reduce and spare diesel streams used as viscosity culte thereby reducing overall make of fuel oil and improving viscosity of residual oils and spare diesel streams used and to increase the yields of net distillates.

Plant No. 209 - Amine Treating Unit

The amine treating unit (209) of crude block in refinery-III (3MMTPA) is the pretreating section for saturated LPG Merox unit (202). In this unit H_2S present in saturated LPG is removed using Diethanolamine. H_2S laden Rich Diethanol amine is regenerated in offsite unit and pumped back as lean Diethanol amine.

This amine treating unit is designed to handle feedstock from either Bombay High or Arab mix. The product coming from this unit is free of H_2S , in order to meet product specification of the downstream Merox unit requirement.

Plant No. 225 - Vapourizer System

This unit is to maintain required pressure in the Fuel gas header by vaporizing LPG. Also to collect off gases (such as sweet gas + H_2 rich gas) from CRU/HCU/PSA II units along with treated gas from Amine recovery unit and charging these gases into F.G header along with vaporized LPG makeup.



Sulphur Recovery Unit

Plant No. 210 - Sulphur Recovery Unit

The unit is designed to produce Sulphur from the Acid gas with 99 % recovery. The unit consists of two trains namely Train A, train B, Common facilities exists for both trains as well as Pellatiser units.

Each train of the SRU has been designed for a capacity of 90 MT/Day of Sulphur with 30 % turndown on feed. The unit can operate with Acid gas from ARU and also Sour gas & NH₃ rich gas from Sour water stripper unit.

Plant No. 209 - Amine Regeneration Unit

The unit has been designed to regenerate rich amine coming from OHCU, CDU/VDU, CRU units and re circulates lean Amine back to the same unit. The circulating amine is a 25% wt of Diethanolamine (DEA) solution with a turndown on feed of 50 %.

H₂S is send to the SRU for recovery of Sulphur.

Plant No. 208 - Sour Water Stripper Unit

SWS consist of two parallel trains. First train consists of a single stage sourwater stripper of 45.5MT/hr capacity for processing sour water from non-hydro processing units. Second train consists of two-stage sour water stripper of 13.4MT/hr capacity for processing sour water from hydro processing units and sour water purge stream from ARU with a turn down of 40% based on stripper conditions.

The treated water from first stage unit is routed to desalter in CDU or refinery effluent treatment plant. Treated water from two stage stripper is normally routed to ETP. The sour gas from 1st stage and and 2nd stage along with ammonia rich gas from 2nd stage is sent to SRU.

Plant No. 221 - Deaerator

The Deaerator is spray cum tray type. LP steam is used to deaerator for heating and cushioning. Thermal deaeration is done here and oxygen is stripped off from the Feed water.

Two numbers of M.P BFW Feed Water Pumps of capacity 120 m³/hr delivering discharge at 22 Kg/cm² and Two numbers of H.P BFW pumps 20 m³/hr delivering discharge at 42 Kg/cm² are available.

Plant No. 222 - Instrument Air Generation Unit

This unit is designed to supply Compressed air for Instrument air requirement as well as Plant air to the refinery-III units. The unit consists of three low-pressure compressors (2motor driven+1steam driven) each with a capacity of 3100 Nm³/hr @8Kg/cm²A and one High pressure reciprocating compressor with a capacity of 250 Nm³/hr @ 32Kg/cm²A and a 2 driers with a capacity of 4070 Nm³/hr.

Plant No. 223 & 226 - Refinery Fuel Oil System

The fuel requirement of Refinery-III units is met by this internal fuel oil system which consists of a two-day tanks, MP Steam heaters with a Circulation pump.

The day tank of capacity 2000m³ is provided with a LP steam heating coils to store FO at 140°C. Fuel oil is heated through a MP Steam heater. The pumps have auto cut-in facilities to ensure continuous supply of fuel oil to the units.

Plant No. 227 - Nitrogen Plant

The inert gas requirement of Refinery-III units are met by the cryogenic air separation.

Plant produces 1280 Nm³/hr (1000gas+280liquid nitrogen) which is rated capacity. High purity nitrogen is required mainly for use of purging of the units before start up and after shutdown. It is used in refinery for initial purging, dry out and for catalyst regeneration.

Plant No. 251 - Cooling Tower VI

Cooling tower VI has 5 Cells (on-stream+1Standby) each with a capacity of 15200 m³/hr. The unit has 6 circulating pumps, basin and the chemical house for various treatments.

The cooling range of the unit is 12°C i.e., return water temperature is 45°C and the supply water temperature is 33°C. It caters to the needs of refinery-III.

320-Tank farm

The main objective of the tank farm area is to receive the products either in finished or in semi finished condition and supply intermediate products for further processing in secondary units. Tank farm has 4 feed tanks (2 OHCU & 2VBU), 7 Naphtha tanks which serve as intermediate storage.

Area-47 (Oily Water, Contaminated Rain Water & Storm Water Systems)

This area has an oily water pit with 3 centrifugal pumps, each of capacity 100m³/hr, Contaminated rain water pit with 4 centrifugal pumps each of capacity 250 m³/hr and 3 floor wash pumps each with capacity 10m³/hr, Storm water pond with 5 pumps (3motordriven+2 Diesel driven) each with capacity of 400 m³/hr.

PLANT 206 NHT / CRU

Naphtha Hydrotreating Process

The purpose of the "Naphtha Hydrotreater" process is to produce a clean hydrotreated reformer feedstock sufficiently low in contaminants such as sulphur, nitrogen, water, halogens, diolefins, olefins, arsenic and metals so as not to affect the performance of the downstream catalytic reaction sections of the Reforming



unit and reduce the benzene precursors to meet the specifications of 1 vol % of benzene in reformat.

Naphtha hydrotreater feed in this case originates from four sources. Stabilized light naphtha from storage, Straight Run Naphtha from CDU, Naphtha from Hydrocracking Unit and Naphtha from Visbreaker Unit.

This process was developed and licensed by M/s Axens, which involves the treatment of the naphtha in an adiabatic reactor over a fixed bimetallic catalyst bed in a hydrogen environment.

A moderately high temperature in the range of 300°C is required to promote the chemical reactions. After the reaction process, the naphtha is stripped to remove light ends, gaseous products (from the contaminants) and water. Then the hydrotreated naphtha is sent to a splitter in order to remove benzene precursors.

As diolefins and olefins are present in the feed, a separate treatment step is required at a lower temperature with a special catalyst to hydrogenate the unsaturated components prior to the higher temperature hydrotreatment.

Catalytic Reforming Unit

The "Reforming process" is a catalytic process to convert low octane naphtha's into higher octane reformat products for gasoline blending. Naphtha feeds to this process include straight run naphtha direct from crude distillation or naphtha boiling range products from other processes such as hydrocrackers, cokers etc. A valuable by-product from this process is the hydrogen released from the aromatic producing reactions. This hydrogen is necessary to support the upstream hydrotreating unit, which is necessary to prepare the naphtha feed to be reformed and other hydrogen consumers within the refinery complex.

This reforming process includes a reaction section, H₂ purification and stabilization. The reforming reactions take place in fixed catalyst beds under a hydrogen environment at a moderately low pressure. A high temperature in the range of 490°C- 520°C is required to promote the chemical reactions, which improve the octane number.

The plant consists of two major Units:

- a) Hydrogen Generation Unit
- b) PSA-II

205 Hydrogen Generation Unit

The Hydrogen Generation Unit (HGU) is designed to process Straight run (SR) Light Naphtha (C5-83°C, sour) from Refinery- III Crude Distillation Unit (80 wt%) + Light Naphtha (C5-95°C, sweet) ex. Hydrocracker Unit (20 wt%) and Full Range Naphtha (C5-160°C, sour) from existing refinery (100%). The unit will also be able to handle HSRN (95-141°C, sour) from existing refinery (check feed case). Hydrogen will be produced from Naphtha based on the following main process steps:

- Naphtha Pre-desulphurization
- Naphtha vaporisation and final desulphurisation
- Steam naphtha reforming
- HT shift conversion
- Process gas heat recovery and cooling
- Hydrogen purification (PSA-I)
- Steam system
- Fuel system

The sour naphtha is desulphurised in a hydro-desulphurisation (HDS) unit where the sulphur reacts to H_2S , which subsequently is removed in a Naphtha stripper. The sour gas from the stripper is sent to Battery Limit. The hydrogen required for the sulphur conversion is provided from the hydrogen product.

The sweet naphtha is used as feed to the hydrogen unit and is pumped to operating conditions before it is vaporised and passes through a final desulfurization step, which also removes the residual chlorides. It is then mixed with steam before entering the reformer. In the reformer naphtha reacts with steam to produce hydrogen, methane, carbon monoxide and carbon dioxide. The reformer effluent is cooled and passed through a HT shift reactor, which converts a major part of the carbon monoxide to carbon dioxide and hydrogen before the final heat recovery and process gas cooling takes place. The process condensate is separated and used with DM water as boiler feed water after degasification for steam generation within the Hydrogen Generating Unit.

The process gas enters the PSA-I. In the PSA-I unit the gas is purified to product hydrogen quality. The off gasses from the PSA-I are used as fuel to supply the major part of heat for the reforming reaction with the firing control on make up sour naphtha fuel.

The steam generated within the hydrogen unit will be used as process steam and for the vaporization of feed naphtha. Surplus steam is sent to Battery Limit as HP steam export.

PSA II

The Pressure Swing Adsorber-II (PSA –II) is designed to process Refinery off-gases from Plant 3 & 4 + Combined CRU and HCU off-gas stream. Following are the main process steps involved in PSA-II

- Compression of Refinery off-gases of Plant 3 and 4
- Mixing of refinery off-gases from Plant 3 & 4 with Combined CRU and HCU off-gas stream
- Feed Preparation for PSA-II
- Hydrogen purification (PSA-II)
- Compression of purge gas



207 Once through Hydro Cracker Unit (OHCU)

Crude oil is submitted to refining process, designed to convert the oils to high value products such as transportation fuels, chemicals, lubricants and so forth. The crude oil is first fractionated by distillation and different fractions are subsequently upgraded by a variety of processes. One such process is "HYDROCRACKING" which uses preferably Gas Oils as its feed stock with boiling range 3000 C to 5800 C from Vacuum distillation & Visbreaker.

Hydrocracking is a catalytic- petroleum refining process that converts heavy, high boiling feedstock molecules to smaller, lower boiling products through carbon bond breaking, accompanied by simultaneous or sequential hydrogenation. Hydrocracking is a process of considerable flexibility because it allows the conversion of a wide range of feedstock's to a variety of products of superior quality.

Other catalytic- process besides Hydrocracking are Hydrotreating (Sulphur, Nitrogen & Oxygen), Reforming, Alkylation & Isomerization.

Stringent market demand on Quality & Cost in the present MDPM scenario and the high demand on Middle Distillates calls the Indian Refineries to opt conversion of Heavy stocks into Light & Middle distillates.

Present conversion of heavy stocks into lighter stocks by FCCU yields considerable amount of FO with frequent catalyst poisoning. Also it calls for some blending and secondary treating process to make the product on spec./ marketable.

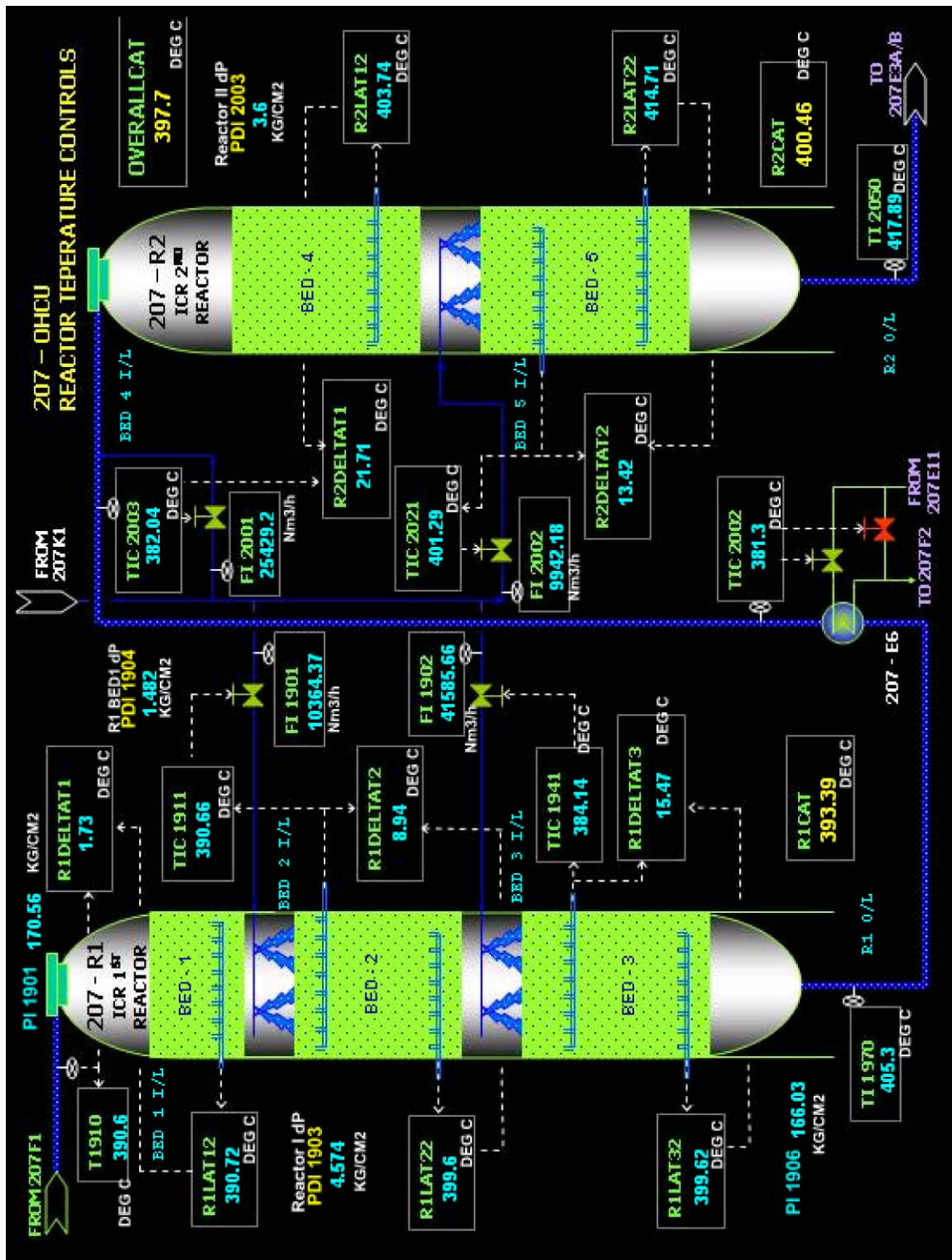
In view of this, hydrocracking gained the entry of INDIAN refinery. So forth CPCL.

The table below shows small comparison of yields between FCCU & Hydrocracker for easy understand.

	FCCU	HYDROCRACKING
Feed Stock	VGO	VGO
Light Distillates.	35	17
Middle Distillates.	45	80
Bottom's	15	Minimum

Many type of patented hydrocracking process have developed and offered for License by major Oil companies. CPCL opted the License of "ISOCRACKING" developed by Chevron Lummus Global LLC "CLG" USA for various reasons, which is out of scope of this part. It is so called "ISOCRACKING" because of predominant yield of "iso" component.

Hence CPCL have licensed Once Through Hydrocracker for partial conversion on the feed into products which is a extremely versatile catalytic- process,





processing Heavy feed stock in the presence of Hydrogen & Catalyst, yielding lighter products & prepare feed to FCCU.

Hydro-cracker unit was designed for 1.85 MM metric ton/year (249.5 m³/hr i.e. 112% of design) as part of a refinery expansion project in Manali. This Hydro-cracker is a single stage, once through unit that has been designed to produce middle distillate fuel of superior quality.

Process Description

The objective of the HYDROCRACKING Unit is to produce middle distillate fuel of superior quality.

Feed to the unit consists of 90% straight run (SR) vacuum gas oil (VGO) and 10% visbreaker (VB) VGO at a design rate of 222.5 m³/hr . The 50% hot and 50% cold up to 90% hot and 10% cold, assuming that VBU VGO is always hot. The primary products from the unit are

Cold Low Pressure Separator Off-gas to Off-plot Hydrogen PSA Unit/Fuel Gas

Sponge Oil Absorber Sweet Off-gas to Fuel Gas

LPG

Stabilized Light Naphtha

Heavy Naphtha

Aviation Turbine Fuel/Superior Kerosene

Diesel

Unconverted Oil (FCC Feed)

The by-products are:

Filter Back flush to Fuel Oil/Off-plot or FCC Feed

Sour Water to Sour Water Stripper

Spent Caustic Solution to Spent Caustic System

Brine Solution

Blow down From Steam Generators to Storm Water Sewer

The ISOCRACKING Unit consists of five principle sections:

1. Feed and Reaction Section
2. Recycle Gas Loop
3. Fractionation Section
4. Light Ends Recovery Section
5. Make Up Hydrogen Compression Section

Feed and Reaction Section

The reaction section contains one reaction stage in a single high pressure loop. The Hydrotreating and Hydrocracking reactions taking place in the reaction stage occurs at high temperature and pressure. A high hydrogen partial pressure is required to promote the hydrocracking reactions and to prevent coking of the catalyst. An excess of hydrogen is recirculated in the reactor loop for reactor cooling, to maintain a high hydrogen partial pressure, and to assure even flow distribution in the reactors.

In the reactors, fresh feed is partially converted to middle distillates and lighter products. Sulfur and nitrogen are also almost completely removed and aromatic content is reduced.

Recycle Gas Loop Section

The Recycle gas loop section contains additional equipment for separation of hydrogen rich gas from the reactor effluents, which is compressed and recycled back through the high pressure reactor loop. The recycle gas contains H₂, by-products generated from the hydrocracking reactions, H₂S, and NH₃. Nearly all of the NH₃ and some of the H₂S are removed in the form of ammonium bisulfate by water that is injected upstream of the cold high-pressure separator. Gas is flashed off the liquids in the cold high and low pressure separators. The high-pressure gas is amine scrubbed to remove H₂S and recycled to the reactor. The low-pressure gas is amine scrubbed to remove H₂S and sent off-plot to a PSA unit for hydrogen recovery.

Fractionation Section

The purpose of the fractionation section is to separate reaction section products into Sour Gas, Unstabilised Naphtha, Kerosene, Diesel, and UCO as fractionator bottoms. Diesel and Kerosene are finished products and are sent to storage or blending. The fractionator bottoms (UCO) are sent to the FCC or storage.

Light Ends Recovery Section

The light end section is designed to take the sour gas and unstabilized naphtha from the product stripper and fractionator overhead, and produce sweet fuel gas, LPG, and light and heavy naphtha as products.

Make up Hydrogen Compression Section

The make up hydrogen compression section consists of three identical parallel compressor trains, each with three stages of compression. The feed to the unit hydrogen of 99.5% minimum purity from an off-plot hydrogen plant. The compressed make up hydrogen is combined with hydrogen recycle gas in the reaction section to form reactor feed gas. The make up hydrogen compression



section is also used to compress a mixture of nitrogen and air during catalyst regeneration.

Feed specifications	SR VGO	VB VGO
Feedstock Sources	CDU/VDU – BH/PG Crudes	VBU
Quality specifications		
Distillation, ASTM D 1160°C		
Start	320	300
10%	380	324
30%	415	378
50%	440-460	402
70%	490	435
90%	540	473
End Point, Max.	585	500
API Gravity	20.8-34.8	20.7
Specific- Gravity	0.825-0.929	0.93
Asphaltenes, Wt %, Max.	0.010	0.020
Iron, PPM	0.0	5
Nitrogen, ppm wt.	1000	2000
Sulphur, Wt %	2.8	5.0
Kinematic- Viscosity at 50°C, cst		46.3
Kinematic- Viscosity at 100°C, cst		9.6
Kinematic- Viscosity at 200°C, cst	0.6-1.65	
Kinematic- Viscosity at 250°C, cSt	0.4-1.1	
CCR, Wt %	0.6	1.0
Nickel + Vanadium, PPM	1.0	9

3.2 Make-up Hydrogen Quality

Parameter	H ₂ Spec.
Hydrogen Purity, Mole %	99.5 (Min.)
CO + CO ₂ , Mole	20 PPM (Max.)
Nitrogen, Mole	50 PPM (Max.)
Water, Mole	50 PPM (Max.)
Chlorine + Chlorides, Mole	1 PPM (Max.)
Methane, Mole %	Balance

Estimated Product Yields and Inspections - SOR

Feed: 90% SR VGO, 10% VB VGO

Case: SOR

Total Feed Rate = 1.85 MM MTPA (112% of Design)

Total Feed Rate = 37,400 BPSD

Chemical Hydrogen Consumption = 256 Nm³/m³

Chemical Hydrogen Consumption = 1,520 SCFB

Product Yields: Start-of-Run

Product	Wt % (1)	LV % (1)
H ₂ S	3.21	
NH ₃	0.13	
C ₁	0.25	
C ₂	0.39	
C ₃	0.67	1.23
iC ₄	0.73	1.20
nC ₄	0.73	1.16
Light Naphtha	3.40	4.7
Heavy Naphtha	5.10	6.21
Kerosene	23.69	27.07
Diesel	21.75	23.99
Bottoms	42.43	46.33
C ₅ +	96.37	108.3
Total	102.48	111.89

Note: Yields are expressed as percentages of fresh feed.



CHENNAI PETROLEUM CORPORATION LIMITED

10. SAMPLING

The operator has two objectives during the production petroleum products. First, to produce products, which will satisfy the customer. Second, to control the refining processes so as to make products in the most economical manner. The operator cannot determine the quality of the products by visual or sensory observation. Therefore the sample of each product are sent to the laboratory for examination by various physical or chemical tests. Likewise, knowledge of properties of certain important process streams enables efficient and safe operation of the unit.

If the results of these tests are to be useful, the sample tested must be identical to the bulk stream that it represents. No sample result is any better than the care and correctness with which the sample is taken. In fact, samples, which are not true representatives, can cause bad customer relations and mislead operations with serious consequences.

Petroleum products and certain process streams are required to meet certain specifications. A specification is a set of parameters, which sets the upper or lower limits of its compositions.

Types of Samples

Two types of samples are used in controlling the operation of refinery units, grab samples and composite samples. The grab sample is also sometimes called a spot sample.

In taking a grab sample, the entire sample is obtained at one time. The sample represents the composition of the total stream at that time. The operator uses the results of grab sample tests to make routine adjustments in operating conditions, if required. In order to follow the continuous operation of the unit, grab samples are sent to the laboratory at certain specified intervals.

To take a composite sample, equal portions of a stream are put in a large sample container at regular intervals over a period of time. For example, a pint (small quantity) of oil might be put into a gallon can once every four hours over a period of twenty-four hours. This would be called a twenty-four hours composite sample and would be representative of the composition of the stream for that period of time. Chiefly, the technical staff use composite samples to:

1. Determine the losses of valuable products into a less valuable stream.
2. To evaluate the effects of changes in operating conditions.
3. To make mass balances around the unit.



Sampling Method

Sampling methods can be quite varied as determined by the nature, temperature and pressure of the sample as well as the type of process container and sample connection. It is beyond the scope of this section to describe in detail the procedures for taking all kinds of samples. Special instructions will be given as required on the individual operating units. However, it is possible to tabulate samples into a few general types and to prescribe general technique for procuring representative samples safely.

Open Container

Open container sampling is the most common type of sample taken. It is used for low vapour pressure samples, most heavy oils and cooling water. Examples would be

1. Reformate
2. Kerosene
3. Diesel Oil
4. Vacuum Still Bottom
5. Boiler feed water

The sample is drawn into an empty bottle. A stopper is placed on the bottle and the sample is labelled properly and sent to the laboratory. The sample point is sometimes equipped with a flexible tubing extension, so that the liquid sample enters the bottle under the liquid level in order to avoid contamination of the sample with air and also to conserve loss of volatile vapour.

Sample Bombs

Sample bombs are used for taking samples of gaseous hydrocarbons and certain hydrocarbon liquids which have high Reid vapour pressure (above 15 psi) Examples would be: 1. Stabilizer gas, 2. Fuel Gas 3. L.P.G. 4. Naphtha.

Bombs are used in two basic sizes, 75 and 150 ml. A larger 300 ml. bomb for composite samples can be used for special samples. The valves on sample bombs should never be more than hand tight, otherwise, the valve seats can get seriously damaged and the valve may leak. The small 75 ml. bomb will be used preferentially. The prescribed procedure for sampling high pressure liquid samples with this bomb is as follows:

1. Open valve B and flush the line well and close.
2. Connect valve C to the sample line.
3. Open valve C and D on the sample bomb.
4. Open the valve B on the sample line and purge the sample bomb well with the sample. Be sure to direct the flow towards the floor.
5. Close valve D and let the bomb fill with the sample.
6. Close the valve C and valve B and unscrew the bomb from sample valve.

7. In case of a liquid sample, hold the bomb in an upright position, and then open the bottom valve and close it quickly so that a portion of the liquid phase escapes. This is to provide a vapour space in the sample bomb. Proper vapour space is between 5 and 10 percent.
8. Check valves C and D on samples bomb for leaks and tag the sample for identification.

The above procedures make use of the sample to displace the air in the container. It is used only for small grab samples. In other types of bomb samples, water displacement is sometimes used. The bomb is first filled with water and the sample pressure into measuring devices displaces the water. This method is generally used for taking composite sample.

Tank Samples

Tank samples are taken in several ways, but the most common basic procedure is to let a weighted sample bottle down into the tank at the end of heavy cord. Sometimes, another string is attached to the cork in the bottle and the cork is pulled at the desired oil height in the tank.

Volatile liquids that are considerably above atmospheric temperature must sometimes be taken through coolers. These are commonly portable 'Buckets' with tubing coiled in term and surrounded with water or ice. Distillate samples with flash points of 110^oF to 200^oF are frequently required from process streams at high temperature (200^oF to 500^oF). These must be taken through sample coolers, which are usually located permanently at regular sample locations. Heavy oils, even though they may have a high flash, must be taken through. Coolers prevent injury to the personnel taking the samples. Rain or other extraneous water such as a wet sample bottle must not be allowed to enter heavy samples taken at temperatures above the boiling point of water (212^oF).

Other special samples such as catalyst, and certain chemicals will require special instructions, which must be followed exactly,

Sampling Hazards

Sampling hazards can be of two basic types: (1) those which give bad samples and erroneous results and (2) those which are unsafe. Sometimes it is felt that the work of collecting samples is a routine duty and monotonous. Great care and extreme caution must be exercised when taking or handling samples. Every unit will have special instructions on how to take samples accurately and safely and these should be followed with extreme caution. However, no set of instructions can replace good judgement and common sense.

It should be remembered that sample improperly taken can cause poor customer relationship and cause unnecessary and expensive change in operations. A poor sample may be caused by any of the following reasons.



1. Sample is taken from a "Dead" line (ie unused line), which contains the product but has no flow through it.
2. Sample is taken during a period of upset on the unit. During this time, operating conditions and product composition are changing.
3. Sample is taken without bleeding off or purging the sample cooler or connection. The sample in this case will be the same as the last sample rather than what is currently being processed.
4. Sample of volatile sample taken is too hot. The lighter components will vaporize and leave a false heavy sample.
5. The sample container is not tightly sealed allowing vaporization of the lighter components.
6. The sample is taken in a dirty bottle or stoppered with a dirty cork or a rubber stopper.
7. The sample may be contaminated with heavy oil or grease from the operators hands.
8. Composite samples must be taken uniformly. If most of the sample is taken at one time, it is not representative.
9. Sample is improperly labelled by name, time etc,
10. A light sensitive sample is taken in a clear bottle instead of a dark bottle.

Some of the safety precautions, which must be followed when taking samples, include the following

1. Use safety equipments as prescribed in the specific instructions. This includes gloves, face shields, goggles, oxygen masks, etc.,
2. Check surrounding area for a source of ignition. Heavy hydrocarbon vapour from the sample will travel along the ground.
3. Allow a vapour space in the sample container for expansion in the case of both bottles and bombs.
4. Keep complete control of the flow of sample.
5. Be careful and complete in tagging sample containers. Wrong labels can cause accidents in the testing equipment in the laboratory.
6. Check the sample containers for cleanliness or foreign material. Water in the bottom or on the walls of a container receiving hot oil can flash to steam.

7. Check sample coolers for water flow and freedom from mechanical failure of plugging before using.
8. If necessary, to climb ladders or mount platforms for samples, use both hands. If necessary, special sampling equipment should be provided to allow both hands for climbing.
9. Attach grounding devices for static electricity dissipation where provided.

Using Sample Results

Test results are frequently received which are not within the allowable limits of the specifications. The integrity of the laboratory is not to be questioned but if the result seems unreasonable, additional available operating information should be checked before changing the unit operation. The single sample may truly indicate something is wrong, but it is possible that the sample was taken during upset conditions, was improperly labelled, or improperly tested or reported.

If the sample results indicate that corrective action should be taken, it is the duty of the operators to do so. After corrective action has been taken and the unit has lined out, it is equally important to resample and test the streams in question to see that the change in operation was proper and effective.

Testing

Many physical and chemical tests are run on hydrocarbons and the other materials used in processing them. A brief description of some of the more common and important tests should help the operator to understand better the importance of controlling the operating variables on the process units.

Gravity

The specific gravity of oil is defined as the ratio of the weights of equal volume of oil to equal volume of water at a standard temperature. The standard temperature used by oil refineries in India is 15°C. The gravity is measured by means of a hydrometer and the observed gravity reading is converted to 15°C by using standard tables. Hydrometer is an instrument, which measures the volume of a liquid, which corresponds to its weight. The basic principle in gravity determination by hydrometer is that floating object in a liquid displaces a volume of liquid equal in weight to that of the floating mass. The hydrometer is graduated to read the gravity. The gravity of petroleum products is also expressed in degrees API. The standard temperature used in this case is 60°F. The relation between API gravity and specific gravity is as follows:

$$\text{Degrees API} = \frac{141.5}{\text{Sp.Gr at } 60^{\circ}\text{F}} - 131.5$$



Gravity is a useful control test, but is not an index of product quality except in certain instances when considered in connection with other tests. The gravity must be known in order to correct measured volumes to 60°F. It is also used extensively in blending operations.

Colour

Petroleum Products may be divided, according to their colour, into two general classes-First, so called white products with range from practically colorless to "pale-straw" and second, pale-straw and darker. In general, however, the colour of most petroleum products is of little importance in connection with quality, except as an indication of contamination.

The so-called "White products" colours are measured by Saybolt chromometer. The colour is determined in this method by measuring depth of Oil necessary to match a standard colour glass. The results are reported as "Saybolt Colour". The colour scale ranges from -16 to +30. The larger the number, the lighter the colour is.

The ASTM colourimeter is used to determine the colour of the "pale-straw" and darker products. Black oils can be evaluated by a dilution method which provides for diluting in the ratio of 15% dark oil to 85% of +21 Saybolt of lighter material, (kerosene). Colour is measured by comparing a fixed thickness of oil with various glass discs. The results are reported as "ASTM Colour". The scale ranges from 1 to 8. The larger the number, the darker the oil is.

Doctor Test

The doctor test is essentially a very sensitive chemical test for hydrogen sulphide and / or mercaptans. It is made by shaking the product to be tested with a solution of sodium plumbite made by dissolving litharge in caustic soda. After shaking vigorously, a pinch of sulphur is added and the mixture is shaken again. If the sample is discolored or the yellow colour of the sulphur film becomes brown or black the sample is called 'Sour' but if it remain unchanged in colour or only vary slightly discolored or flecked with black, the sample is reported sweet.

An immediate black precipitate before the sulphur addition indicates hydrogen sulphide. In the absence of hydrogen sulphide the change is frequently gradual going through orange, red and brown to black. The test is used to indicate the presence of mercaptans, which, in higher concentration, produce a characteristic objectionable odour.

pH

Water which is collected in reflux drums can become very corrosive if it is acidic or basic (Alkaline). Samples of the circulating water are sent to the laboratory periodically to determine whether the water is basic or acidic. The laboratory reports small concentrations of acids or bases in a solution as the pH of the solution. The pH scale ranges from 1 to 14 and actually starts in the middle i.e., the pH of neutral solution (distilled water) for example, is 7. As the solution

becomes more acidic, the pH value decreases down to one, which represents a fairly strong acid solution. If the scale goes upwards from seven towards fourteen, the solution becomes more basic.

Distillation

The distillation test is one of the test by which volatility is determined. It involves the general procedure of vaporizing the liquid under test and recording a set of figures indicating the relation between vapour temperatures in the distilling vessel and quantities of distillate that have been liquefied by the condenser. The distillation results are very important for control purposes. Practically all distillation towers are operated to obtain streams with a specified distillate. Distillation results are an indication of certain performance characteristics of gasolines. Various boiling points in the distillation test of motor gasoline have been correlated with engine performance. In general, case of starting and a satisfactory warm-up period are assured by specifying a maximum temperature of 10% evaporated or a minimum percentage evaporated at some moderately low temperature such as 158°F. To lesser extent warm-up the 50% and 90% points influence period. Excessive heavy ends may result in uneven distribution of the fuel to the various cylinders and may result in crankcase dilution. They are usually limited by specifying a maximum 90% evaporated point or maximum end point.

Flash Point

Flash point may be defined as the temperature to which an oil must be heated in order to give off sufficient vapour to form an inflammable mixture with air; Flash points are principally employed to indicate fire hazards of petroleum products in connection with light oils and fuels; flash points are specified (minimum and maximum) in order to ensure proper uniformity of product and ease of ignition in burners.

The measured flash point of a substance varies with the apparatus and procedure. Although a large number of so called 'flash-testers' have been developed, only the closed cup testers will be discussed. These testers have two elements in common-one is a cup which is equipped with a stirrer for holding the samples. Another is a water bath or some other means for slowly raising the temperature of the sample.

Tag Closed Cup Tester

This instrument is designed and operated to yield the greatest possible degree of accuracy. It consists of a water bath a cup without a stirrer. It is essential that the rate of heat input be carefully controlled. This is accomplished by using water as a medium for transmitting heat to the oil under test.

Penske-Martin Closed Cup Tester

This instrument is used almost exclusively, the world over for determining flash point of fuel oil and gas oil. Fuel oils frequently have high viscosities and stirring of the oil during the test is essential to ensure maximum accuracy. The test



procedure is similar to the closed cup method. However, a water bath cannot be used because of the high temperature range of this instrument.

Reid Vapour Pressure

The vapour pressure of a substance is a measure of the tendency of the substance to vaporize. Therefore it is an indication of "light ends" in a stock. Vapour pressure is generally expressed in pounds per square inch absolute. Vapour pressure of petrol has been correlated with vapour lock tendencies in automotive and is more useful in this connection than the initial boiling point or other low distillation points. Vapour pressure is also used in connection with transportation safety regulations. The test is usually applied to petrol or to products containing naphtha such as jet fuels.

In the Reid method for measuring vapour pressure, the sample is placed in a bomb, connected to a sensitive pressure gauge and heated in a water bath to 100°F. The vapour pressure is determined in the presence of a volume of air four times the volume of gasoline. This standardizes the extent of evaporation, lessens the effect of dissolved gases, and permits direct reading of the vapour pressure in absolute units. Corrections to the pressure gauge readings are made for air expansion and change in vapour pressure of water intentionally added to ensure constant humidity, for all tests.

Sulphur

Small amounts of sulphur in petroleum products can cause severe corrosion. Sulphur in gasoline can damage an automobile engine, especially in the winter time. Some of the products of combustion get into the crankcase and remain in the cylinders when the engine is stopped, causing serious corrosion of parts, such as bearing starter chain, cylinder walls etc; Sulphur in products used for heating can cause corrosion of burners boilers, stacks and auxiliary equipment.

For the purpose of this test, the sulphur content is considered as the total amount of sulphur present in the petroleum product regardless of how it is chemically combined with other elements. The Lamp Method analyzes petroleum products for sulphur in the laboratory. Burning a sample of the material in a small lamp oxidizes the sulphur. The combustion products are passed through a solution of hydrogen peroxide. The solution is analyzed with a sodium hydroxide solution and the sulphur is determined by calculation.

Octane Number

The Octane number, of rating, is a number used to measure the anti-knock properties of gasoline. It is the percentage by volume of iso-octane C₂, 2, 4-trimethyl pentane, in a mixture of iso-octane and normal heptane that matches the gasoline being tested in knocking characteristics. The higher the octane number, the lower is the knocking tendency. Since pure iso-octane and normal heptane are, very expensive in many laboratories, the gasoline being tested is compared with a reference fuel which has been calibrated with the pure standards (iso-octane and normal heptane). There are two sets of operating conditions or

methods; the motor method in general represents the fuel's behavior in high-speed performance. The results of neither method are completely satisfactory in predicting the overall road performance of a fuel, although the research method is considered better in this respect and it is the research octane number which is generally quoted as the "Octane number". Fuels of different compositions may have the same octane number yet respond quite differently to such engine variables as speed, engine design, spark timing, jacket and manifold temperatures, and air to fuel ratio. Road ratings, therefore, vary with different makes of cars and also between different cars of the same make.

B.S & W

The specifications for many of the finished products from refineries require them to be free from water and sediment. It is also important that there, is no water or sediment in the charge to the units. Sediment can cause exchanger and furnace fouling. Inclusion of water in feed can result in violent explosions when the water is converted to steam and expands to about 1600 times the original volume.

The water and sediment is determined in the laboratory as B.S. & W, which stands for Bottom Sediment and water. In testing oil for B.S. & W it is first diluted with benzene into a 50-50 mixture. It is then spun in centrifuge for a specified length of time. The container for the oil is graduated so that the amount of B.S. & W may be read directly from the markings.

Carbon Residue

In certain types of oil burning equipment and in internal combustion engines where both the fuel and lubricant may deposit coke, it is important to know the relative coke forming tendencies of various fuels and oils. This tendency is indicated by the carbon residue test. This test also indicates the yield of carbon, which might be expected in cracking the oil. The carbon residue is reported in terms of weight percent. This test can be used on fuel oil, gas oil and lubrication oil. To obtain a carbon residue on hydrocarbon samples, it is necessary to evaporate the oil in an apparatus so designed to exclude air to provide for proper control of rate heating, and to eliminate possible condensation of distillate in or on the oil contained. The unevaporated material remaining is weighed and reported as carbon residue, Two methods are commonly used, Conradson and Ramsbottom for carbon residue test.

Viscosity

Viscosity of an oil is a measure of its resistance to flow. Because viscosity changes with temperature, a numerical value of viscosity has no meaning unless the temperature is specified. In commercial work, viscosity is usually expressed in seconds of time for a given volume of oil to flow through a certain orifice. Since viscosity is a measure of oil's resistance to flow, it is important in all movement of oil, whether it be through a wick in a kerosene lamp, or the pumping of oil through a circulating system or a pipeline. The ease with which a fuel oil may be atomized in a burner is also a function of viscosity.



Many instruments have been developed for measuring viscosity, but only one will be discussed in this text Saybolt viscometer. The Saybolt method has two variations, Universal and Furol, differing in the size of the outflow orifice. The Universal orifice is used for gas oils and lubricating oil, the standard temperatures being 100°, 130° and 210°F. The Furol orifice (Furol is a contraction of the phrase "Fuel and road oils") is usually used for heavy oils and road fuels. The temperature used for fuels is usually 122°F, though 77100 or 210°F are also used.

Cloud and Pour Points

As a sample of oil is cooled, the cloud point is the temperature at which paraffin wax or other solid substances begin to crystallize out. The Pour Point of petroleum is the lowest temperature at which the oil will pour or flow when it is chilled without disturbance under definite prescribed conditions.

The cloud point is of some value when a haze or cloud in the oil would be objectionable for any reason. The pour point gives an indication of the temperature at which it may not be possible to pour or remove oil from its container or below which it might be dangerous to use the oil in gravity flow lubricating system. It is also a measure of the lower temperature limit for pumping fuel oil.

Corrosion

Petroleum products are frequently used in contact with metal. When it is essential that the metal shall not be corroded, it is customary to require that the petroleum products pass an appropriate corrosion test. The corrosive substance most likely to be present in such products as gasoline and kerosene is free sulphur, which attacks copper readily. It is, therefore, customary to require that products shall pass a test involving contact with polished copper for a specified period of time, at a specified temperature. The Copper Strip Corrosion test involves determinations of the discoloration produced when a strip of sheet copper is immersed in the sample for half an hour at 212°F. It is applicable to kerosene and other transparent products. The exposed strip is compared to a series of 12 standard strips and the sample assigned a corrosion number of 1a to 4c depending upon the degree of discoloration.

GUM

Cracked gasoline, upon exposure to oxygen of the air as in ordinary storage, may undergo oxidation with formation of undesirable components. Upon evaporation of the gasoline, a resinous material is formed which is called "gum". This gum may cause in take valves to stick or it can interfere with carburetor operation. It is a common practice to refer to the yield of residue obtained by an evaporation test of the gum content of the gasoline.

In the gum existent method, a sample of gasoline is evaporated rapidly at an elevated temperature (320°-330°F) in a current of heated air. The results are expressed as milligrams of gum per 100cc of sample. Note: Existent gum is defined as the amount of the nonvolatile residue present in the gasoline as received for the test.

The results are an index of the tendency of the gasoline to deposit gum in an engine before storage. In general, however, only a fraction of the gum content of the gasoline analyzed appears as deposits.

ORSAT

The theory of gas analysis is simple. It consists of taking a measured volume of gas sample removing components one by one by suitable reactions and measuring the decrease in volume caused by each removal. Oxygen, carbon monoxide and carbon dioxide are commonly determined by this method.

Aniline Point

The aniline point is an index of the paraffinicity of petroleum oils and to some extent an indication of the solvent power of naphtha and solvents derived from petroleum. The procedure is to determine the temperature at which a solution of equal volumes of aniline and oil becomes cloudy upon cooling.

The aniline point increases with an increase in the molecular weight of the hydrocarbons in a sample. So it is necessary to know the approximate composition of the sample. This is accomplished by obtaining certain boiling range fractions. Then an equal volume of sample and aniline is stirred and cooled until a cloudy mixture is obtained, the temperature is observed and from this the amount of aromatics may be determined from a correlation.

Bromine Number

The Bromine number is a measure of the amount of olefins (unsaturated compounds) in a hydrocarbon sample. As the amount of olefin increases, the accuracy of the test, however, decreases somewhat. Bromine will react with olefin in such a manner that one molecule of bromine will add to each double bond present. A known quantity in excess of the amount needed is added to the sample. The quantity of bromine which did not react with the olefins is determined by analysis of the amount of bromine which reacted with the olefins. The difference between quantity of bromine charged, and the quantity of bromine remaining is determined. This quantity of bromine [which reacted] is expressed as milligram of bromine per gram of sample. This is the bromine number.



11. GLOSSARY

Absorption Tower

A bubble column, or packed tower in which certain components of a gas stream are absorbed into a substantially non-volatile liquid.

Accumulator Drum

A vessel or tank serving as surge capacity for fluids, from which streams are drawn for charging to other points-for example "reflux accumulator"

Additives

A compound added to a semi-finished product in very small quantities to improve some characteristic of the product or to prevent certain undesirable from occurring in its use. Examples are viscosity and pour point improvers, anti-oxidants and corrosion inhibitors.

Algae

Seaweeds, pond-scums and a variety of microscopic plants inhabiting fresh and salt waters in countless numbers

Aniline point

A laboratory test for measure of the tendency of oil to crack.

Anti-Oxidants

See-"Inhibitors"

API Gravity

The API Gravity scale is an arbitrary one, which is related to the specific gravity of a petroleum product in accordance with the formula.

$$\text{Degree API} = \frac{141.5}{\text{Sp.Grav.at } 60^{\circ}\text{F}} = 131.5$$

Aromatics

A generic term applied to hydrocarbons having as part of their basic structure the benzene ring.

Asphalt

Brown to black solid or semi-solid bituminous substance occurring in nature or obtained as a residue from the distillation of certain crude petroleum. They consist



chiefly of a mixture of comparatively non-volatile hydrocarbons and their derivatives.

ASTM Distillation

ASTM an atmospheric batch-type of distillation performed under definite conditions with specific equipment.

ASTM Gum

ASTM Gum test D-381-46 is a measure of the existent gum in gasoline as indicated by the amount of non-volatile residue.

Baffle

A partition placed in a container to cause a fluid to change its flow of direction.

Barometric Condenser

Condensation by direct contact with water gets sufficiently high so that the water drains from it through a barometric hot leg into a hot well.

Barrel

The petroleum industry in general uses the 42 U.S. gallon barrel as the standard barrel. Crude oil, for example, is also measured in 42-gallon barrels and crude is bought on that basis.

B/cd

An abbreviation for the term "Barrels per calendar day". The figure is usually obtained by computing the total barrels flowing per year and dividing by 365. This value includes all shutdown and stand-by time.

Bitumen

Generic term applied to naturally occurring hydrocarbons such as native asphalts.

Blending

The process of mixing two or more oils having different properties to obtain oil intermediate properties.

Blind

A solid plate or cover designed to prevent the flow of fluids through a nozzle of equipment or through a pipe.

Blocked-Out Operation

Operation of a unit or part of a unit for alternately different processing operations.

Blow-Down

A term applied to a system used for the disposal of accumulated wastes, spent process streams, or process fluids during the interruption of the process. It may also be applied as a term to describe these wastes, spent streams, or process fluids.

Blow-Down Drum

A tank in which the contents of a unit may be emptied when an emergency arises. Usually provided with connections for steam or water injection to prevent ignition of contents. Outlet is connected to blow-down stack.

BOB Guage

A term applied to the gauge, consisting of a chain or wire rope attached to a float at one end and a pointer at the other, used to indicate the height of fluid in a tank.

Bomb

A laboratory vessel designed for the storage or reaction of materials under high pressures.

Booster Pump

A pump used to raise the pressure level of any fluid stream, which has been previously subjected to a pumping operation.

Bottoms

In a distilling operation, those portions of the charge remaining in the still or flask at the end of the run.

Bottom Steam

A term applied to the steam injected into the bottom of a tower or still to effect stripping of light materials.

Break

Separation into two layers such as oil and water.

Breathing

The movement of gas (oil vapours or air) in and out of the vent lines of storage tanks due to alternate heating and cooling.

Bridge-Wall

A vertical wall serving on the confining walls of a furnace and used for separating the combustion or radiant zone from the convection zone.



Bromine Number

A measure of the degree of unsaturation of the material to which the test is applied (ASTM D875.46T)

B/sd

An abbreviation for the term "Barrels per stream day". The total number of barrels of materials flowing through a unit in a given process period divided by the number of actual lion stream days will yield the average B/SD.

B.S. & W

An abbreviation for the terms "Bottom sediment and water" A volumetric measure of the sediment and water in petroleum product as determined by ASTM D96-46.

Bubble-Cap

A cup-like element of the "Bubble-cap tray" placed over the chimney-like "risers" of the tray. It directs the ascending vapours in a fractionating column into contact with the liquid maintained on the trays.

Bubble-Place

A term applied to the elements of a fractionating column consisting of a casting perforated with a multitude of chimney-like "Risers" which, in practice, are capped with the bubblecaps.

Bubble Tower or Column

A fractionating tower so constructed that the vapours generated in a tower pass upward through layers of condensate contained on a series of trays. The vapour passes from a given tray to the next above by bubbling under a cap and out through the liquid layer. An approach of equilibrium between the vapour and the liquid on the tray is thus obtained, the less volatile components of the vapour condense and the excess liquid overflows to the tray next below and so back to tower bottom.

Bunker Fuel

A class of residual oil possessing high viscosity, requiring burners equipped with preheaters.

Carbon Residue

The amount of carbon residue left on evaporating oil under specified conditions, reported in wt. % of the original sample. See ASTM D189-46.

Catalysts

Any substance, which, by virtue of its presence, alters the rate of a chemical reaction and which, in general, remains unchanged at the end of the reaction.

Catalyst Extruded

Catalyst formed by forcing a paste-like mixture through small holes, cutting into short lengths and drying.

Catalyst Fluidised

A term usually applied to a solid catalyst, which has been reduced to particles small enough that the catalyst will flow in the manner of a liquid.

Catalyst Impregnated

A catalytic medium consisting of a solid porous particle serving as a carrier for the activating salt with which it has been impregnated.

Caustic Soda

A solution of sodium hydroxide (lye) used for the neutralization of oils following acid treatment.

Caustic Neutralization

The chemical reaction in which acidic materials are rendered neutral by the addition of caustic soda.

Caustic Treating

Any process involving the use of a caustic solution for removal of H₂S, mercaptans, and other acidic constituents.

Cetane Number

A measure of the tendency of diesel fuels to knock in an engine.

Clear Gasoline

Unleaded water white gasoline motor fuel.

Coalescer

Generally a device which employs a fixed Porous bed of material insoluble in the fluids passed through it and which promote by mechanical means the coalescence of finally dispersed materials to render them readily separable.

Coke

Carbonaceous material deposited on the catalyst cracking unit during the cracking reaction. Also forms in Platforming and Unifining catalyst more slowly. Sometimes found in hot exchangers as a fouling material.

Colour Stability

A measure of the tendency of a material to resist change in colour, usually expressed as loss in colour units after storage or exposure to light.



Compressors

A device for raising the pressure level of a gas or vapour to a higher pressure.

Condenser

Equipment used for liquefying oil vapours coming from distillation equipment. Generally uses water as cooling medium.

Condensate

The liquid product coming from a condenser.

Conradson Carbon

The carbon residue obtained by combined combustion and evaporation of petroleum oil in accordance with ASTM testing procedures. (ASTM D189-46).

Continuous Treater

A piece of equipment, designed to operate continuously, in which a process stream is brought into desired contact with a treating stream and then afforded adequate means of separation. The treating stream brings about desired changes in the chemical composition of the material being processed.

Convection Section

The section of a furnace shielded from direct flame radiation in which heat transfer takes place by conduction and convection from hot exit flue gases.

Conversion

A measure of the degree of catalytic cracking defined as the percent of the gas oil charge, which disappears.

$$\% \text{ Conversion} = \frac{100 \times \text{Bbls charges} - \text{Bbls Cycle oil produced}}{\text{Bbls charged}}$$

Cooling Tower

Equipment for recirculating hot water, once used, cooling it by evaporation with air pulled up through the tower by fans and pumped back to the process units for reuse as cool water.

Copper Number

A measure of the Mercaptan sulphur content of a stock expressed as milligrams of Mercaptan sulphur per 100 milliliter of sample.

Cracked Stock

Oil which has been subjected to a breaking-down action by heating to high temperatures. Such oil contains a higher percentage of "unsaturated" compounds

than does straight run stock from crude. Such unsaturated compounds are desirable in oils used as motor fuels and solvents, but require treating or the addition of inhibitors to make stable finished products.

Cracking

A decomposition process of making oils of low boiling range (100°F to 550°F) to be used for motor fuels and burning oils from oils to high boiling ranges (550°F to 800°F such as gas oil and fuel oil.

Crestylate

Products of reaction of caustic with olefinic hydrocarbons.

Crude Petroleum

A naturally occurring mixture, consisting predominantly of hydrocarbons and /or sulphur, nitrogen and/or oxygen derivatives of hydrocarbons which is removed from the earth in liquid state or is capable of being so removed. Crude petroleum is commonly accompanied by varying quantities of extraneous substances such as water, inorganic matter and gas.

Cut

A portion of the distillate from a distillation tower which is kept separate from the remainder of distillate. In running crude at the Crude Unit for example, the product may include a light naphtha cut, heavy naphtha cut, kerosene cut, etc, each of which is collected separately.

Cutback

To reduce the viscosity of an oil by mixing with it another oil of lower viscosity.

Cycle Stock

Gas oil which has been subjected at least once to the cracking process, and which is ordinarily lower in API gravity for a given boiling point, lower in aniline number higher in unsaturation and aromaticity, and more refractory towards further cracking than the virgin charging stock from whom which it was made.

Cyclic Compound

A compound containing a ring molecular structure.

Cyclones

A device to separate solids from vapour by centrifugal action.

Debutanizer

A device, usually some form of a fractional distilling column, used for removing butane from a hydrocarbon stream.



Decanted Oil

An oil which is separated from heavier material by pouring off from the top of the container. In general usage applied to our refinery refers to slurry oil removed from the bottom of the main fractionator at the catalytic cracking unit after settling out the catalyst.

Dehydrogeneration

Removal of hydrogen usually by a catalytic process is an example.

Demulsifier

Equipment or a chemical for separating emulsions into separates layers.

Desalter

Equipment for removing salt from crude oil.

Diesel Index

Measures diesel fuel ignition quality. Diesel Index Number- (API Gravity) x (Aniline Pt.) x (0.01)

Diplegs

Pipe extensions on cyclones that dip underneath the catalyst bed level to return separated catalyst back to the bed.

Distillation

Distillation generally refers to vaporization processes in which the vapour evolved is recovered usually by condensation and a separation is effected between those fractions which Vaporize and those which remain as liquid.

Doctor Test

A Laboratory test to determine when a stock is sweet.

Downcomer

A pipe which carries the overflow liquid from one tray to the next lower in a fractionating or stripping bubble tower.

Dry Gas

Gas which contains little or no recoverable naphtha (condensable). Refinery fuel gas from the VRU is an example of "Dry Gas".

End Point

The highest temperature reading observed on the distillation thermometer during the laboratory distillation procedure (ASTM D86-46).

Ethyl Fluid

A commercial form of tetraethyl lead. This mixture contains certain additional ingredients, which are added chiefly for the purpose of preventing deposits of lead oxide from building up in the engine.

Excess Air

Air above that is required for providing the exact amount of oxygen required for complete combustion in a firebox.

Exchanger

Closed coil heat exchangers (tube and shell type) are used throughout the plant wherever there is a possibility of conserving heat. Hot oil is run counter current to cold oil.

Explosive Limits

The range of percentages of a combustible material in the presence of air which will explode; often expressed as a percent of the lower explosive limit as determined on an M.S.A. combustible gas testing.

FBP

In ASTM distillation (D83-46) the maximum temperature observed on the distillation thermometer. Final Boiling Point.

Filter

A porous article or mass as of cloth paper, sand or charcoal, through which a liquid is passed to separate from it matter held in suspension, or in some cases, dissolved impurities or coloring matter.

Fire Point

The temperature to which a material must be raised to support continuous combustion when tested under standard conditions (ASTM D92-46).

Flash Point

Flash point is the temperature at which oil will vaporize sufficiently to support combustion momentarily. Used extensively to determine oil storage conditions. (ASTM D93-46, D56-36, D92-46).

Flash Distillation

Vaporization in which all the vapour formed remains in contact with the residual liquid during the vaporization process.



Flash Tower

A tower in which the entering feed consisting of a vapour liquid mixture is flashed. The tower may or may not have reflux and plates but no reboiler and effects a rough separation of the feed into vapour and liquid.

Floating Head

The head over the end of a tube bundle within a heat exchanger which is not anchored to the shell but is free to move longitudinally to allow for thermal expansion.

Flooding

A condition which occurs in a fractioning column when the vapour velocity in the tower exceeds a critical value. This increased velocity is accompanied by increased pressure drop through the liquid. This results in excessive liquid build up on the trays.

Fractionation

Separation of a material into several parts by repeated operations, such as distillation, crystallization, precipitation etc. as ordinarily used in the plant, fractional distillation is meant.

Fresh Feed

Feed stock that enters the unit for the first time as differentiated from recycle feed.

Fuel Oil

Any liquid petroleum product used for the generation of heat in a furnace or firebox, the controlling factors being cost and adaptability.

Furnace

An enclosed vessel in which heat for transmission is produced by fuel combustion

Furnace Oil

A heavy oil suitable for combustion in a furnace.

Gas Oil

A term originally used by gas companies, meaning oil suitable for making gas.

Gasoline

A petroleum product suitable for use as fuel in the present-day automobile or aircraft engines. A petroleum product of low initial boiling point (about 100°F) and a more or less uniform distillation range up to the maximum boiling point, the latter point varying with different gasoline from about 250°F to 400°F end point.

Gland Oil

Oil injected into the shaft packing at pumps to prevent the escape of material being pumped.

Gum (Gasoline)

A mixture of compounds of high molecular weight believed to be formed by the polymerization and oxidation of unsaturated materials in gasoline. Gum formation is accelerated by long storage, heat, presence of air and certain metal catalyst. It is very undesirable in gasoline.

Header

A metal place located at the end of a heat exchanger for the purpose of directing the flow of one bank (series) of tubes into another bank. Also, a pipe or vessel, with one or more inlet connections and a multiplicity of take-off connections used as a common supply to various other vessels.

Heavy Ends

A term used in speaking of oils where the distillation range is of importance, meaning the highest boiling portion presents. The maximum or end point as obtained in the 100°C distillation of a sample of gasoline is determined largely by the amount and character of the "heavy ends" present in the gasoline.

Hot Spot

A localized area of excessive temperature on a furnace tube or reactor shell.

Inhibitor

Any substance, the presence of which, even in very small amounts, greatly diminishes the rate of a chemical reaction. The unqualified term most often refers to an anti-oxidant, which is added to gasoline to reduce the formation of gum.

Initial Boiling Point

Temperature at which the first drop is recovered in an Engler distillation.

Image

A measure of the depth of liquid in a tank or other container. Normally, tank gauges are image gauges unless otherwise specified.

Intercooler

A cooler located at an intermediate stage of an absorber for lowering the temperature of the absorbing liquid as it descends in the column; or a cooler placed between stages in a multi-stage compressor to remove the heat of compression.



Isomerization

The process whereby a straight-chain hydrocarbon is changed to an isomeric form without change of molecular weight.

Jump-Over

A term used to describe a bypass line i.e., a pipe leading around equipment or from one line to another.

Kerosene

A general term covering the class of refined oils boiling between 350°F and 572°F used in domestic oil lamps and cooking stoves. Also used as a fuel in some internal combustion engines.

Lead Index

The lead contents of gasoline components do not usually blend volumetrically. Accordingly, the TEL content is converted to a lead index scale, which does blend volumetrically. The resultant lead index is then converted back to a TEL content. It is especially useful in blending gasoline to a certain octane level by calculating the TEL required.

Leading

The addition of Tetraethyl Lead to hydrocarbon naphtha.

Lead Susceptibility

The improvement in Octane number realized from the addition of incremental quantities of tetraethyl lead to a gasoline fraction.

Lean Oil

In an absorbing process, the oil which is lean in the components being absorbed.

Light Ends

In any given batch of oil, that portion of lowest boiling point. In gasoline the portion distills off up to about 158°F. In making lubricating oils, the 'light ends' or light distillates must be removed in order to produce finished oils of high flash point.

LPG

Liquefied petroleum gas, usually propanes, butanes or a mixture of the two.

Mercaptan

A compound contains a radical group 'SH'. These compounds have a very offensive odour, which is detectable even when they are present in extremely small concentrations.

Merox

A patented process for the sweetening of naphtha involving the use of catalyst.

Motor Octane Number

See Octane Number, Motor.

Naphtha

Oil or low boiling ranges (80°F to 440°F) usually of good colour and odour when finished.

Naphthalene

A saturated ring molecule composed entirely of carbon and hydrogen. There may be two or more attached saturated rings in naphthalene molecule.

Naphthenic Crude

A crude, the characteristics of which are similar to or approach those of naphthenic hydrocarbons. A Watson and Nelson characterization factor of less than 11-50 are used to denote this type of crude.

Nozzle

A nozzle is a flanged opening in a tower, drum or large pipe used for connecting lines.

Octane Number

A measure of the tendency of a motor fuel to knock in an internal combustion engine as compared with a mixture of normal heptane and ISO-octane in the same engine. Thus a fuel with an octane number of 100 being measured knocks under the same conditions as pure ISO-octane and fuel with an octane number of 50 knocks under the same conditions as a 50-50 mixture of normal heptane and ISO-octane.

Octane Number Motor

The motor octane number is a measure of the antiknocking characteristic of gasoline. Its numerical value is expressed as that percentage of iso-octane, which must be mixed with normal heptane in order to match the knock intensity of the gasoline when tested in a standard motor fuel-testing engine.

Octane Number, Research

The research octane number is a measure of the antiknocking characteristic of a gasoline when tested under less severe conditions than those employed for obtaining the motor octane number.



Octane Number, Road

The road octane number is a measure of the knocking tendencies of a gasoline under normal driving conditions. It is estimated by the formula $M + \frac{2}{3}(R - M)$ where M and R are the motor octane and research octane values, respectively of the fuel. This quantity may also be determined under specified conditions in test automobiles.

Once-Through

A once-through operation is a single pass of the reactants through a reactor.

Operating Factor

The ratio of the total 'on-stream' time of a unit to the total time that it could have been on stream if it did not have to be shut down for cleaning, Repair and stand-by service.

ORSAT

Apparatus for determining concentrations of O₂, CO and CO₂ in flue gases.

Overhead

In a distilling operation, that portion of the charge which is vapourised off through suitable lines and condensed in cooling coils back to liquid, thus separating it from the portion of the charge remaining in the still.

Paraffinic Crude

Crude, which has basic properties similar to those of the saturated straight chain paraffins. A characterization factor greater than 11.81 is used to denote this type of crude.

pH

A measure of acidity, negative logarithm to the base 10 of hydrogen ion concentration

Plate

A substantially horizontal structure supported in vertical cylindrical chambers and adapted for intimately contacting vapours or gases rising from below the structure to bubble through the retained liquid. The plates are usually of the bubble cap type, valve type or perforated plates. Also, a cover to close manway openings in a vessel.

Platforming

It is patented regenerative catalytic reforming process developed by United Oil Products Company to produce a high yield of high octane gasoline from virgin naphtha.

Platformate

The catalytically reformed product from the Platformer.

Plenum

The collecting chamber for flue gas on a furnace or vapours from cyclone separators.

Polymer

An organic compound of high molecular weight formed by combining unsaturated or cyclic compounds.

Priming

Roughly equivalent to puking.

Puking

A still is said to "puke" when the oil foams and rises in the still so high that part of the charge is driven overhead through the vapour line in the liquid state.

Pump-Out Line

A line for removal of the material in a vessel without any loss usually used on unit or individual equipment shutdowns.

Purge

The cleaning or removal of existing materials by displacing with another medium.

Quench

Sudden cooling of hot products by injection of cold oil.

Radiant Section

That portion of the furnace coil which is located in such a manner so as to be exposed to direct radiation from the flames.

Range Tube

A part of a flow-indicating instrument that determines the pressure differential range over which it will operate and which can be changed to suit requirements of the service in which the flow instrument is operating.

Reactor

A vessel in which a reaction takes place, more often it refers to the catalyst vessel in a catalytic process.

Reactor Effluent

The mixture of products leaving a reactor.



Reboiler

A tubular heat exchanger placed at the bottom of a fractionating tower or stripper to supply the necessary tower heat. The liquid from the bottom tray passes through the boiler where it is heated by indirect exchange with a hotter liquid or by steam. The heated liquid and vapours formed then return to the bottom of the tower. A direct fired coil may sometimes be used instead of a tubular exchanger

Recirculation

The re-passage of one or more of the components of a stream through a given system.

Recycle

That portion of the products of a process, which is re-submitted to the process.

Reduced Crude

The bottoms remaining from a distillation of crude oil are referred to as "reduced crude". The terms 20%, 40% and 60% reduced crude represent crude which have been reduced to 20%, 40%, 60% of their original volume by distillation. See also "residuum".

Reduction

A distillation where the oil remaining in the still (the bottom) is an important product of the run, this bottom being concentrated (reduced) to viscosity or other required test by distilling off the lighter portions of the charge.

Reflux

The condensed distillate which is returned to the top of a fractionating tower to serve as a heat and material-transfer medium in the fractionation process. It is frequently called "pump-back" by plant operators.

Reflux Rate

Rate of addition of a cool liquid to a tower in order to remove heat and thereby to induce reflux in the tower.

Reformate

Product of a reforming operation

Reforming

The submission of virgin naphtha to a cracking operation for the purpose of producing a product of improved knock value by changing the molecular structure.

Refractive Index

Ratio of the velocity of light in a vacuum to its velocity in a substance. Useful in identifying substances.

Refractory

A hard lining used to resist abrasion or heat. Used in reactors, regenerators, furnaces and lines. Can also mean difficult to crack. Oils that have been cracked once are refractory.

Regeneration

Process by which coke deposited on a catalyst is burned off and the catalyst thereby reactivated. In general, any process by which a spent material is made available for reuse.

Regenerator

The vessel in which regeneration of used catalyst or other material takes place.

Regular Gasoline

A name used to designate a lower octane motor gasoline as compared to a higher grade called "Super-Premium".

Reid Vapour Pressure (RVP)

The vapour pressure at 100°F, as determined in the laboratory

Research Octane Number

See Octane Number, Research.

Residual Fuel Oil

Reduced crude or viscous residuums obtained from refinery operations and suitable for burning & furnace or firebox.

Residuum (RESID.)

The coloured, highly viscous oil remaining in a still from a charge of crude oil, after the more volatile portion of the charge has been distilled off.

Rich Oil

The exit oil stream from an absorber. So called because it is relatively rich in those components which it is designed to absorb.

Riser

One of a number of small vertical pipes extending slightly above the surface of bubble plate through which vapours from the next lower plate pass upward.

Road Octane Number

See Octane Number, Road.



Run Down Line

Lines of pipe leading to the tanks from process units.

Running-Gauge

A tank gauge which is taken at a time when material is being pumped into or out of the tank.

Saybolt Viscosity

A measure of viscosity of petroleum products as determined in a Saybolt Viscometer (ASTM D88-44)

Scale

The general term refers to any hard incrustation formed on equipment. When ferrous structures, rust, the iron oxide corrosion products usually remain in the form of a scale. When natural waters are passed through equipment, deposits of calcium and magnesium salts occur.

Scrubber

A piece of equipment designed to remove a particular component from a gas or vapour stream usually by counter current contact with a liquid.

Scrubbing Tower

A vessel designed to act as a scrubber.

Sensitivity (Octane)

A term referring to the difference between the research and motor octane ratings, the more sensitive fuels exhibiting greater differences. The sensitivity represents the decrease in octane rating of a fuel occasioned by a change in the severity of test conditions from the research to the motor method.

Separator

A device, usually a drum, employed for the division of a multiphase system (usually two phases) into its constituent phases. May be used to separate vapours from liquids of different densities.

Separator Drum

A synonym for "Separator" but is more specifically applied to small cylindrically shaped containers.

Severity Factor

A factor usually associated with cracking processes to indicate the severity of operation, i.e. in catalytic cracking the factor used is catalyst to oil ratio divided by the weight hour space velocity.

Shell Side

The space between the tube bundle and the outer shell of a heat exchanger. The shell side liquids are that which flows through this space.

Shielded Section

A group of furnace tubes which, by their position in the furnace, are shielded either by other tubes or by a bridgewall from direct sight of the flame.

Side Stream

A stream taken from any intermediate plate in a fractionating tower, i.e., from the side rather than the top or bottom of the tower.

Single Pass

When used in conjunction with heat transfer equipment (usually reboiler and condensers), single pass means that the medium on the tube side flows in one direction. Multiple passes may be had on both shell and tube sides by a baffle arrangement.

Skimmer

A device for allowing oil to be separated from water by removing the shallow layer of oil.

Slip Stream

A portion of stream, which is removed, subjected to a separate operation, and returned to the main stream i.e., recycle.

Slop

A term rather loosely used to denote odd ends of oil produced at various places in the plant, which must be returned or further processed in order to be brought into suitable conditions for use.

Slurry

Any mixture of solids and liquids. Most commonly used on FCCU in reference to fractionators bottoms oil containing catalyst.

Sock

Hold on oil at an elevated temperature to allow a reaction to proceed to desired point.

Sour

Gasoline, naphtha and refined oils are said to be "sour" if they show a positive "doctor test". Sourness is directly connected with odour it being usual for a "sour" gasoline to have a bad odour while a "Sweet" gasoline has a good odour (See "Sweet")



Space Velocity (Various Units)

A factor used in catalytic reforming and cracking processes giving the relative amounts of reacting material and catalyst; common units are volume per hour per volume of catalyst and weight.

S.S.U.

Seconds saybolt Universal, a measure of viscosity.

Stabilizer

A fractionating column and heat exchanger system operating under pressure which is used to remove and recover the volatile light hydrocarbons always present in distillate and absorption plant.

Stock

In general, any oil, which is to receive further treatment before going into finished products. Used also in a more restricted sense, meaning any oil which is finished as far as refining operations are concerned but which must still be mixed, blended, or compounded with some other oil before becoming a finished product. More properly spoken of in this sense as "Finished Stocks".

Strapping of Tank

Calibrating the volume of a tank.

Stripper

A fractionating device use to remove relatively low boiling materials from a liquid stream made up mostly of higher boiling components. This is accomplished by counter-current scrubbing with a stream of gas, such as fuel gas or steam or may be accomplished by heating the liquid in the bottom of the fractionator.

Stripping Steam

Steam used in a stripper to remove low-boiling components from a liquid stream.

Superheat

Heat added to vapour to raise its temperature above the dew point at the pressure existing. The term is also applied to the temperature difference between the vapour and its dew point.

Surface Condenser

A condenser in which the cooling medium and the vapour to be condensed are separated by metal surfaces.

Sweet

Gasoline, naphtha and refined oil are said to be sweet if they show a negative "doctor" test.

Sweetening

The process of treating a hydrocarbon stock for the purpose of removing or converting to a less undesirable form the sulphur compounds present.

Tape Gauge

A gauge taken with a tapeline.

Tar

Heavy bottoms which did not distill overhead

Tetra Ethyl Lead (TEL)

A gasoline additive used to increase octane number. This material is highly toxic and must be handled with special precautions.

Topped Crude

See "Reduced Crude"

Torch Oil

This term refers to oil, which is burned for the purpose of keeping a torch lit. In the case of fluid catalytic cracking unit it refers to oil burned in the regenerator for the purpose of keeping the unit in heat balance or for start up.

Tower

Vessel containing fractionating trays or packing in which fractional distillation takes place.

Transfer Line

Refers to a line carrying oils and/or gases at some elevated temperature (usually from a furnace) to some other equipment i.e., line from outlet of a furnace to a reactor or reboiling system.

Tray

Also termed "Bubble plate" in petroleum refining, usually refers to a part of a fractionating tower the purpose of which is to contact liquid and vapour in a counter-current manner.

Trickle Valve

A check valve on the bottom of cyclone diplegs to prevent backflow of catalyst into the cyclones.

Tube Sheet

The section in a heat exchanger which separates the liquid flowing through the tubes from the liquid in the shell and holds the tubes in place. In a furnace, a sheet or metal wall into which the tubes are secured by tube rolling.



Tube Side

Pertains to material flowing through the tubes of a heat exchanger.

Turnaround

The shutdown period for an operation unit usually for mechanical reconditioning. The period from the end of one run to the beginning of the next, i.e., off-stream to on-stream period.

Unifining

A patented catalytic process for the removal of sulphur, nitrogen and oxygen compounds from naphtha or distillates.

Vapour

A substance in the gaseous state which can be condensed by cooling or compression.

Vapour Line

The pipe through which the oil vapours is led from the still to the condenser.

Vapour Phase

In the gaseous state

Vapour Pressure

The pressure exerted by a vapour, which is in a state of equilibrium with a solid, or solution at a specified temperature.

Virgin Stock

Oil derived directly from crude oil and which contains no cracked material. Pure crude oil with out any slop materials mix up.

Viscosity

The resistance to flow displayed by a fluid (liquid or gas). In the petroleum industry, the viscosity of the liquids is usually measured by the Saybolt viscometer

Volatility

The tendency of a liquid to turn to vapour.

Weir

A weir is a flat-notched dam or obstruction to liquid flow and it normally used for either the measurement of fluid flows or to maintain a given depth of fluid as on a tray of fractionating tower

Wet Gas

Wet Gas is gas containing important amounts of heavier hydrocarbons such as butane, pentane, etc., useful as gasoline components.

General Conversion - Length

To convert To obtain Multiply by	Inches	Feet	Yards	Miles	Milli meters	Centi meters	Meters	Kilo meters
Inches	1	12	36	6.336 $\times 10^4$	3.937 $\times 10^{-2}$	.3937	39.37	3.937 $\times 10^4$
Feet	8.333 $\times 10^{-2}$	1	3	5280	3.281 10^{-3}	3.281 $\times 10^{-2}$	3.281	3281
Yards	2.778 $\times 10^{-2}$	.3333	1	1760	1.094 $\times 10^{-3}$	1.094 $\times 10^{-2}$	1.094	1094
Miles	1.578 $\times 10^{-5}$	1.894 $\times 10^{-4}$	5.682 $\times 10^{-4}$	1	6.214 $\times 10^{-7}$	6.214 $\times 10^{-6}$	6.214 $\times 10^{-4}$	.6214
Millimeters	25.4	304.8	914.4	1.609 $\times 10^6$	1	10	10^3	10^6
Centimeters	25.4	30.48	91.44	1.609 $\times 10^5$	.1	10	10^3	10^6
Meters	2.54 $\times 10^{-2}$	.3048	.9144	1609	.001	.01	1	10^3
Kilo meters	2.54 $\times 10^{-5}$	3.048 $\times 10^{-4}$	9.144 $\times 10^{-4}$	1.609	10^{-6}	10^{-5}	.001	1



General Conversion Table - Volume

To obtain To convert Multiply by	Cu.inches	Cu.feet	Cu.yards	Cu.meters	Pints	Quarts	U.s.gallons
Cu.inches	1	1728	46.656	6.102 $\times 10^4$	28.87	57.75	231
Cu.feet	5.787 $\times 10^{-4}$	1	27	35.31	1.671 $\times 10^{-2}$	3.342 $\times 10^{-2}$	.1337
Cu.yards	2.143 $\times 10^{-5}$	3.704 $\times 10^{-2}$	1	1.308	6.189 $\times 10^{-4}$	1.238 $\times 10^{-3}$	4.951 $\times 10^{-3}$
Cu.meters	1.639 $\times 10^{-5}$	2.832 $\times 10^{-2}$	.7646	1	4.732 $\times 10^{-4}$	9.464 $\times 10^{-4}$	3.785 $\times 10^{-3}$
Pints	3.463 $\times 10^{-2}$	59.84	1616	2113	1	2	8
Quarts	1.732 $\times 10^{-2}$	29.92	807.9	1057	.5	1	4
U.s. Gallons	4.329 $\times 10^{-3}$	7.481	202	264.2	0.125	.25	1

General Conversion Table - Area

To convert To obtain Multiply by	Sq. inches	Sq. feet	Sq. yards	Sq. miles	Acres	Sq. cms	Sq. meters	Sq.kilo meters
Sq.inches	1	144	1296	4.015 $\times 10^9$	-	0.155	1550	1.55 $\times 10^9$
Sq.feet	6.944 $\times 10^{-2}$	1	9	2.788 $\times 10^7$	4.356 $\times 10^4$	1.076 $\times 10^{-3}$	10.76	1.076 $\times 10^7$
Sq.yards	7.716 $\times 10^{-4}$	.1111	1	3.098 $\times 10^6$	4840	1.196 $\times 10^{-4}$	1.096	1.196 $\times 10^6$
Sq.miles	-	3.587 $\times 10^{-8}$	3.228 $\times 10^{-7}$	1	1.562 $\times 10^{-2}$	3.861 $\times 10^{-11}$	3.861 $\times 10^{-7}$	.3861
Acres	-	2.296 $\times 10^{-5}$	2.066 $\times 10^{-4}$	640	1	-	2.471 $\times 10^{-4}$	2.471
Sq.cms	6.452	929	8361	2.59 $\times 10^{10}$	-	1	10^4	10^{10}
Sq.meters	6.452 $\times 10^{-4}$	9.29 $\times 10^{-2}$	.8361	2.59 $\times 10^6$	4047	.0001	1	10^6
Sq.kms	6.452 $\times 10^{-10}$	9.29 $\times 10^{-8}$	8.361 $\times 10^{-7}$	2.59	4.047 $\times 10^{-3}$	10^{-10}	10^{-6}	1

General Conversion Table - Weight

To obtain To convert Multiply by	Grams	Kilograms	Ounces	Pounds	Tons
Grams	1	1000	28.35	453.6	1.016×10^6
Kilograms	.001	1	2.835×10^{-2}	.4536	1016
Ounces	3.527×10^{-2}	35.27	1	16	3.584×10^4
Pounds	2.205×10^{-3}	2.205	6.250×10^{-2}	1	2240
Tons	9.842×10^{-7}	9.842×10^{-4}	2.790×10^{-5}	4.464×10^{-4}	1

**General Conversion Table - Speed**

To obtain To convert Multiply by	Mts/sec	Mts/min	Kms'hr	Ft/sec	Ft/min	Mph	Knots
Mts/sec	1	1.667 $\times 10^{-2}$	.2778	.3048	5.080 $\times 10^{-3}$	4770	.5148
Mts/min	60	1	16.67	18.29	.3048	26.82	30.88
Kms/hr	-	.06	1	1.097	1.829 $\times 10^{-2}$	1.609	1.853
Ft/sec	3.281	5.468 $\times 10^{-2}$	.9113	1	1.667 $\times 10^{-2}$	1.467	1.689
Ft/min	196.8	3.281	54.68	60	1	88	101.3
MPH	2.237	3.728 $\times 10^{-2}$	.6214	6818	1.136 $\times 10^{-2}$	1	1.152
Knots	1.943	3.238 $\times 10^{-2}$	.5396	.5921	9.868 $\times 10^{-3}$	0.8684	1

General Conversion Table - Pressure
British Pressure Equivalent 1lb/IN2 = 0.07 .307 kg/cm²

lb/in ²	Kg/cm ²	lb/in ²	Kg/cm ²	lb/in ²	Kg/cm ²	lb/in ²	Kg/cm ²	lb/in ²	Kg/cm ²	lb/in ²	Kg/cm ²
10	.706	210	14.764	410	28.826	610	42.887	810	56.949	1010	71.010
20	1.406	220	15.468	420	29.529	620	43.590	820	57.652	1020	71.713
30	2.109	230	16.171	430	30.232	630	44.293	830	58.355	1030	72.416
40	3.812	240	16.874	440	30.935	640	44.937	840	59.058	1040	73.119
50	3.515	250	17.577	450	31.638	650	45.700	850	59.761	1050	73.822
60	4.218	260	18.280	460	32.341	660	46.403	860	60.464	1060	74.526
70	4.921	270	18.983	470	33.044	670	47.106	870	61.167	1070	75.229
80	5.625	280	19.686	480	33.747	680	47.809	880	61.870	1080	75.932
90	6.328	290	20.389	490	34.450	690	48.512	890	62.573	1090	76.635
100	7.031	300	21.092	500	35.144	700	49.215	900	63.276	1100	77.328
110	7.734	310	21.795	510	35.857	710	49.918	910	63.979	1110	78.041
120	8.437	320	22.498	520	36.560	720	50.621	920	64.683	1120	78.744
130	9.140	330	23.201	530	37.263	730	51.324	930	65.386	1130	79.447
140	9.843	340	23.904	540	37.966	740	52.027	940	66.089	1140	80.150
150	10.546	350	24.607	550	38.669	750	52.730	950	66.792	1150	80.853
160	11.249	360	25.311	560	39.372	760	53.433	960	67.495	1160	81.556
170	11.592	370	26.014	570	40.075	770	54.136	970	68.198	1170	82.259
180	12.655	380	26.717	580	40.778	780	54.840	980	68.901	1180	82.962
190	13.358	390	27.420	590	41.481	790	55.543	990	69.604	1190	83.665
200	14.061	400	28.123	600	42.184	800	56.246	1000	70.307	1200	84.369



Metric Pressure Equivalents
1 kg.per cm² = 14.223 lb Per Sq.in

kg/cm ²	lb/in ²	kg/cm ²	lb/in ²	kg/cm ²	lb/in ²	kg/cm ²	lb/in ²	kg/cm ²	lb/in ²	kg/cm ²	lb/in ²
50	711.17	70	995.6	90	1280.1	110	1564.6	130	1849.0	150	2133.5
51	725.39	71	1009.9	91	1294.3	111	1578.8	131	1863.3	151	2147.7
52	739.61	72	1024.1	92	1308.5	112	1593.0	132	1877.4	152	2161.9
53	753.84	73	1038.3	93	1322.8	113	1607.2	133	1891.7	153	2176.2
54	768.06	74	1052.5	94	1327.0	114	1621.5	134	1905.9	154	2190.4
55	782.28	75	1066.7	95	1351.2	115	1635.7	135	1920.1	155	2204.6
56	796.51	76	1081.1	96	1365.4	116	1649.9	136	1934.4	156	2218.8
57	810.73	77	1095.2	97	1379.7	117	1664.1	137	1948.6	157	2233.1
58	824.95	78	1109.4	98	1393.9	118	1678.3	138	1962.8	158	2247.3
59	839.18	79	1123.6	99	1408.1	119	1692.6	139	1977.4	159	2261.5
60	853.40	80	1137.9	100	1422.3	120	1706.8	140	1991.3	160	2275.7
61	867.62	81	1152.1	101	1436.6	121	1721.0	141	2005.5	161	2290.0
62	881.85	82	1166.3	102	1450.8	122	1735.2	142	2019.7	162	2304.2
63	896.07	83	1180.5	103	1465.0	123	1749.5	143	2033.9	163	2318.4
64	910.29	84	1194.8	104	1479.2	124	1763.7	144	2048.2	164	2332.7
65	924.52	85	1209.4	105	1493.4	125	1777.1	145	2062.4	165	2346.9
66	938.74	86	1223.2	106	1507.7	126	1792.1	146	2076.6	166	2361.1
67	952.96	87	1237.4	107	1521.9	127	1806.4	147	2090.8	167	2375.3
68	967.19	88	1251.7	108	1536.1	128	1820.6	148	2105.0	168	2381.5
69	981.41	89	1265.9	109	1550.3	129	1834.8	149	2119.3	169	2403.7

Temperature Conversions

°C	°F	°C	°F	°C	°F
-40	-40	-2.2	82.4	31.1	190.4
-37.2	-31	-1.1	86	32.2	194.0
-34.4	-22	0	89.6	33.3	197.6
-31.7	-30	1.1	93.2	34.4	201.2
-28.9	-4	2.2	96.8	35.6	204.8
-26.1	5	3.3	100.4	36.7	208.4
-23.3	14	4.4	104.0	37.8	112.0
-22.8	15.8	5.6	107.6	40.6	121.0
-22.2	17.6	6.7	111.2	43.3	230.0
-21.7	19.4	7.8	114.8	46.1	239.0
-21.1	21.2	8.9	118.4	48.9	248.0
-20.6	23.0	10	122.0	51.7	257.0
-20.0	24.8	11.1	125.6	54.4	266.0
-19.4	26.6	12.2	129.2	56.2	275.0
-18.9	28.4	13.3	132.8	60.0	284.0
-18.3	30.2	14.4	136.4	62.8	293.0
-17.8	32.0	15.6	140.0	65.6	302.0
-16.7	35.6	16.7	143.6	68.3	311.0
-15.6	39.2	17.8	147.2	71.1	320.0
-14.4	42.8	18.9	150.8	73.9	129.0
-13.3	46.4	20	154.4	76.7	338.0
-12.2	50	21.1	158.0	79.4	247.0
-11.1	53.6	22.2	161.6	82.2	156.0
-10.0	57.2	23.3	165.2	85.0	365.0
-8.9	60.8	24.4	168.8	87.8	374.0
-7.8	64.4	25.6	172.4	90.6	383.0
-6.7	68	26.7	176.0	93.3	392.0
-5.6	71.6	27.8	179.6	98.9	410.0
-4.4	52	28.9	183.2	104.4	428.0
-3.3	78.8	30	186.8	110.0	446.0



Temperature Conversions

°C	°F	°C	°F
115.6	434	232.2	842
121.1	482	237.8	860
126.7	500	243.3	878
132.2	518	248.9	896
137.8	536	254.4	914
143.3	554	260	932
148.9	572	265.6	950
154.4	590	271.1	968
160.0	608	276.7	986
165.6	626	282.2	1004
171.1	644	287.8	1022
176.7	662	293.3	1040
182.2	680	298.9	1058
187.8	698	304.4	1076
193.3	716	310.0	1094
198.9	734	315.6	1112
204.4	752	-	-
210.0	770	-	-
215.6	788	-	-
221.1	806	-	-
226.7	824	-	-

Properties of Inflammable Solids, Liquids and Gases

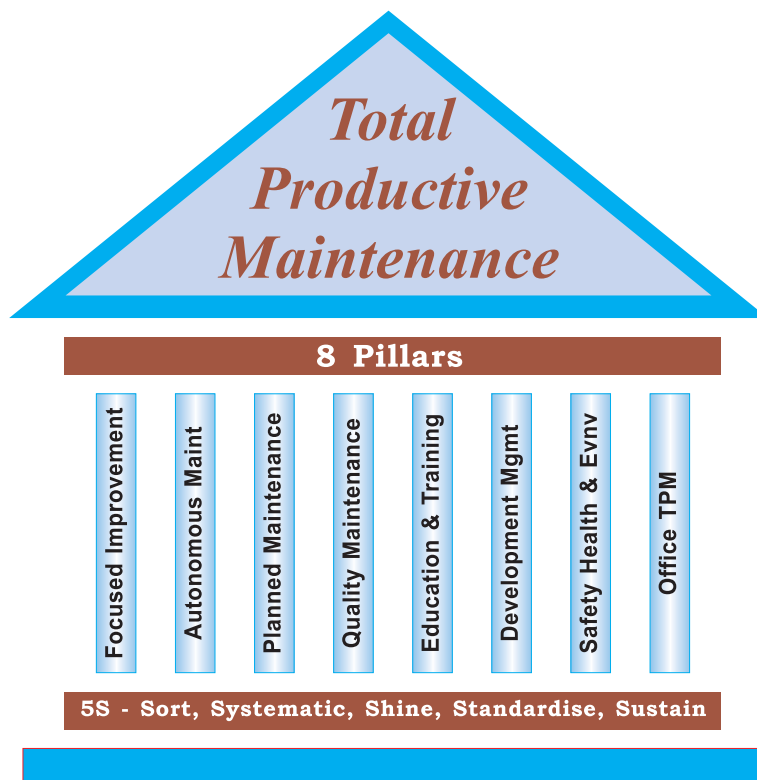
Ref: Lange's Book of Chemistry

Substance Name Alphabetical Order	Melting Point		Boiling Point		Closed Cup Flash Pt.		Explosive Limits % by Volume in Air		Vapour Density Air-1.00	Auto Ignition Temp		Flame Temp	
	°C	°F	°C	°F	°C	°F	Lower	Upper		°C	°F	°C	°F
Hydrogen Sulphide	-83	-117	-60	-76	GAS	GAS	4.3	45.5	1.189	260	500	-	-
KEROSENE	-	-	-	-	+37.8 to 74	+100 to + 165	-	-	-	254	490	-	-
METHANE	-184	-300	-161	258	GAS	GAS	5.3	13.9	0.554	537	999	1875	3407
MHBK	-85	-121	+118	+244	+16.7	+62	-	-	3.45	-	-	-	-
MEK	-86	-123	+80	+176	-11	+30	1.81	11.5	2.41	-	-	-	-
NAPHTHNE	<-45.6	<-50	+149 to 204	+300 to 400	+37.8 to 43.03	+100 to 110	1.1	6.0	-	+232 to 260	450 to 500	-	-
OCTANE-n	-56	-69	+125	+257	+13.3	+56	0.84	3.2	3.86	322	450	-	-
PENTANE -n	-132	-206	+36	+97	<40	<-40	1.4	8.0	2.48	309	588	-	-
PHENOL	+42	+108	+181	+358	+79.4	+175	-	-	3.24	715	1319	-	-
PROPANE	-190	-310	-44	-45	GAS	GAS	2.37	9.5	1.56	466	871	1925	3507
PROPYLENE	-185	-301	-50	-58	GAS	GAS	2.0	11.1	1.49	-	-	1935	3515
SULPHUR	+112	+234	+444	+832	+207	+405	-	-	-	232	450	-	-
TOLUENE	-92	-134	+111	+232	+4.4	+40	1.27	7.0	3.14	608	1026	-	-



Properties of Inflammable Solids, Liquids and Gases Ref: Lange's Book of Chemistry

Substance Name Alphabetical Order	Melting Point		Boiling Point		Closed Cup Flash Pt.		Explosive Limits % by Volume in Air		Vapour Density Air-1.00	Auto Ignition Temp		Flame Temp	
	°C	°F	°C	°F	°C	°F	°C	°F		°C	°F	°C	°F
Acetone	-94	-137	+56.7	+134	-17.8	0	2.15	13.0	2.00	548	118	-	-
Acetylene	-	-	-84	-119	GAS	GAS	2.5	80.0	0.91	335	635	2325	4217
Ammonia	-77	-107	-38.3	-37	GAS	GAS	16.0	27.0	0.597	580	1436	1700	3092
Asphalt (Typical)	+93	+200	+371	>700	>+204	>+400	-	-	-	485	905	-	-
Benzene	+5	+41	+80	+176	-11	12	1.4	8.0	2.77	580	1076	-	-
Butane-n	-135	-211	+0.56	+33	-60	-76	1.6	8.5	2.046	430	806	1895	3461
Butylene-n	-130	-202	-5	+23	GAS	GAS	1.7	9.0	0.668	-	-	1930	3506
Carbon Monoxide	-206	-339	-192	+314	GAS	GAS	12.5	74.2	0.967	651	1204	-	-
Carbonyl Sulphide	-138	-216	+50	+122	-	-	11.9	28.5	2.10	-	-	-	-
Charcoal	>3485	>6300	+4206	+7600	-	-	-	-	-	-	-	-	-
Decane-n	-32	-26	+173	+344	+46	+115	0.67	2.6	4.90	>260	>500	-	-
Ethane	-172	-27	-89	-128	GAS	GAS	3.12	15.0	1.049	510	950	1895	3461
Ethanolamine	+10.56	+50	+172	+342	+93	+200	-	-	2.10	-	-	-	-
Ethyl Alcohol	-117	-178	+78	+173	+12.8	+55	3.28	19.0	1.59	426	799	-	-
Ethylene	-169	-272	-104	-155	GAS	GAS	3.02	34.0	0.975	543	1009	1975	3587
Furfural	-38	-36	+161	+322	+60	+140	2.0	-	3.31	393	739	-	-
Gasoline	<-45.6	<-50	+38 to 204	+100 to 400	-45.6	-50	1.3	6.0	3 TO 4	257	495	-	-
Gas Oil	-	-	-	-	+65.6	>+150	-	-	-	338	640	-	-
Heptane-n	-90	-130	+97.8	+208	-3.9	+25	1.0	6.0	3.45	233	4.52	-	-
Hexane-n	-94	-137	+69	+156	-21.7	-7	1..25	6.9	2.97	247	477	-	-
Hydrogen	-260	-435	-252	-422	GAS	GAS	4.1	74.2	0.069	580	1076	2045	3713



HRD CENTRE

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