N2 Plant Operation Theory

Gateways to Engineering Studies - Chris Brink

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Gateways to Engineering Studies

Plant Operation Theory
N2

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⚙	In the workplace	📝	Theoretical – questions, reports, case studies, etc.
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Module 1

Basic Chemistry

Learning Outcomes

On the completion of this module the student must be able to:

- Name the following for nuclear atoms:
  - Proof and ingredients
  - Elements and isotopes
  - Atomic weight, number and counted number
- State the orbital 1 to 20 elements for atomic models
- Describe the principles of chemical changes
- Describe the types of chemical reactions
- Describe the following for systematic and basic organic chemistry:
  - Multiplicity of connections
  - Structure and use of a few types of organic compounds
- Describe the following for these industrial gasses CO, H_2, CH_4 and NH_3:
  - Appearance of gasses – where and how
  - Preparation in the laboratory and in large quantities (except CH_4)
  - Physical and chemical properties
  - Tests for gasses
  - Application (uses) of these gasses

1.1 Introduction

In the ancient Western world, it was believed that matter consisted of four elements, namely water, air, earth and fire. These elements could have the following properties: cold, wet, dry or warm. For example, air could be warm and wet, and water cold and wet.

In 5 BC the Greek philosopher Democritus believed that all matter consisted of very small indivisible particles, which he named "atomos" (meaning indivisible).

This was a very popular belief and even in the first century BC the Roman poet and philosopher, Epicurus, wrote his work De Rerum Natura (On the Nature of Things), in which he thought of the whole universe as a combination of atoms, and even showed some concept of evolution. Almost 2 000 years later, the English school teacher and scientist John Dalton formulated his atomic theory in 1808.

The ancient Greek philosophers could only speculate and think about the composition of matter. Nowadays all sciences use the scientific method to investigate phenomena. Dalton's idea of atoms was not just an idea: it was a scientific theory. 1t explained the many observations and measurements that he and the scientists before him had made.

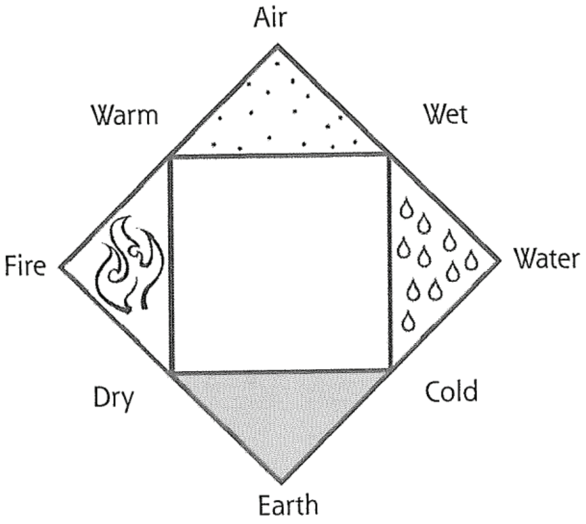

Figure 1.1

The **scientific method** is the systematic approach to research used by all sciences. There are 5 steps in the scientific method:

Step 1: Identify and state the problem.

Step 2: Do experiments; collect data; make careful observations.

Step 3: Analyse the data and propose a possible solution to the problem by formulating a hypothesis.

Step 4: Do more experiments to test the hypothesis. Make sure the conclusions are correct.

Step 5: Formulate the results as a conclusion. The conclusion can be in the form of a theory or a law.

- A hypothesis is a tentative explanation of the results of experiments or of a set of observations.
- A theory is a hypothesis that has withstood extensive testing.
- A law is a verbal or mathematical description of behaviour based on the results of many experiments. Laws are consistent and have no known exceptions.
- A model is a real or mental picture that results from ideas and assumptions that are imagined to be true. It is used to explain certain observations and measurements.

Dalton's work marked the beginning of the modern era of chemistry.

The main ideas of his hypothesis about the nature of matter can be summarised as follows:

- Elements are made up of extremely small particles called atoms.

- All atoms of a given element are identical, having the same size, mass and chemical properties.
- The atoms of one element are different from the atoms of all other elements.
- Compounds are formed from atoms of more than one element.
- Only whole atoms can combine in fixed ratios to form a compound.
- In a chemical reaction atoms can be separated, combined or rearranged - atoms cannot be created or destroyed.

In the early 1900s, experimental evidence showed that atoms contained at least two kinds of particles, some with a positive charge and some with a negative charge.

JJ Thompson experimented with a cathode ray tube and accurately measured the electron's charge to mass ratio. He thought that the atom was like a plum pudding- negatively charged electrons (plums) were embedded in the positively charged pudding.

A **cathode ray tube** is an apparatus that sends out a ray of electrons.

In 1910 Ernest Rutherford made quite an amazing discovery. He and two colleagues, Geiger and Marsden, were carrying out an experiment in which they shot alpha particles (positive helium nuclei) at a very thin piece of gold foil, in a vacuum. Most of the alpha particles went straight through the foil, some went through but changed direction slightly, and an even smaller number actually bounced back.

Rutherford concluded that the atom must consist mainly of empty space, but that there was a strong concentration of positive charge in its centre - the nucleus. The positive particles were called protons. Negatively charged particles around the outside were called electrons.

This basic model of the atom is still used today.

Many more scientists have contributed to our present-day model of the atom, and many more scientists are researching and defining new refinements to the model. For 2 000 years humanity believed the ancient Greek philosophers' version of matter, but now we know that their ideas were inaccurate.

In the future, scientists might prove our current model wrong or inaccurate and come up with something that we cannot even imagine at this moment.

Research into the universe suggests that there are still more questions than answers. A true scientist always has an open and enquiring mind. The scientific future certainly will challenge our creativity.

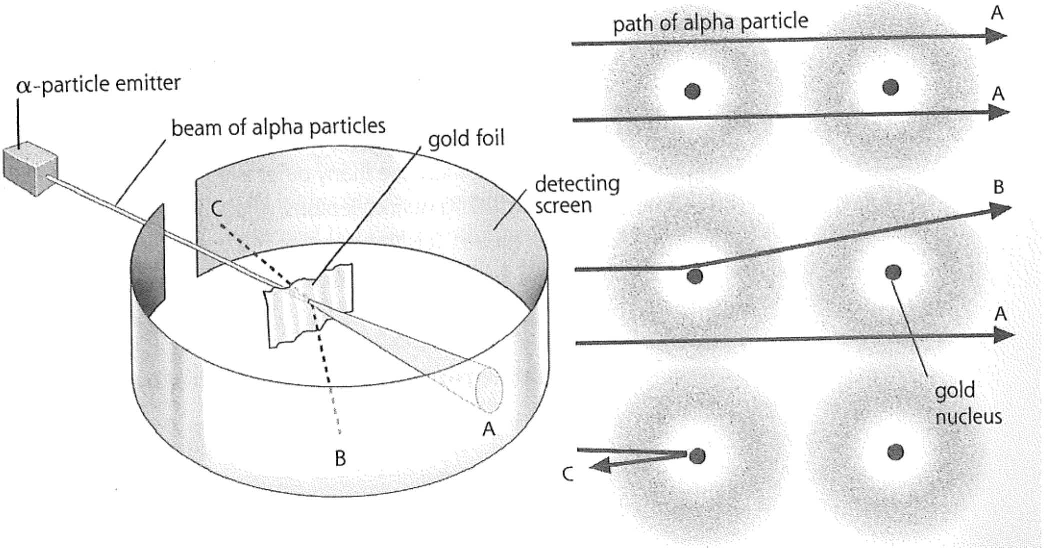

Figure 1.2 Rutherford's experimental design for measuring the scattering of particles from a piece of gold foil showing a magnified view of α-particles passing through and being deflected by nuclei

1.2 The structure of the atom

Atoms consist of three main particles: protons (p^+), neutrons (n^0) and electrons (e^-). The nucleus of an atom lies at its centre and contains protons and neutrons, collectively called the nucleons.

Electrons are found in the space around the nucleus. Protons and neutrons have about the same mass.

The electron's mass is negligible. ($\frac{1}{1\,840}$ that of a proton.) A proton has a small positive electrical charge, and an electron has an equal but opposite (negative) charge. Atoms have no overall charge: in an atom the number of protons must equal the number of electrons.

Although all the mass of the atom is concentrated in its nucleus, the volume of the atom is determined by the space that the electrons occupy.

The volume that the nucleus occupies in comparison to the volume of the total atom can be compared to a pea on the centre point of a football stadium.

Many scientists believe that there are many other even smaller sub-atomic particles, including quarks, leptons, anti-quarks, photons, gravitons, bosons and gluons. It is thought that protons and neutrons are made from quarks, and electrons from leptons.

We can now summarise the properties of the three sub-atomic particles.

Particle	Relative mass	Relative charge
Proton (p^+)	1	+ 1
Neutron (n^0)	1	0
Electron (e^-)	Very small (negligible)	- 1

Table 1.1

Although Rutherford and other scientists thought that there must be a neutral particle in the nucleus of an atom, it was James Chadwick who proved it in 1932. He called it a neutron, because it has no charge.

The diagram below shows a helium atom. In the centre of the atom is the nucleus with its 2 positive protons and 2 neutral neutrons. Two electrons move in the space around the nucleus.

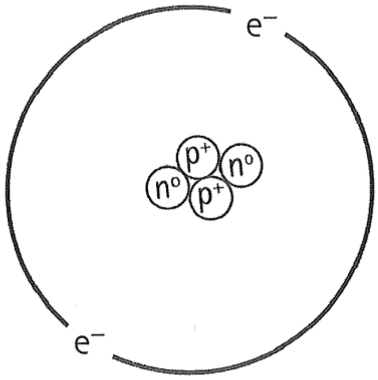

Figure 1.3

1.3 The atomic nucleus

The simplest part of an element that can participate in a chemical reaction is called an atom. An atom consists of a nucleus with one or more protons and neutrons in the atom, and one or more electrons.

Every atom is designated by one or more letters. Should atoms have the same first letters, then the second letter or another letter will be used to describe it, for example:

Calcium - Ca; Chromium - Cr; Carbon - C; Cesium - Cs.

The first atomic theory was put forward by Dalton, but is now outdated.

The modern theory on atoms was originated by Bohr and others.

According to Bohr the atom consists of a nucleus around which electrons are moving in fixed circles.

The atom is made up of several small parts, being:

a) Proton

The mass of a proton is approximately equal to the mass of a hydrogen atom (1,672 x 10^{-24} gram).

The charge on the proton is positive and equal, but opposite to that of the electron and the charge is indicated by a +.

The charge is + 1,602 x 10^{-19} measured in coulomb.

b) Electron

The mass of the electron is approximately 0, 00054 that of the proton. The charge is negative and the symbol used is e-.

It is the same size charge as the charge for the proton.

c) Neutron

The neutron is a neutral particle within the nucleus. The mass of a neutron is approximately the same as that of a proton, but its charge is neutral (n). The nucleus contains only protons and neutrons.

The electrons move around the nucleus in different layers.

A certain layer can contain only a maximum number of electrons and the different layers are indicated by the letters, K, L, M, N or they can be numbers 1, 2, 3 etc.

The different layers are known as energy layers or levels:

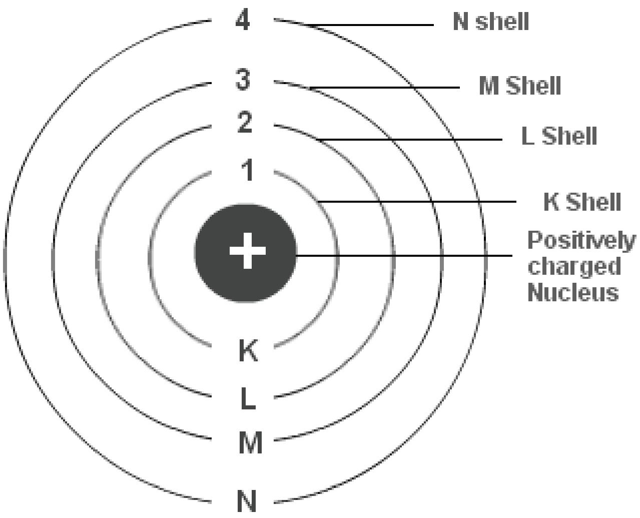

Figure 1.4 Energy levels

Level K can only carry a maximum of 2 electrons. Level L can carry 8 electrons, M = 18 and N = 32. The number of electrons in the outer level determines the chemical properties of the element.

1.3.1 Atomic Number

The number of protons in the nucleus will indicate the atomic number, for example, magnesium has an atomic number of 12. Therefore it consists of 12 protons in the nucleus and 12 electrons circling the nucleus. The number of electrons in each layer will be 2-8-2 with the last 2 electrons in the outer layer.

The neutrons will not influence the chemical properties of the atom, but will only affect the mass of the atom.

1.3.2 Elements and Isotopes

Elements: are distinct types of matter that will contain only one type of atom.
Isotopes: these are atoms of the same kind, which differ in one respect from one another and that are the mass of each atom. The mass will differ because of the number of neutrons in the nucleus.

Examples of isotopes

16 17 18
0 0 0
8 8 8

1.3.3 Atomic Mass of an Atom

The atomic mass is equal to the sum of the masses of all the particles from which the atom is formed.

As the mass of an electron is so small, it is discarded and the atomic mass is equal to the sum of the protons and neutrons contained in the nucleus of an atom.

As there are isotopes for approximately every given element, the average atomic mass of an element is usually not a whole number. This is why the atomic mass for hydrogen which contains 1 proton and 1 electron is not given as 1 but instead as 1,0079 amu.

Therefore, when atoms combine to form matter, the molecules of that matter will also have mass. Molecular mass/formula mass is the sum of mass of the atoms in the molecule/ionic crystal that have bonded together.

1.4 Atomic models

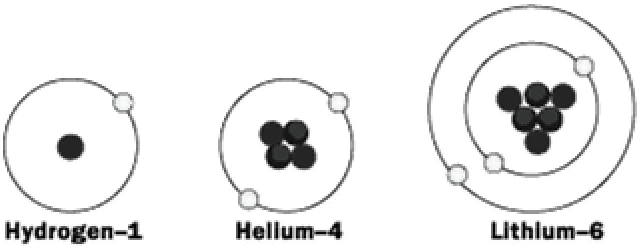

Figure 1.5 Atomic models for elements 1 – 3

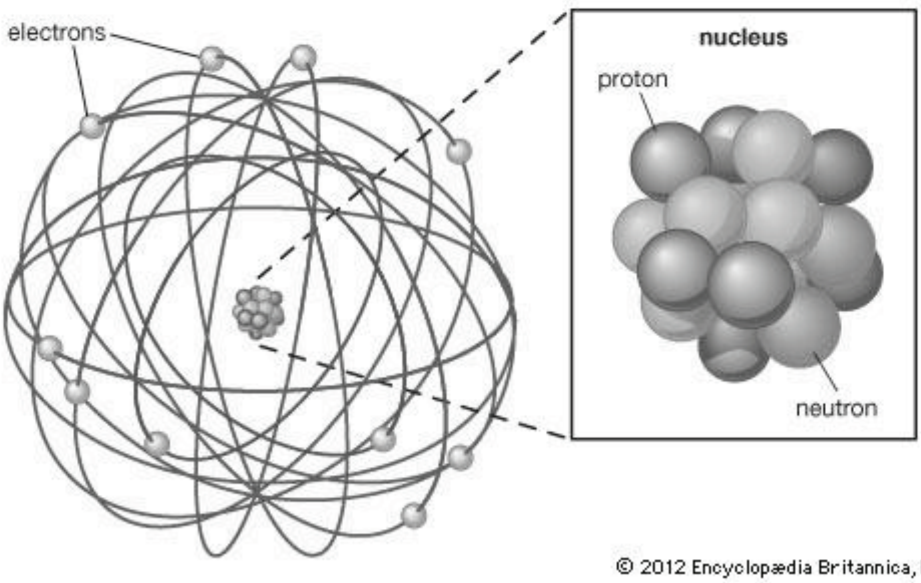

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Figure 1.6 Neon – 10

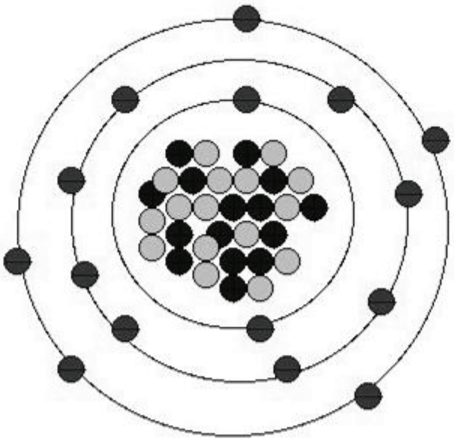


Figure 1.7 Phosphorous - 15

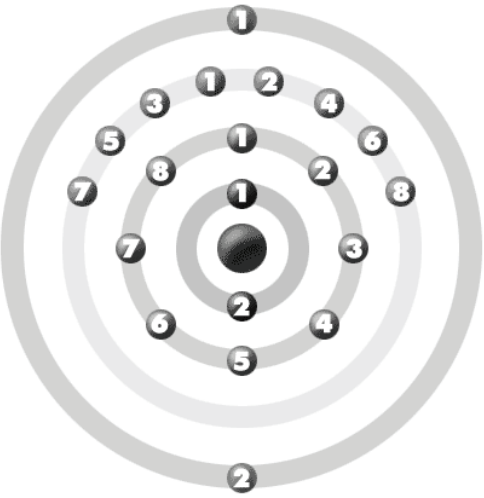


Figure 1.8 Calcium - 20

1	H	$1s^1$	$1s^1$
2	He	$1s^2$	$1s^2$ = [He]
3	Li	$1s^2 2s^1$	[He] $2s^1$
4	Be	$1s^2 2s^2$	[He] $2s^2$
5	B	$1s^2 2s^2 2p^1$	[He] $2s^2 2p^1$
6	C	$1s^2 2s^2 2p^2$	[He] $2s^2 2p^2$
7	N	$1s^2 2s^2 2p^3$	[He] $2s^2 2p^3$
8	O	$1s^2 2s^2 2p^4$	[He] $2s^2 2p^4$
9	F	$1s^2 2s^2 2p^5$	[He] $2s^2 2p^5$
10	Ne	$1s^2 2s^2 2p^6$	[He] $2s^2 2p^6$ = [Ne]
11	Na	$1s^2 2s^2 2p^6 3s^1$	[Ne] $3s^1$
12	Mg	$1s^2 2s^2 2p^6 3s^2$	[Ne] $3s^2$
13	Al	$1s^2 2s^2 2p^6 3s^2 3p^1$	[Ne] $3s^2 3p^1$
14	Si	$1s^2 2s^2 2p^6 3s^2 3p^2$	[Ne] $3s^2 3p^2$
15	P	$1s^2 2s^2 2p^6 3s^2 3p^3$	[Ne] $3s^2 3p^3$
16	S	$1s^2 2s^2 2p^6 3s^2 3p^4$	[Ne] $3s^2 3p^4$
17	Cl	$1s^2 2s^2 2p^6 3s^2 3p^5$	[Ne] $3s^2 3p^5$
18	Ar	$1s^2 2s^2 2p^6 3s^2 3p^6$	[Ne] $3s^2 3p^6$ = [Ar]
19	K	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$	[Ar] $4s^1$
20	Ca	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$	[Ar] $4s^2$

Table 1.1 The electron configuration for elements 1 – 20.

1.5 Principles of a Chemical Change

The atoms of different types of matter bond differently to form a molecule. A molecule is the smallest part of a compound which still possesses the property of that compound.

Atoms strive to take over the structure of the noble gases. This means that the atom will try to fill its outer layer with electrons. There are two ways in which this process can take place: Electrons can be transferred or they can be shared.

1.5.1 Transfer of Electrons: Ionic bonding

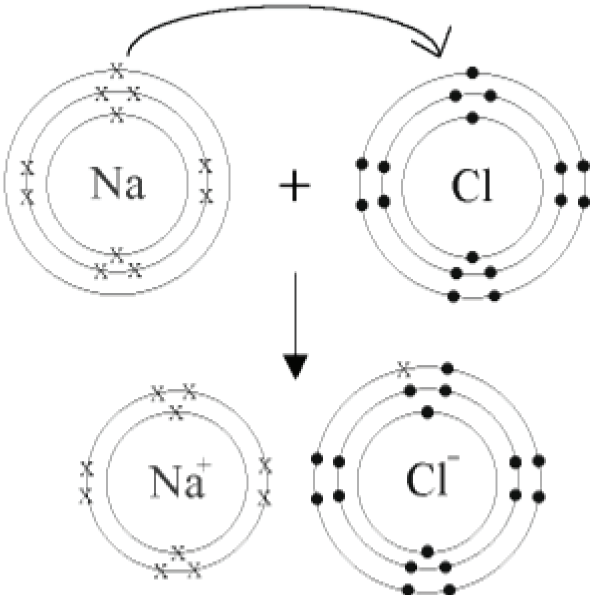


Figure 1.9 Ionic bond

Na (2,8,1) + Cl(2, 8, 7) Na^+ (2,8) + Cl^- (2,8,8)

This reaction can be written as follows:

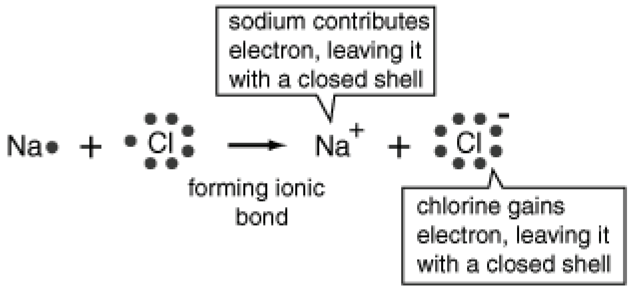


Figure 1.10

The Na atom will have 1 electron too many in its outer layer which will be lost to give a noble gas structure. The Cl atom needs 1 electron to fill the outer orbital and it therefore accepts the electron from the Na atom.

From the example above it can be seen that the metal loses an electron and the non-metal gains an electron. The valency number of an atom is equal to the numbers of electrons which are lost from the outer layer or are gained in the outer layer to form a stable noble gas structure.

1.5.2 Covalent Bonding

The electrons are shared and not transferred.

Consider the following example:

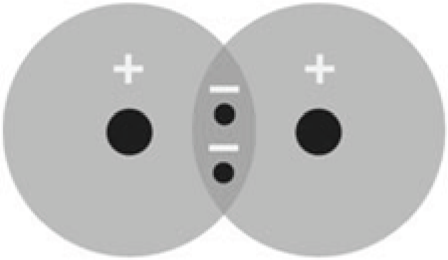


Figure 1.11 Hydrogen

Once again a stable structure is obtained because there are 2 electrons in the outer layer. In general, there is very little attraction between these molecules and therefore this type of matter is normally a liquid or a gas.

1.5.3 Valency Number

The valency number can be defined as follows: The valency number of an element is defined as the number of atoms of a monovalent (valency of 1) element which will combine with another atom.

Example 1:

$H_2 + ½0_2$........................... H_20

Where H = monovalent

0 = divalent

Thus: 1 atom of oxygen combines with 2 atoms of hydrogen. That is why the oxygen is a divalent element (as hydrogen is monovalent).

Example 2:

$H_2 + Cl_2 = 2HC1$

From the above it can be seen that Chlorine (Cl) is also monovalent.

Example 3:

Beryllium has 4 electrons, 2 of which are found in the first orbital and the other 2 in the second orbital. It appears that Be is just as inactive as He because the 2nd orbital can only contain 2electrons and is therefore full, but the energy of the electrons in the second orbital is less than the energy of the first orbita1.

Should additiona1energy be given to the electrons in the second orbital, they would be capable of escaping completely from the second orbital. If this should happen they will become free electrons and could be acquired by another atom. Beryllium is thus divalent. eg $BeCl_2$

$C + 2H_2 = CH_4$
Carbon then, is tetravalent (meaning 4 valencies).

Example 4:
$Fe + ½0_2 = FeO$
What is the valency of iron? From example 1 we see that oxygen is divalent. Therefore, if 1 iron atom combines with one oxygen atom, iron must be divalent.

1	2	3	4	5
Monovalent	**Bivalent or Divalent**	**Trivalent**	**Tetravalent**	**Pentavalent**
Na K Ag Cl Br H	Cu Hg Mg Ca Ba Zn Sn Mo Fe O S	Al Fe P	Sn C S	P

Table 1.2 Valency numbers

Some of the elements will appear in more than one column. These elements will have an interchangeable valency number. Take for example, Sulphur:

We get H_2S and $S0_2$

From the first example the valency number for sulphur is 2 and from the second example the valency number is 4, with the valency number of 2 for oxygen.

It is often the practice to give a valency number to a certain group of atoms which could not exist alone. Such groups are called radicals.

1	2	3
Hydroxide – OH^- Ammonium – NH_4^+ Chlorate – $C10_3$ Nitrate – NO_3^- Nitrite – NO_2^- Bicarbonate – HCO_3^-	Sulphate – SO_4^{2-} Sulphite – SO_3^{2-} Carbonate – CO_3^{2-}	Phosphate – PO_4^{3-}

Table 1.3 Radicals and valency numbers

Typical reactions:

$H_2 + NO_3 = 2HNO_3$

$2KCLO_3 \rightarrow 2KCl + 30_2$

$2K + 2H_2O = 2KOH + H_2$

Attention must be given to the valency number and the quantities of each element. The quantities of each element or the atoms on the left-hand side of the equation must correspond with the quantities on the right-hand side.

1.5.4 Structural Formulae

This type of presentation of the structures of molecules, has been started with hydrocarbons. The bonding between atoms is represented by lines that represent the valency number of the atoms.

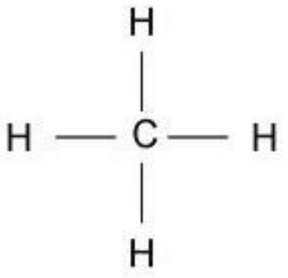


Figure 1.8 Methane

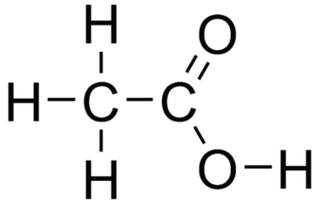


Figure 1.12 Acetic Acid(CH_3CQOH)

The lines show part of the electron pair and are mainly used to represent carbon (organic) bondings.

1.5.5 Catalyst

Some chemical reactions are promoted by catalysts.

These specific agents increase the rate of chemical reaction without themselves becoming changed. The catalyst can therefore be recovered in its original form at the end of the reaction.

i) $Zn + HCl + CuS0_4 = CuS0_4 + ZnCl_2 + H_2$
$CuS0_4$ = Catalyst
ii) $2KC10_3 + Mn02 = Mn0_2 + 2KCl + 30_2$
$Mn0_2$ = Catalyst

1.6 Frequency of Bonding

The ability of carbon to combine with itself to form chains or rings of carbon atoms gives rise to the well-known hydrocarbons.

Forms of hydrocarbons having the same formula, but different structures, such as C_5H_{12}, pentane and iso-pentane, are called isomers. The so-called pentane C_5H_{12} has three different structures, namely the straight chain n-pentane.

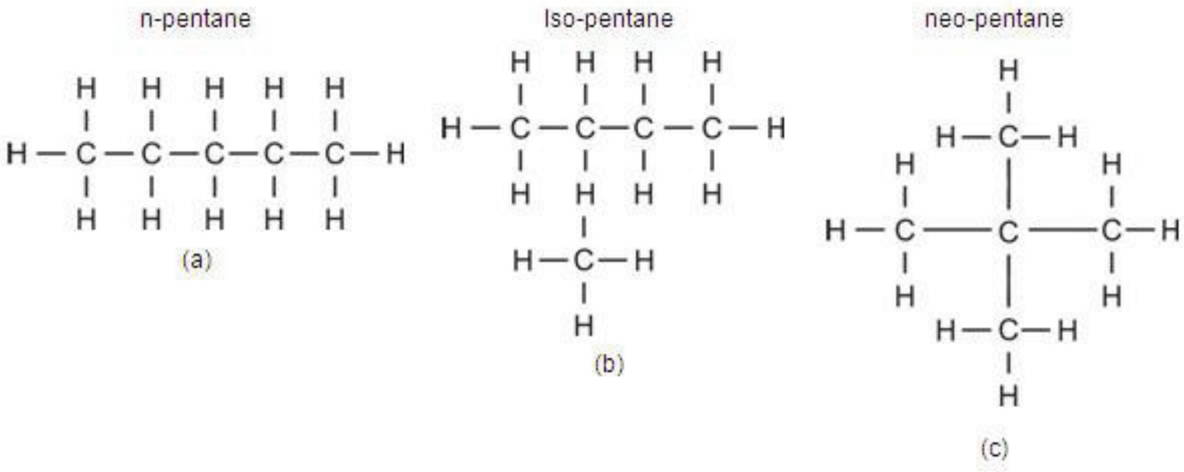


Figure 1.13

The possible forms of isomers increase proportionally to the number of carbon atoms, so that, for instance, there are eighteen isomers for C_8H_{18} and 4×10^9 possible isomers for $C_{30}H_{62}$.

It is necessary to understand the IUPAC (International Union of Pure and Applied Chemistry) terms, in connection with hydrocarbons.

Hydrocarbons can be classified into 4 groups and each has a particular name:

1. The Alkanes (IUPAC = Parafino)
   These are the saturated straight chain hydrocarbons which are connected by single covalent bonds. **Example: Ethane C_2H_6**
2. The Alkene and Alkynes (IUPAC = olefins and acetelynes)
   These are also straight or branched chains with a double or triple covalent bond between carbon atoms, for **example, ethene C_2H_4 (ethylene) and ethyne C_2H_2 (acetylene).**
   These hydrocarbons are chemically very reactive.
3. The Cyclo-alkanes (IUPAC Napthalene or Cycloparaffin)
   These are the saturated bondings having a ring formation, for **example, cyclo-hexane (C_6H_{12}) cyclo-propane (C_3H_6).**
4. The Cyclo-alkenes (I UPAC = Aromatics)
   Unsaturated ring bondings or aromats, for **example cyclo-hexene (C_6H_{10}) benzene (C_6H_6) and toluene ($C_6H_5CH_3$) or methyl benzene.**

1.6.1 Uniformity of Hydrocarbons

The following is a list of formulas and names of alkanes which you should know. The names of the first four members follow no system.

From pentane, the first part of each name is a Greek or Latin numerical prefix indicating the number of carbon atoms. The letters prefix ‘n’ indicate a straight chain isomer.

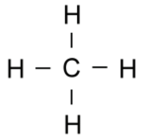
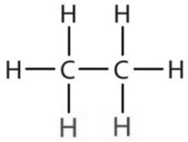
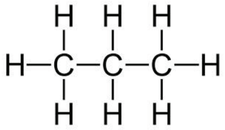
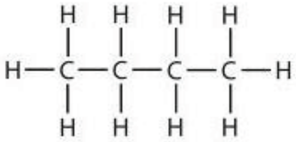
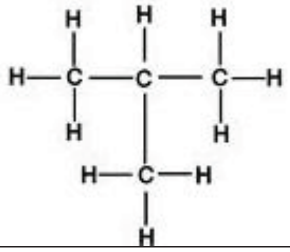
	Number of carbon atoms	Formula	Name
1		CH_4	Methane
2		C_2H_6	Ethane
3		C_3H_8	Propane
4	 or 	C_4H_{10}	n-butane Isobutane

Table 1.4

5	Isomers	C_5H_{12}	Pentane
6		C_6H_{14}	Hexane
7		C_7H_{16}	Heptane
8		C_8H_{18}	Octane

Table 1.5

The following conclusions can be drawn from the table:

1. The bondings all have the same functional group and as a result have the same chemical properties and can inevitably be chemically produced in the same way.
2. Each part of a series has the same general formula, namely C_nH_{2n+2} where n is the number of carbon atoms in the chain.
3. The series increases or expands by -CH_2- on each molecule. This means that the molecule in sequence with 14 atomic mass units, differs in mass from each other. The atomic mass of C being 12 and that of H being 1.
4. There is a progressive change in the physical properties of each molecule in the series, for example the boiling point increases uniformly with the number of C atoms in the molecule as expressed in the following graph.

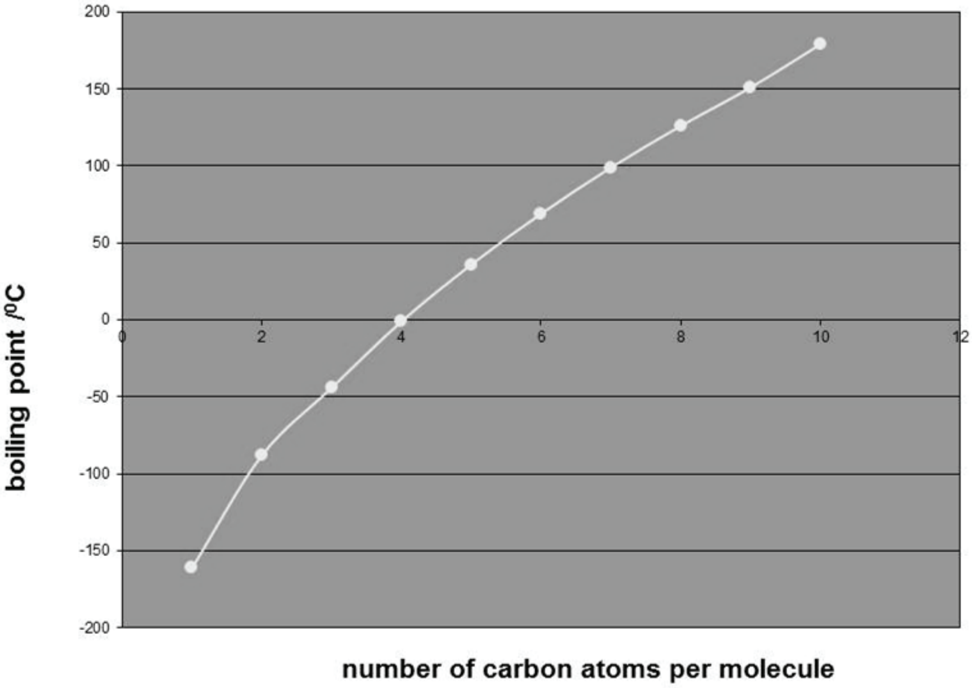
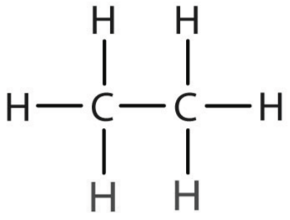


Figure 1.11 Boiling points of first ten alkanes against number of carbon atoms per molecule

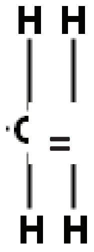
1.6.2 The Alkanes (paraffins) Alkenes and Alkynes (olefins and acetylenes)

To indicate the uniformity, only a few of these bondings will be discussed.

The alkene and alkynes are unsaturated straight chain molecules in which double bonds and triple bonds appear between carbon atoms and as a result contain less hydrogen atoms.

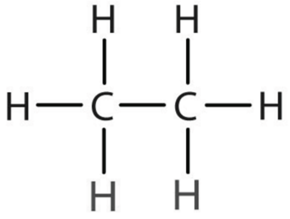


- 2H
→



alkanes (paraffins)
general formula
C_nH_{2n+2}

Alkenes (olefins)
(general formula
C_nH_{2n})



- 4H
→

$H - C \equiv C - H$

Alkanes (general
formula C_nH_{2n+2}

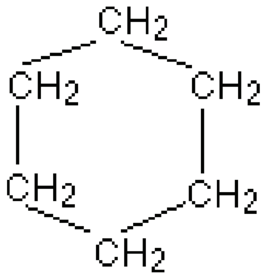
Alkynes (acetylenes
(general formula
C_nH_{2n-2})

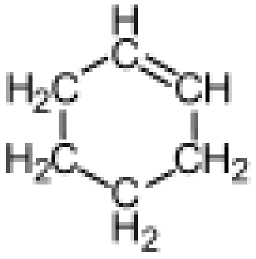
It can be seen that the name of the hydrocarbon changes according to the group in which it belongs, for example:

CH_3CH_3 ethane (C_2H_6) becomes C_2H_4ethene
(or ethylene) and this again becomes
$HC \equiv CH$ ethyne (C_2H_2) (or acetylene)
$CH_3CH_2CH_3$propane (C_3H_8) becomes $CH_2CH = CH_2$
Propene (C_3H_6) (or propylene) and with a triple bond becomes
$CH_3C \equiv CH$ propyne (C_3H_4)

1.6.3 The Cyclo-alkanes and Cyclo-alkenes (Cyclo-paraffins and aromats)

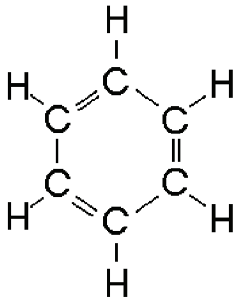
Cyclo-hexane C_6H12 - 2H → Cyclo-hexene C_6H_{10}



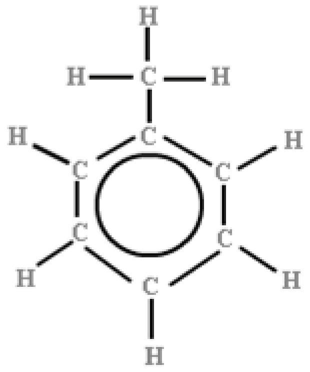


Benzene and toluene (methyl benzene) are the most important unsaturated ring bondings and their structure is as follows:

Benzene C_6H_6



Toluene $C_6H_5CH_3$



1.7 Physical Properties of the Hydrocarbons

1.7.1 Properties of the Paraffins (alkanes)

1. The first four members of the paraffins are gases at normal temperature and pressure.
2. As the molecules grow with an increase in carbon atoms, they become heavier and as a result some of them become liquids and others solids at normal temperature and pressure. The solids have low melting points.
3. The alkanes are insoluble in water, but dissolve readily in other organic soluble agents and groups of their own kind.
4. They do not conduct electricity.
5. They all have specific shapes.
6. Methane, butane and propane (gases) are important fuels.

Name	Formula	State	Boiling Point (°C)
Methane	CH_4	Gas	-161
Ethane	C_2H_6	Gas	-84,4
Propane	C_3H_8	Gas	-42,2
Butane	C_4H_{10}	Gas	0
Pentane	C_5H_{12}	Liquid	36
Hexane	C_6H_{14}	Liquid	69
Heptane	C_7H_{16}	Liquid	98,3
Octane	C_8H_{18}	Liquid	124,4
Nonane	C_9H_{20}	Liquid	150,5
Decane	$C_{10}H_{22}$	Liquid	174

Table 1.5

Up to C_{15} all paraffins are liquids, but from C_{16} they become solids, namely paraffin waxes.

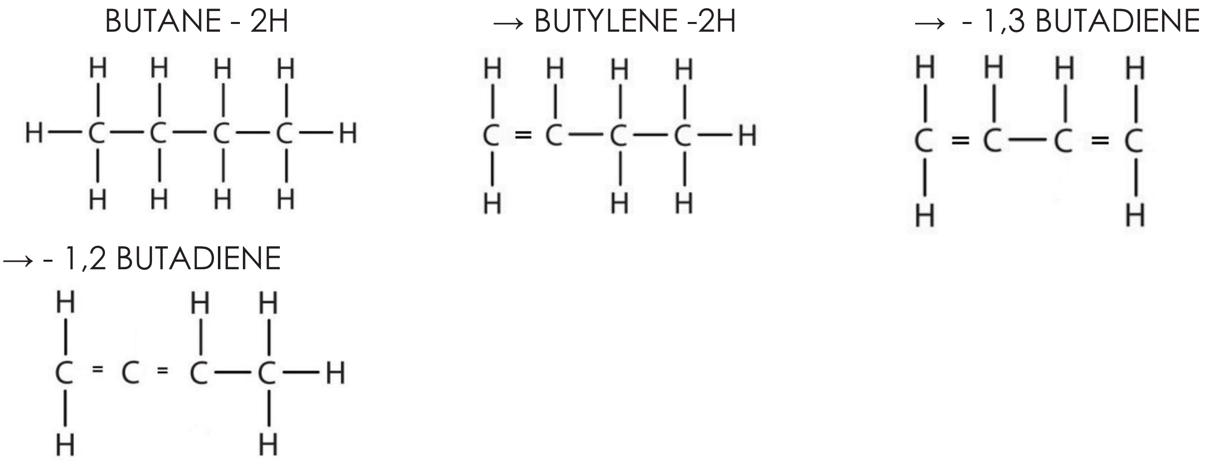
1.7.2 Properties of the Olefins and Acetylenes (alkenes and alkynes)

They are chemically more active than the paraffins as a result of their unsaturated bondings which give them the tendency to react with other compounds, for example, acids.

Each of them has its own properties, depending upon structure, and it is therefore difficult to list all properties.

1.7.3 Diolefins

Molecules having more than one double bond between C atoms, are called diolefins. The most well-known of these are probably butadiene (1,3 - butadiene) and isoprene (2 methyl - 1,3 - butadiene).



As has already been noticed, the position of the double bond has been indicated by the numbers 1, 2 or 3 to identify the specific bonding.

The following table shows the boiling points of a few other diolefins. Note the difference in boiling points between the different molecules although the bonding does not differ much.

The boiling points of the molecules that contain 5 carbon atoms, namely the C5 group, are all between 9°C and 39°C.

Name	Symbol	Formula	Boiling Point °C
Ethylene	C_2^-	$CH_2 = CH_2$	-103,3
Propylene	C_3^-	$CH_2 = CH - CH_3$	-47,8
Iso-butane	iC_4	$(CH_3)_3CH$	-12
Normal butylenes	nC_4^-	Butylene -1 $CH_2 = CH - CH_2 - CH_3$ Butylene – 2 $CH_3 - CH - CH = CH_2$	-6,6
Butadiene	C_4^-	$CH_2 = CH - CH = CH_2$	-5
Iso-butylene	iC_4^-	$CH_2 = C - (CH_3)_2$	-7,2

Table 1.6

From this we can see why it is important that the temperatures in distillation processes have exact boundaries, otherwise the products will easily be mixed with other molecules.

This part of the hydrocarbons covers only a very small part of the organic chemistry which is a very wide, complicated and exceptionally interesting field of study.

1.8 Organic Chemistry

Organic chemistry is an important branch of chemistry which has a wide range of applications in everyday life. A modern way of life would be unthinkable without organic products.

Organic substances form essential components of the food we eat and of the clothes we wear. They are used as fuels and are found in medications, drugs, solvents, preservatives, plastics, adhesives, rubber, synthetic fibres, detergents, flavouring dyes and explosives.

Amino acids, which are the building blocks of proteins; vitamins, fats, enzymes and hormones, without which life is impossible, are all organic compounds.

A short introduction to organic chemistry is thus necessary.

The name 'organic' is an indication of the origin of this group of compounds. It was originally thought that organic compounds were derived from living organisms and that they were formed by the application of a certain 'life-force' - hence the term 'organic'.

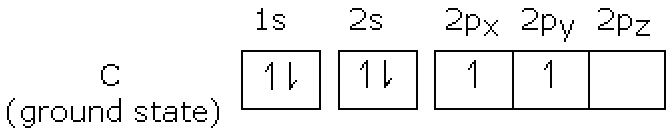
However, in 1828 Friederich Wohler succeeded in preparing the compound urea from inorganic substances and since then thousands of new organic compounds have been prepared in the laboratory.

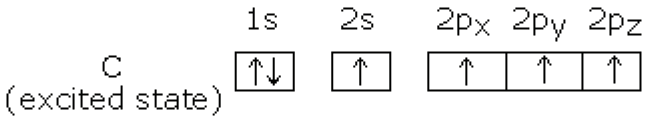
Organic compounds are not only derived from living organisms but can be described as compounds which contain carbon. So organic chemistry can also be regarded as the chemistry of carbon compounds.

Carbon atoms have the property of being able to form one or more covalent bonds with other carbon atoms which, in turn, can form one or more covalent bonds with still other carbon atoms. In this way a linking of carbon atoms can occur to form chain or ring structures.

It is this property of carbon which makes it possible for an infinite number of compounds to be formed. About two million organic compounds are currently known.

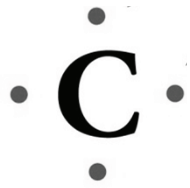
Carbon $_6C = 1s^2\ 2s^2\ 2p^2$



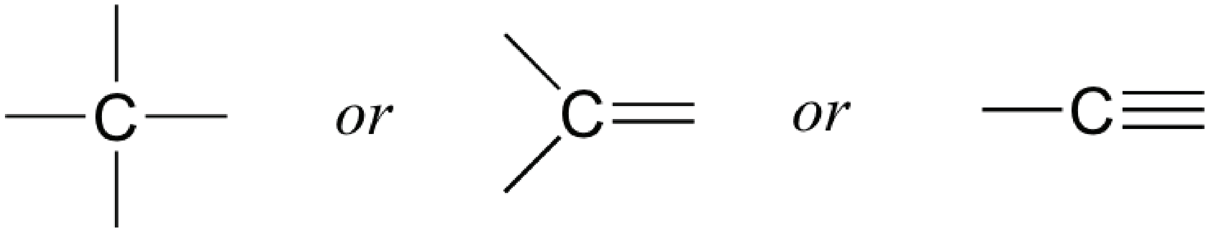


Carbon is able to form four covalent bonds:

Lewis:



Couper:



1.9 Hydrocarbons

The hydrocarbons are organic compounds which are made up of only carbon and hydrogen.

It is necessary to understand the IUPAC (International Union of Pure and Applied Chemistry) terms in connection with hydrocarbons.

The hydrocarbons can be divided into groups according to the type of bonding involved. The hydrocarbons which consist of chain structures are divided into alkanes, alkenes and alkynes based on the type of bond between the carbon atoms.

1. The Alkanes (IUPAC) (parafino).
   These are the saturated straight chain hydrocarbons which are connected by single covalent bonds. **Example: Ethane C_2H_6**
2. The Alkene and Alkynes (IUPAC) (olefins and acetelynes)

These are also straight or branched chains with a double or triple covalent bond between carbon atoms. **Example: Ethene C_2H_4 (ethylene) and $_2C_2H$ (acetylene)**. These hydrocarbons are chemically very reactive.

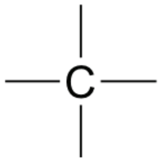
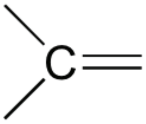
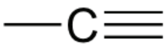
Hydrocarbons		
Alkanes	**Alkenes**	**Alkynes**
Saturated bonds	Unsaturated bonds	Highly unsaturated bonds
Name ends in **–ANE** Contains only single bonds between C-atoms	Name ends in **–ENE** Contains double bonds	Name ends in **–YNE** Contains triple bonds
Functional Group 	**Functional Group** 	**Functional Group** 
General formula: C_nH_{2n+2}	**General formula**: C_nH_{2n}	**General formula**: C_nH_{2n-2}
Examples: CH_4 methane C_2H_6 ethane C_3H_8 propane C_4H_{10} butane	**Examples**: C_2H_4ethene C_3H_6 propane C_4H_8 butane	**Examples**: C_2H_2ethyne C_3H_4propyne C_4H_6butyne

Table 1.7

3. The Cyclo-alkanes (IUPAC) (Napthas or cycloparaffin)
   These are the saturated bondings having a ring formation.
   Example: Cyclo-hexane C_6H_{12} and cyclo-propane C_3H_6.

4. The Cyclo-a/kenes (IUPAC) (aromatics)
   Unsaturated ring bondings or aromats.
   Examples: cyclo-hexene C_6H_{10}. benzene C_6H_6 and toluene $C_6H_5CH_3$ or methyl benzene.

1.10 Naming of Organic Compounds:

The names of organic compounds consist of two parts:

(a) The prefixes (start)- this tells us how many carbon atoms there are in the chain.

(b) The suffix (end)- this indicates what function group is present in the compound.

Prefix	No of carbon atoms
METH	1
ETH	2
PROP	3
BUT	4
PENT	5
HEX	6
HEPT	7
OCT	8
NON	9
DEC	10

Table 1.8

These prefixes must be learnt, before attempting to continue with any further topic.

The suffixes are more complicated, and will be dealt with as each functional group is discussed.

Suffix	Class of organic compound
-ANE	ALKANE
-ENE	ALKENE
-YNE	ALKYNE
-OL	ALCOHOL
-OIC ACID	CARBOXYLIC ACID
-YL –OATE	ESTER
-ONE	KETONE
-AL	ALDEHYDE

Table 1.9

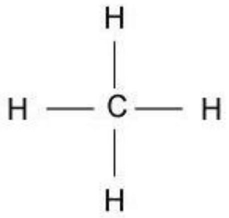
METHANE: METH = 1 CARBON ATOM -ANE =ALKANE
METHANOL: METH = 1 CARBON ATOM -OL = ALCOHOL

As you learn more about the different classes of compounds, the naming will become easier, if you follow the pattern of using the prefix and the suffix to identify the number of carbon atoms and the type of compound.

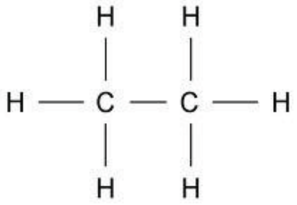
1.11 Alkanes (paraffins)

This group of compounds is characterised by the exclusive presence of single covalent bonds between the carbon atoms. A single covalent bond is very stable. These substances thus have low chemical reactivity and are known as saturated hydrocarbons.

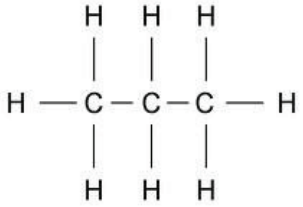
The simplest compound in this group is methane, which has only one carbon atom. It has the following structural formula:



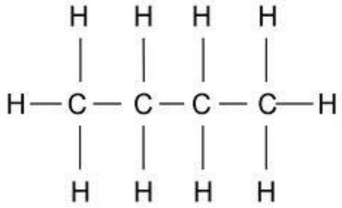
The second member of this series is ethane, which has the following structural formula:



Propane and butane are the third and fourth members of the series and they have the following structural formula:



Propane



Butane

1.11.1 Isomerism:

This is the phenomenon whereby compounds having the same molecular formulae have different structural formulae, as shown below for C_4H_{10}.

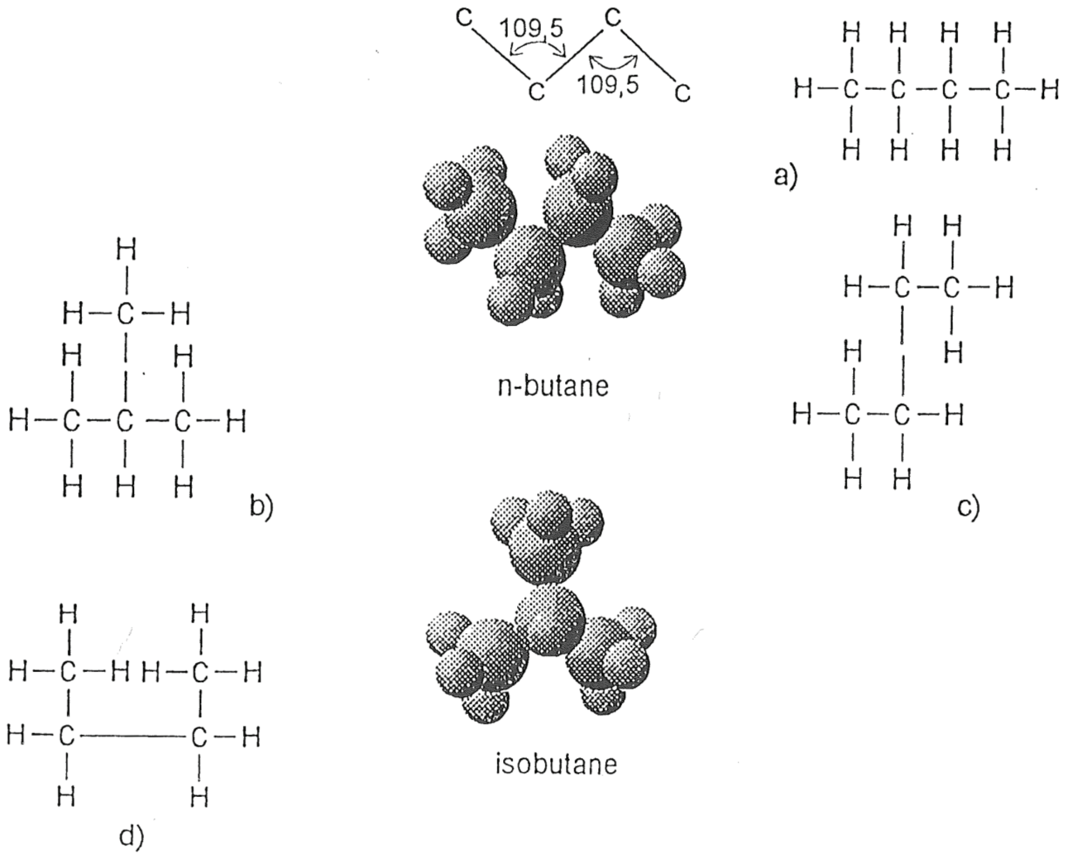


Figure 1.14

Structural formulae (a) and (b) represent different compounds with actually exist and have different properties. These two compounds are isomers.

Structures (c) and (d) are identical to (a). This is because there is freedom of movement about the single bonds so that (c) and (d) can be transformed into (a) by simple rotation of atoms. However, (b) cannot be transformed into (a) unless bonds are broken and re-formed. (a) is called normal butane of n-butane; (b) is 2-methyl propane or iso-butane.

1.12 Branched alkanes:

The atoms of C_4H_{10} can be put together to form two isomers, the straight-chain compound butane and the branched-chain compound isobutane.

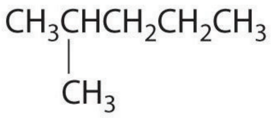
In the series of alkanes from CH_4 to C_nH_{2n+2}, where $_n$ can be any integer, the number of isomers is unity for CH_4 through C_3H_8 (propane), but increases rapidly thereafter;

For example, C_9H_{20} has 35 isomers and $C_{40}H_{82}$ has 62 491 178 805 837. This means that non-descriptive names are inadequate to deal with the problem. What is needed is a naming system that will allow anyone to draw the structure that goes with any name, even if he has never heard the name before.

The best way to learn the system is to look at some examples. Methane, ethane, propane, butane, pentane, and so on, are the unbranched normal alkanes, as before "Isobutane" becomes 2-methylpropane, because it is propane with a methyl group replacing one of the two equivalent hydrogens on carbon atom 2.

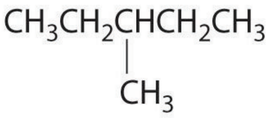
The compounds 2-methylpentane and 3-methylpentane are isomers of hexane.

Hexane:
$CH_3CH_2CH_2CH_2CH_2CH_3$



$$\underset{\displaystyle CH_3}{CH_3\underset{|}{C}HCH_2CH_2CH_3}$$

2-Methylpentane



$$CH_3CH_2\underset{\underset{\displaystyle CH_3}{|}}{C}HCH_2CH_3$$

3-Methylpentane

1.12.1 Physical properties of alkanes

The melting points and boiling points of some of the alkanes in the homologous series are given below:

n	Molecular formula	Name	Melting point °C	Boiling point °C	State at room temperature
1	CH_4	methane	-182	-164	gas
2	C_2H_6	ethane	-182	-89	
3	C_3H_8	propane	-188	-42	
4	C_4H_{10}	butane	-135	-1	
5	C_5H_{12}	pentane	-129	36	liquid
6	C_8H_{14}	hexane	-94	69	
7	C_7H_{16}	heptane	-91	98	
8	C_8H_{18}	octane	-57	126	
9	C_9H_{20}	nonane	-54	151	
10	$C_{10}H_{22}$	decane	-30	174	
18	$C_{18}H_{38}$	octodecane	28	316	solid

Table 1.10

The intermolecular forces between the molecules of the alkanes are relatively weak because the molecules have no polar groups or unpaired electrons. The result is that the alkanes have lower melting and boiling points than other organic compounds with the same molecular masses.

Further, it is clear from the table that the melting and boiling points of the alkanes gradually increase with the increase in the number of carbon atoms in the molecule that is with an increase in the molecular mass.

The substances in the series vary from gases of low density to colourless liquids and waxy solids at room temperature. This gradual change in physical properties is characteristic of a homologous series.

1.12.2 Uses of the alkanes

The alkanes are chemically relatively unreactive because of the saturated bonds.

However, they burn in oxygen to form water and carbon monoxide and/or carbon dioxide depending on the oxygen supply.

As a result of this property, the alkanes are used as fuels in both the gaseous phase as well as the liquid phase.

The lighter alkanes which cannot be used as liquid petroleum or as petrol are used in gas form. Thus a 1:1 mixture of propane and butane is marketed in steel cylinders under a wide range of trade names.

The higher alkanes which are liquid at room temperature are used as motor car fuel.

The alkanes used for this purpose are primarily those of chain length C_7 to C_{10}.

Mixtures of these alkanes and air in the correct ratio are explosive. This reaction is the basis for the use of alkanes as fuel in internal combustion engines. We will look at the combustion of hexane as an example of such a reaction:

$2\ C_6H_{14} + 19\ 0_2 \rightarrow 12\ CO_{2(g)} + 14H_2O_{(g)} + \text{energy}$
$2\ C_6H_{14} + 13\ 0_2 \rightarrow 12\ CO_{(g)} + 14H_2O_{(g)} + \text{energy}$

Hexane + air → carbon dioxide/carbon monoxide + water vapour

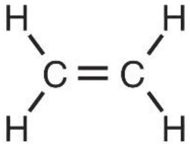
1.13 Alkenes (olefins)

The alkenes are hydrocarbons which contain one double bond between two carbon atoms over and above single covalent bonds. Because a double bond is not as stable as single bonds, the alkenes are chemically more reactive than the alkanes.

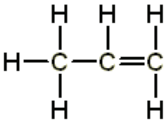
As a result of the double bond the carbon atoms are not bonded to the maximum number of hydrogen atoms and so they are called unsaturated hydrocarbons.

The alkenes form a homologous series with the general formula CnH2n · Their names are derived from the alkanes with the same number of carbon atoms, by simply replacing the suffix -ane by -ene.

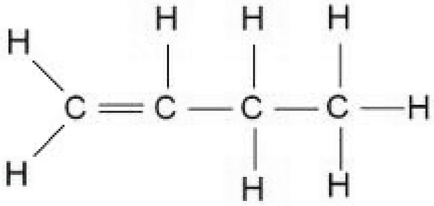
Because the double bond must occur between two carbon atoms, the simplest member of this series has the molecular formula C_2H_4. The substance is ethene and it has the following structural formula:



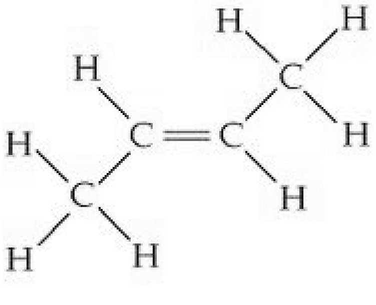
The second member of the series is propene, which has the molecular formula C_3H_6 and has the following structural formula:



Butene is the third member of the alkene series and has the molecular formula C_4H_8. Here the double bond can occur between the first and second or between the second and third carbon atoms, as follows:



But-1-ene



But-2-ene

In the first case where the double bond occurs between the first and second carbon atoms, the compound is known as but-1-ene. ('but' indicates four carbon atoms; '-ene' indicates the double bond and '1' indicates that the double bond is between the first and second carbon atoms).

In the second case the double bond is between the second and third carbon atoms and the compound is known as but-2-ene.

Note that the carbon chain can be numbered from left to right or from right to left.

But-1-ene and but-2-ene are further examples of structural isomerism.

1.13.1 Dienes (di-olefins)

Some alkenes have two double bonds and are called dienes, some have three double bonds and are trienes, and so forth. (Each double bond has to be located by a number).

$CH_2 = CHCH = CHCH_3$	$CH_2 = CHCH_2CH = CH_2$	$CH_2 = CHCH = CHCH = CH_2$
1,3-pentadiene	1,4-pentadiene	1,3,5-hexatriene

1.14 Alkynes (acetylenes)

Just as the alkenes, so are the alkynes unsaturated hydrocarbons. Whereas the alkenes are characterised by a double bond between two carbon atoms, the alkynes are characterised by a triple covalent bond between two carbon atoms in the molecule.

The alkynes form a homologous series with the general formula C_nH_{2n-2} .

Their names are also derived from those of the alkanes with the same number of carbon atoms, excepting that the suffix -ane is replaced by -yne.

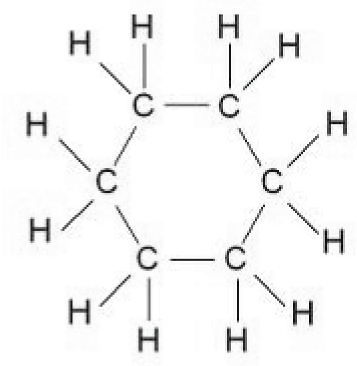
The simplest member of the series is ethyne (C_2H_2), which is often also called acetylene. It has the following structural formula:

$$\mathbf{H - C \underline{=} C - H}$$

The most common use of ethyne (acetylene) is in an oxy-ethyne or oxyacetylene torch for cutting and welding of metals. The ethyne burns in oxygen and produces an intense, hot flame, with a temperature of up to 3000°C.

1.15 Cycloalkanes

The compound cyclohexane has two hydrogen atoms less than hexane. A model of hexane can be converted into a model of cyclohexane by removing hydrogen atoms from carbons 1 and 6 and connecting these carbons together to form a ring. The cyclohexane ring is still somewhat flexible, although not quite so flexible as hexane itself.



1.16 Aromatic Hydrocarbons (unsaturated ring compounds)

1.16.1 The bonds in benzene

If cyclohexane is heated to a high temperature over a catalyst such as platinum, it loses six hydrogen atoms and forms a compound C_6H_6 known as benzene.

The fact that six atoms of hydrogen have been removed suggests that the product ought to have three double bonds. It is easy to construct a model of a compound with three double bonds in a six-member ring.

1.16.2 Alkylbenzenes (alternating single and double bonds)

The simplest alkylbenzene is methylbenzene, or toluene. Toluene can be made either from benzene and methyl chloride or by dehydrogenation of the heptane fraction of petroleum.

1.17 Industrial Gases

1.17.1 Carbon Monoxide (CO)

Carbon monoxide is formed when carbonaceous matter is burnt in a deficiency of oxygen or air.

Structure

The electron structure of CO is such that the molecule can be drawn as follows:

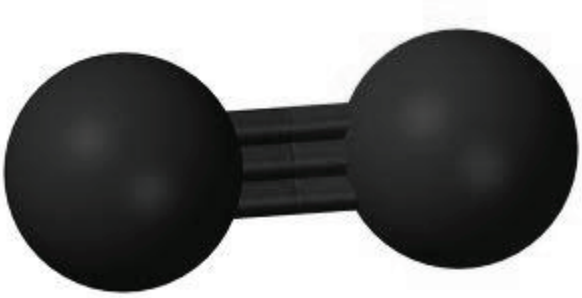


Figure 1.15 Carbon Monoxide

The molecular mass is 28. (0 = 16 C = 12)

Physical Properties

- It is less dense than air and only slightly soluble in water.
- It is a very poisonous gas; it destroys the ability of blood to absorb O_2. It combines with red blood cells and the victim will die of asphyxia. If poisoning occurs, remove the victim to an area with fresh air.
- It is a colourless, odourless gas.

Chemical Properties

- CO will burn with a light blue flame in air to form$C0_2$.
  $\frac{1}{2}O2 \rightarrow C0_2$-- $C0_2$)
- CO is a powerful reducing agent.
  CO+ metal oxide → $C0_2$+ metal.
  eg $3CO_{(g)} + Fe_20_{3(s)} \rightarrow 2Fe_{(s)} + 3C0_{2(g)}$
- CO is used for synthesizing organic compounds.
  Methanol (CH_30H) is made from CO and H_2 under pressure. $CO + 2H_2 \rightarrow CH_30H$. Carbon monoxide is also used in the synthesis of many other organic compounds.

Uses

- CO is used as a fuel for heating purposes.
- As a reducing agent it is used to extract nickel and other metals.
- It is used to manufacture metal carbonates.
- Used in a mixture with ethylene to preserve spoilable foods.
- Used in the manufacture of certain catalysts.
- Used to manufacture organic acids, esters and hydroxyl acids.
- Used to recover nickel from ore that contains copper, cobalt and iron.
- Used for the synthesis of hydrocarbons in the Fisher-Tropsch process.

Preparation

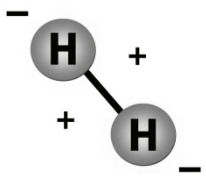
Various methods can be used:

- By reducing carbon dioxide:
  $C0_{2(g)} + C_{(s)} \rightarrow 2CO_{(g)}$
- By action of steam on hot coke:
  $C_{(s)} + H_20_{(g)} \rightarrow CO_{(g)} + H_{2(g)}$
- By decomposition of formic acid:
  $HCOOH_{(aq)} \xrightarrow{H_2SO_4} H_20_{(l)} + CO_{2(g)}$

1.17.2 Hydrogen (H_2)

Structure

This is element No 1 on the Periodic Table. Atoms combine to form an H_2molecule (each shares its 1selectron with the other), with the 1s orbital of both atoms filled.



Physical properties

- H_2 is a diatomic, colourless, tasteless, odourless gas.
- It can be liquefied by compression and cooling in liquid Nitrogen.
- H_2 is the lightest molecule (14,4 times lighter than air).

Chemical properties

- H_2 burns in air, and under certain conditions reacts explosively with oxygen and other halogens:
  $2H_{2(g)} + 0_{2(g)} \rightarrow 2H_20_{(1)}$
  $H_{2(g)} + Cl_{2(g)} \rightarrow 2HCl_{(g)}$
- It reacts partially with boiling sulphur to give hydrogen sulphide:
  $H_{2(g)} + S_{(l)} = H_2S_{(g)}$
- Reacts with Nitrogen in the presence of a catalyst to form ammonia.
- Reduces metallic oxides to metals at high temperatures.

Hydrogen:

- Is a colourless, odourless and tasteless gas;
- In chemistry it is the lightest matter (lighter than air);
- It burns in air but does not maintain combustion;
- Burns with air to form water;
- Is a reducing agent combines actively with halogen.

Uses

- To change oils into fats, for example vegetable oils become fats to form margarine. (Process called hydrogenation).
- Extraction of petrol and oil from coal. Pulverized coal under a high pressure and at 450°C gives off a mixture of hydrocarbons, from which synthetic petrol is manufactured. In the Fischer-Tropsch process steam is passed over heated coke.
  $C + H_20 = CO + H_2$
  The water-gas ($CO + H_2$) is then enriched by H_2 and under pressure, at 200°C is led over a catalyser.
  $8CO + 17H_2 = C_8H_{18}$ (octane) $+ 8H_20$
- In the Haber process hydrogen is used in the manufacturing of synthetic NH_3. (Manufacture of fertilisers)
- Releasing of weather balloons.
- To manufacture hydrochloric acid $H_2 + Cl_2 \rightarrow 2HC1$
- To obtain metals from ore by reduction.
- Used as a liquid fuel for rockets.

Preparation

Hydrogen can be prepared by various methods:

- Action of water on metals:
  $2Na_{(s)} + 2H_20_{(l)} \rightarrow 2NaOH_{(aq)} + H_{2(g)}$
- Action of dilute acids on metals. Hydrogen is normally prepared in the laboratory by reacting zinc with dilute hydrochloric acid. The reaction can be catalysed by either copper or platinum which, by themselves, do not evolve hydrogen from acids - the hydrogen being evolved from the non-zinc surface.
  Platinum is known to be a very effective catalyst for the recombination of hydrogen atoms:
  $Zn_{(s)} + 2HCl_{(aq)} \rightarrow ZnC1_{2(s)} + H_{2(g)}$
- Action of strong alkalis on zinc and aluminium:
  $Zn + 2NaOH \rightarrow (Na0)_2Zn + H_2$
  $2A1 + 2NaOH + 2H_20 \rightarrow 2NaA10_2 + 3H_2$
- Electrolysis of water.
  $2H_20_{(l)} \xrightarrow[\text{electricity}]{} 2H_{2(g)} + 0_{2(g)}$

Testing for Hydrogen

Collect an amount of hydrogen in a flask by the downward displacement of water.

The flask must be held upside-down near a flame. A loud popping sound will be heard and water will be formed. Test the water with dry (white) copper sulphate crystals. The crystals will become blue.

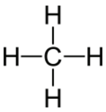
Occurrence

- Will appear in small amounts in the atmosphere.
- Is found in many organic combinations such as oils, methane gas, petrol etc.
- Is found in all acids.
- Will be found in volcanic gases.

1.17.3 Methane (CH4)

Methane is the first saturated hydrocarbon in the series.

Structure



$$\begin{array}{c} H \\ | \\ H-C-H \\ | \\ H \end{array}$$

This is a saturated hydrocarbon compound.

Physical Properties

- Methane is a colourless, odourless gas.
- It is much lighter than air.
- Methane is a gas that is toxic to humans.

Chemical Properties

- CH_4 can be oxidised to $C0_2$ and H_20:
  $CH_4 + 20_2 = C0_2 + 2H_20$
- Reaction with halogens to produce acid:
  $CH_4 + Cl_2 \xrightarrow[250°C]{\text{in dark}} CH_3C1 + HCl$

Uses

- As a fuel in industry (greatest use)
  $CH_4 + 0_2 \rightarrow C0_2 + 2H_20$
- To manufacture carbon black
  $CH_4 + 0_2 \rightarrow C + 2H_20$ or $CH_4 \rightarrow C + 2H_2$
- To manufacture hydrogen: $CH_4 \rightarrow C + 2H_2$
- To manufacture halogen derivatives:
  $CH_4 + 4Cl_2 \rightarrow CCl_4 + 4HCl$
- To manufacture ethylene $2CH_4 \rightarrow CH_2 = CH_2 + 2H_2$
- In the manufacture of steel and glass (used as a gas to keep glass molten).

Preparation

- Pass H_2 over carbon at 1100°C
  $C + 2H_2 \rightarrow CH_4$
- Sodium acetate + sodium hydroxide
  $CH_3COONa + NaOH \rightarrow CH_4 + Na_2C0_3$
- Drip methyliodin on a compound of ZN and Cu
  $CH_3I + 2H \rightarrow CH_4 + HI$

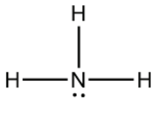
Occurrence

- Often found in mines, eg coal mines.
- In sewage systems.
- In decomposed organic materials.

1.17.4 Ammonia (NH3)

Structure

The hydrogen atom bonds covalently to a nitrogen atom.



Occurrence

- NH_3 is found in small amounts in the atmosphere.
- When coal is distilled, dry ammonia will be set free.

- Decomposing nitrogen organic materials such as horse stables and chicken coops.

Physical Properties

- Ammonia is a liquefiable gas with a characteristic smell.
- It is readily soluble in water and the solution turns red litmus paper blue (ammonium hydroxide, ie forms an alkali).
- It is lighter than air (± 0,75 of mass of air).
- Ammonia (if compared to other gases) has a high boiling point (-33°C) and a very high melting point (-78°C) (due to hydrogen bonds).
- Many salts dissolve and dissociate in liquid ammonia.

Chemical Properties

- Ammonia is a reducing agent:
  $2NH_3 + 3Cl_2 \rightarrow N_2 + 6HC1$
- Ammonia burns in pure oxygen
  $4NH_3 + 30_2 \rightarrow 2N_2 + 6H_20$
- At ordinary temperatures it is a stable compound. However, it decomposes into nitrogen and hydrogen at high temperatures.
- Ammonia dissolves in water in large amounts. 700 volumes dissolve in 1 litre of water. A part of the ammonia reacts with water and ionises.
  $NH_3 + H_20 \rightarrow NH_4^+ + OH^-$
- The unshared pair of electrons on nitrogen in a NH_3 molecule, enables ammonia to bond to metallic ions thus, NH_3 appears in complex ions such as $Cu(NH_3)_4^{++}$ and $Ag(NH_3)_2^+$

Uses

- As fertilizers, eg. Ammonium sulphates and nitrates.
- As a cleaning agent to remove fats and oils (in washing powders).
- As a refrigerant in mechanical cooling systems.
- For making other compounds, eg. vitamins and drugs.
- As a neutralising agent in the petroleum industry.
- It is used in the Leclanche electrical cell in the form of NH_4Cl.

Preparation

- By decomposing ammonium compounds
  $Ca(OH_2) + 2NH_4Cl \rightarrow CaC1_2 + 2NH_3 + 2H_20$
- By the destructive distillation of bituminous coal. When coal is distilled dry, eg Iscor and Sasol, ammonia is a by-product.
- Synthesis of ammonia by the Haber process. Chemists long ago discovered that ammonia is formed when an electric spark passes through a mixture of nitrogen and hydrogen. The reaction is reversible:
  $N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)} + 22kCal$ (or kilojoules)

The reaction between nitrogen and hydrogen is exothermic. Higher temperatures increase the rate at which the molecules of nitrogen and hydrogen react. At a pressure of 1000atmospheres, and with the aid of a catalyst, about 40% - 60%ammonia can be produced.

The use of a catalyst of porous iron and oxides of potassium and aluminium, enables the reaction to proceed at a temperature of 400°C - 550°C. The ammonia is produced in special chrome - vanadium steel converters designed to withstand the tremendous pressure.

Ammonia is separated from the unreacted nitrogen and hydrogen by being dissolved in water, or by being cooled until it liquefies. The uncombined gasses (hydrogen and nitrogen) are returned to the converters and exposed again to the action of the catalyst.

Figure 1.16 is a flow diagram of the Haber process.

Ammonia gas produced in the catalyst chamber is condensed into a liquid in the cooler. The uncombined nitrogen and hydrogen are re-circulated through the catalyst chamber.

Test for Ammonia

- Hydrochloric vapours form white smoke vapours when in contact with ammonia.
- Nessler solution is the most sensitive test and forms a reddish-brown colour when ammonia bubbles through the system or when a drop of it is shaken in a flask containing NH_3.
- A light blue copper sulphate solution becomes dark blue when NH_3 is allowed to bubble through it.

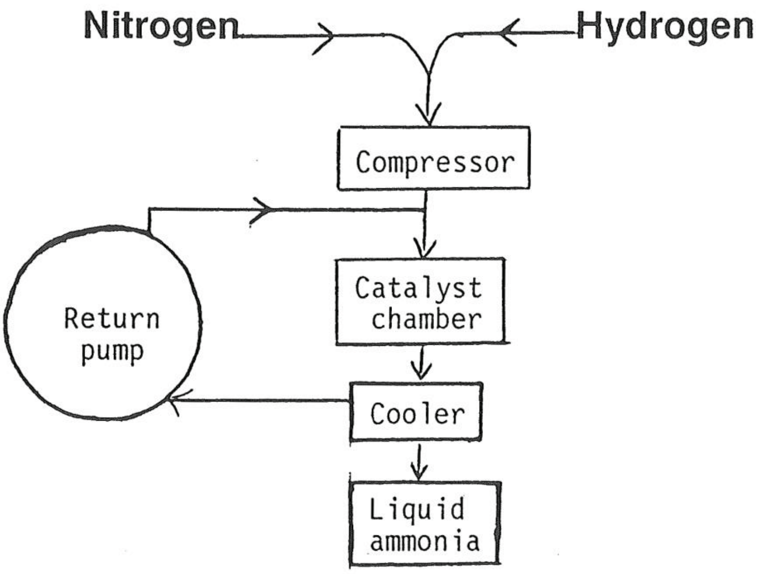
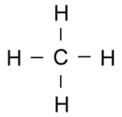
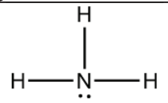


Figure 1.16

	Carbon Monoxide	Hydrogen	Methane	Ammonia
Occurrence	Formed when carbonaceous matteris burned in a deficiency of air	• Small amount in atmosphere • Many organic compounds • Found in all acids • Found in volcanic gases	• Often found in coal mines • In sewage systems • In decomposed org. materials • Natural gas	• Small amounts in atmosphere • When coal is distilled dry ammonia is set free • Decomposing nltrogn, organic materials
Structure	$\overset{\ominus}{:C}\equiv\overset{\oplus}{O:}$	**H : H**		
Preparation	• Reducing carbon dioxide $CO_{2(g)}+C_{(s)} \rightarrow 2CO_{(g)}$ • Steam on hot coke $C_{(s)}+H_20_{(g)}\rightarrow CO_{(g)}+H_{2(g)}$ • Decomposition of formic acid $HCOOH(aq) \xrightarrow[\text{dehydration}]{H_2SO_4} H2O_{(l)}+CO_{(g)}$	• Action of water on metals $2Na_{(s)}+2H_2O_{(l)} \rightarrow 2NaOH_{(aq)}+H_{2(g)}$ • Action of dilute acid on metals $Zn_{(s)}+2HCl \rightarrow ZnCl^{2(s)} + H_{2(g)}$ • Strong alkalis on Zn and Ae $Zn+2NaOH \rightarrow (NaO)_2Zn+H_{2(g)}$ $2Al+2NaOH+2H_2O_{(g)} \rightarrow 2NaAlO_2+H_{2(g)}$ • Electrolysis of water $2H_2O_{(l)} \xrightarrow[\text{electricity}]{} 2H_{2(g)}+O_{2(g)}$	• Pass H2 over carbon - 11OO° C $C+2H_2 \rightarrow CH_4$ • Sodium acetate+sodium hydroxide $CH_3COONa+NaOH \rightarrow CH_4+Na_2CO_3$	• Decomposing ammonium salts $Ca(OH)_2+2NH_4Cl \rightarrow CaCl_2+2NH_3+H_2O$ • By-product of coal distillation • Haber process
Physical properties	Colourless; odourless gas; less dense than air; only slightly soluble in water; poisonous (destroy ability of blood to absorb 02)	Lightest, diatomic; colourless, tasteless, odourless gas, liquefied by compression and cooling.	Colourless, odourless gas; lighter than air; toxic.	Liquefiable gas, sharp smell; soluble in water(alkaline); lighter than air; bp (-33°C), mp (-78°C) good solvent for salts
Chemical properties	• Burns in air – light blue flame $CO+\frac{1}{2}O_2 \rightarrow CO_2$ • Powerful reducing agent CO + metal oxide → CO_2+metal • Synthesis of org. compounds $CO+2H_2 \rightarrow CH_3OH$ methanol	• Burns in air: $2H_{2(g)}+O_{2(g)} \rightarrow 2H_2O_{(g)}$ Reacts with halogens: $H_{2(g)}+Cl_{2(g)} \rightarrow 2HCl_{(g)}$ Reacts with boiling sulphur: $H_{2(g)}+S_{(l)} \rightarrow H_2S_{(g)}$ • Reacts with nitrogen $3H_{2(g)}+N_{2(g)} \xrightarrow{\text{catalyst}} 2NH_{3(g)}$ • Reduces metallic oxides high temp! $CuO+H_{2(g)} \rightarrow Cu+H_2O$	• Can be oxidized to CO2 and water $CH_4+2O_{2(g)} \rightarrow CO_2+2H_2O$ • React with halogens to produce acid $CH_4+Cl_2 \xrightarrow[250^\circ C]{\text{In dark}} CH_3Cl+HCl$	• Weak reducing agent $2NH_3+3Cl_2 \rightarrow N_2+6HC$ • Burns in pure oxygen $4NH_3+3O_2 \rightarrow 2N_2+6H_2O$ • Decomposes into N_2 and H_2 at high temp • Dissolves in water in large amounts $NH_3+H_2O \rightarrow NH_4+OH$ • Appears in complex ions such as Cu(NH3)42+
Test		• Loud popping sound when a flame is brought near a flask with H2. Water formed. • Dry copper sulphate crystals become blue in the water		• Hydrochloric vapours form white smoke vapours when it is contact with ammonia. • Nessler solution - reddish brown colour when ammonia bubbles through the system • Light blue CuS04 solution becomes dark blue when NH3 is bubbled through
Uses	• Fuel for heating • Reducing agent to reduce iron • Manufacture of carbonyls • Manufacture of catalysts • Manufacture of organic comp. • Synthesis of hydrocarbons	• Hydrogenation: alkenes to alkanes – oils into fat. • Extraction of petrol and oil from (Fischer-Tropsch) • Haber Process • Releasing of weather balloons (gas is very light) • Manufacture of HCl • Obtain metals from ore - good reducing agent at high temp. • Liquid fuel for rockets	• As a fuel in industry $CH_4+2O_2 \rightarrow CO_2+2H_2O$ • To produce carbon black $CH_4+O_2 \xrightarrow{800^\circ C} C+2H_2O$ or $CH_4+ \xrightarrow{\text{cracking}} C + 2H_2$ • To manufacture hydrogen $CH_4+ \xrightarrow{\text{high temp}} C + 2H_2$	• As fertilizers, eg (MH4)2SO4 • Cleaning agent to remove fats and oils • Refrigerant in mechanical cooling systems • Making vitamins and drugs • Neutralising agent in petroleum industry • Used in Leclanche electrical cell to form NH_4Cl • To trace Cl2 leaks

			• Manufacture halogen derivatives $CH_4+4Cl_2 \rightarrow CCl_4+4HCl$ • Manufacture ethylene $2CH_4 \rightarrow CH_2=CH_2+2H_2$ • Manufacture of steel and glass	(NH4Cl – white fumes)

Table 1.11 Industrial gases

Activity 1.1

Complete the following examples:

$Zn + 2HCL =$
$Zn + H_2SO_4 =$
$H_2 + Cl_2 =$
$NH_3 + H_2SO_4 =$
$3H_2 + 2PO_4 =$
$Na + Cl_2 =$
$H_2 + O_2 =$
$CuO + H_2 =$
$H_2O + Fe =$

Activity 1.2

1. Sketch the complete structure of an aluminium atom, showing the number of orbitals, their shape and number of electrons. Also give the electron configuration.
2. Determine the molecular mass of CH_3COONa and show your calculations.
3. Give the complete chemical equation for the reduction of copper oxide to copper by carbon monoxide.
4. List ***FOUR*** uses of carbon monoxide, except the one in question 3.
5. List the uses of ammonia.
6. Briefly describe a laboratory method to test for hydrogen.
7. Give the general formula of hydrocarbons concerning alkanes, alkenes and alkynes.

Activity 1.3

Indicate whether the following statements are ***TRUE*** or ***FALSE***.

1. A molecule refers to the smallest particle of a compound.
2. In the periodic table, elements with the same number of energy levels are grouped horizontally in periods from left to right.
3. Oxygen contains 16 neutrons.
4. Ch_4 is a component in natural gas.

5. NH_3 is a cleaning agent to remove fats and oils.
6. Atoms with the same number of protons and neutrons in the nucleus are called isotopes.
7. The atomic mass of Ca is 40 amu.
8. Electrons have a positive charge.
9. An electrovalent bonding refers to covalent bonds.
10. CO is slightly soluble in water.
11. Neutrons have a negative charge.
12. A compound refers to the chemical combination of two or more atoms.
13. The second period of the periodic table consists of six elements.
14. CO gas is slightly soluble in water.
15. NH3 gas is heavier than air.

Activity 1.4

1. Determine the molecular mass of $Ca(OH)_2$ and show your calculations.
2. Describe each of the following:
   a. Atomic mass
   b. Isotope
3. Describe a test to identify H_2.
4. Sketch the complete structure of a phosphorous atom, showing the number of orbitals, their shape and number of electrons.
5. Complete the following equation:
   $2K + H_2O = 2KOH + \ldots\ldots \uparrow$

Activity 1.5

1. With the aid of an appropriate chemical reaction, explain a method for the preparation of hydrogen by means of an acid.
2. Give the IUPAC name of paraffin and acetylene and give the formula for each.
3. Explain what the following formula represents: $3C_2H_6$.
4. State ***TWO*** Characteristic properties of hydrogen.

Activity 1.6

1. Discuss the conditions necessary for covalent bonding. Illustrate the answer by means of a diagram.
2. Determine the molecular mass of NH_4NO_3 and show the calculations.
3. State ***SIX*** properties of electrons.
4. State where methane can be found.
5. Draw an abridged periodic table giving the first 20 elements in their groups and periods.

6. List the properties of alkanes.
7. With the aid of an applicable chemical reaction explanation give the chemical properties of ammonia (NH_3).
8. Determine the molecular mass of NH_3 and show your calculations.

Self-Check		
I am able to:	**Yes**	**No**
• Name the following for nuclear atoms:		
o Proof and ingredients		
o Elements and isotopes		
o Atomic weight, number and counted number		
• State the orbital 1 to 20 elements for atomic models		
• Describe the principles of chemical changes		
• Describe the types of chemical reactions		
• Describe the following for systematic and basic organic chemistry:		
o Multiplicity of connections		
o Structure and use of a few types of organic compounds		
• Describe the following for these industrial gasses CO, H_2, CH_4 and NH_3:		
o Appearance of gasses – where and how		
o Preparation in the laboratory and in large quantities (except CH_4)		
o Physical and chemical properties		
o Tests for gasses		
o Application (uses) of these gasses		
If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 2

Liquids

Learning Outcomes
On the completion of this module the student must be able to:

- Explain the history of fluid flow; water
- Explain fluid flow through gravity
- Describe fluid flow performance
- Identify and explain flow rate
- Identify and describe the following types of fluid flow:
  - Equal flow
  - Turbulent flow
- Describe and explain the following principles which influence fluid flow:
  - Pressure and pressure altitude
  - Pressure and flow rate ratio
  - Continuous flow (with problems)
  - Flow and pressure loss (with problems)
  - Viscosity fluids, statement and impact of temperature
  - The effect of pressure
  - Causes of loss of pressure, namely;
    - Size of the pipe
    - Length of the pipe
    - Roughness
    - Change of direction
    - Viscosity
    - Thickness
  - Typical flow system (with examples of problems)

2.1 Introduction

As early as 5000 years ago, it was documented that King Menes of Egypt dammed up the Nile River. Particulars of his methods, and the type of materials used are vague, but it is possible that he used turf or clay banks when the water level was low.

In 1000bc, the "Shadoof" was in general use. It consisted of a bucket which was lowered into the water and attached to a long pole. It was then lifted to a higher level where the bucket was turned over to let the water run out. This was a primitive yet effective method, out more advanced lifting methods were invented such as the Archimedes screw. This apparatus pumped water up an incline of 30° by using a long corkscrew type of screw in a cylinder. With the rotation the water was transported up the screw and into canals from where it was led to irrigation lands.

Later the "Saqia" was designed. This is an apparatus similar to the water wheel used in mills. The buckets scooped the water up and discharged it into a duct which distributed the water to where it was required.

Irrigation of farmlands via the above method became common place. Channels were covered with materials to prevent water evaporation.

As early as 312 BC the method of gravity flow and channels was introduced to supply Rome with water. Water was also used to take sewage from the city through channels to the sea.

The siphon was also used to transport water, provided the taps were situated at a point lower than the inlet side. King Hiskia built a dam to supply Jerusalem with water in 300BC, using the principle of the siphon.

2.2 Fluid flow through gravity

If we put a fluid in an open container, we can tilt the container in any direction, and the fluid level will always be perpendicular to the axis through the centre of the earth, but parallel to the ground, providing we do not stand on an incline.

Tidal force refers to energy of water in motion, which is utilized to generate electricity. In this case, the energy of the water in motion due to tidal changes of the sea is used. An important pre-requisite is that the tidal height between high and low tide must be significant.

If any fluid is connected to a hollow object through which water can flow, and the point of this hollow object is lowered, the fluid will flow in the direction of the lowered point. Therefore we know that water will always run down an incline and this flow will take place naturally because of the earth's attract ion force.

The process operator which often has to transfer fluids from one point to another can seldom make use of the earth's attraction force. A mechanical or external pressure device must be used to transport the fluids, such as a pump.

2.3 Basic fluid flow performance

To transport a fluid from a higher to a lower level is easy because it will happen of its own accord, providing a path is made for it.

It is actually a very difficult task to transport the fluid from a lower to a higher level. External work or energy is required which, in turn, must correspond with the quantity, mass, height and time required for the process to take place.

Different types of pumps are used for this purpose.

Loss of pressure in pipes:

Density of a fluid is the **mass of the liquid per volume** thereof and more energy is needed to displace a fluid with a high density than a fluid with a low density during the **same time lapse**.

The higher the density of the fluid, the **greater the loss of pressure in the pipe**.

2.4 Flow rate

In the metric system flow is measured in cubic metres per certain time.

Normally it can be expressed as cubic metres per minute or cubic metres per hour. However, when a large quantity is to be transported, eg in irrigation schemes, the cusec or cubic metre--per second is used. For smaller quantities litre per second can be used. Therefore the units used are:

m^3/s or often written as $m^3 5^{-1}$
l/s or often written as $l.5^{-1}$

Often it is necessary to determine the mass flow rate, when kilogram per second (kg/s or kg 5^{-1}) is used.

2.5 Types of flow

- Continuous flow
- Turbulent flow

2.6 Principles that will influence flow

When a fluid in an open channel flows due to gravity alone, a continuous or laminar flow in the middle of the stream will take place with layers of molecules within the fluid will flowing together.

At the bottom and sides the layers of fluid molecules in contact with the ground or concrete of the channel, adhere to the material and prevent movement. This is referred to as adhesion.

Between molecule layers a force will exist which is referred to as cohesion. It requires force or energy to separate these layers as a result of the cohesion that exists.

Where this happens, turbulent flow will take place. The one layer of molecules moves faster than the other and whirl streams will result which will disrupt the continuous or smooth flow of the flow pattern.

Both types of flow are found in pipes. Turbulent flow will result in the loss of pressure in the pipe and this loss of pressure will increase with the lengthening or narrowing of the pipe.

More energy will be needed to ensure that the velocity of flow over a long distance is maintained. The energy needed, must be provided by a pump or other external source to supply the necessary pressure.

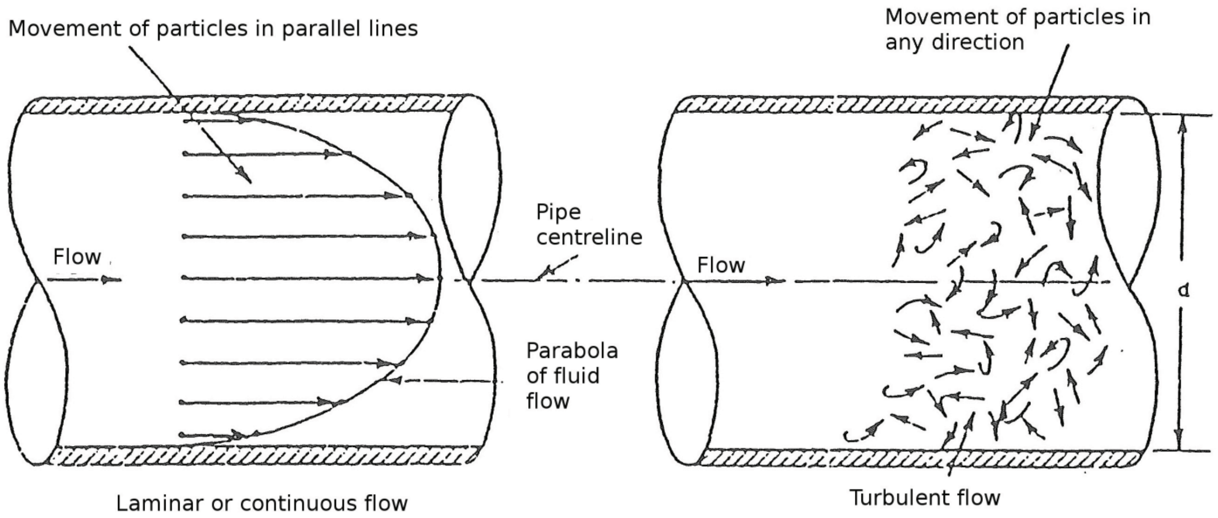


Figure 2.1

2.6.1 Pressure and pressure height

It often happens that a fluid has to be pumped against an internal pressure in a sealed container, to a certain height.

The total effect of the two factors, as can be expected, is the sum of the two effects plus the friction of the fluid against the sides of the pipe.

For our purpose, the friction in the pipe is negligible but must be included as a factor in calculations, for the sake of accuracy.

The pressure, against which the fluid must be pumped, is taken as the static pressure height of the fluid, plus the internal pressure in the container into which the fluid is pumped.

Total delivery pressure:
= static pressure + internal pressure
= density x gravity x height (head) + P (internal)
= pgh + P

Note that kg x gravity = newton, and gravity is used as 9,81m/s^2. For convenience, however, gravity is often taken as 10m/s^2. This means that the pressure of 1 kg of a fluid = 9,81 newton per area of 1 square metre, irrespective of the diameter of the pipe.

1m^3 of a fluid will have an area of 1m^2 and a height (head) of 1m. The pressure of a fluid is then calculated per m^2. The density of the fluid is given in kg/m^3.

Example 1

A pump delivers fluid with a density of 1080 kg per cubic metre (kg/m3) against a head of 15 metres into an open container. Calculate the pressure delivery of the pump. Ignore the friction and suction head.

Solution

Delivery pressure = pgh
= 1080 x 10 x 15 Pa
= 162 000 Pa
= 162 kPa

Example 2

Under what conditions will a tank fill up the quickest way?
a) When the delivery pipe is installed in the top of the tank?
b) When it is installed at the bottom of the tank?
c) What will be the disadvantage of (b)?

Use the values of Example 1 and include the depth of the tank which is 3m. This depth must also be included in the 15m head.

Solution

a) The delivery pressure of the pump was calculated (example 1) as 162 kPa.
b) The delivery pressure of a pump will vary with the depth or height of the tank or container, even when it is empty or when it is full. The average pressure is therefore half of the empty total head (h_1) +full total head (h_2)

Pressure = pg$\left(\frac{H_1+H_2}{2}\right)$

= 1 080 x 10 x $\left(\frac{12+15}{2}\right)$
= 1 080 x 10 x 13,5
= 145 800 Pa
= 145,8 kPa

The pump will have a lighter working load in case (b) and therefore the tank will be filled first, or the quickest way in this case.

c) The disadvantage of case (b) is that the tank may run dry and therefore provision, to prevent this, must be made by installing a stop valve.
This valve must be installed between the pump and the tank.
In case (a) only the pipe will run dry if a stop valve is not installed.

Example 3

A pump is installed 1,5m below the level of the water and the fluid must be pumped to a height (head) of 18,5m above the pump. Calculate the delivery pressure of the pump.

Solution

Pressure = density x gravity x static head
= 1 000 x 10 x (18,5- 1,5)
= 170 000 Pa
= 170 kPa

Note: the density of water is always 1000 kg/m3 unless you have been told differently.

2.6.2 Head and pressure equivalent

The following table gives the pressure at different head in kilopascal, bar and pounds per square inch. The values are approximated because the density of water will change with a change in temperature, and because gravity will change with height above sea level.

Head	kPa	Bar	psi	Head	kPa	Bar	psi
1	10	0,1	1,45	85	850	8,5	123,29
2	20	0,2	2,90	90	900	9,0	130,55
3	30	0,3	4,35	95	950	9,5	137,80
4	40	0,4	5,80	100	1000	10,0	145,05
5	50	0,5	7,25	110	1100	11,0	159,56
6	60	0,6	8,70	120	1200	12,0	174,06
7	70	0,7	10,15	130	1300	13,0	188,57
8	80	0,8	11,60	140	1400	14,0	203,07
9	90	0,9	13,05	150	1500	15,0	217,58
10	100	1,0	14,51	160	1600	16,0	232,08
15	150	1,5	21,76	170	1700	17,0	246,59
20	200	2,0	29,01	180	1800	18,0	261,09
25	250	2,5	36,27	190	1900	19,0	275,60
30	300	3,0	43,52	200	2000	20,0	290,10
35	350	3,5	50,77	210	2100	21,0	304,61
40	400	4,0	58,02	220	2200	22,0	319,11

45	450	4,5	65,27	230	2300	23,0	333,62
50	500	5,0	72,53	240	2400	24,0	348,12
55	550	5,5	75,78	250	2500	25,0	362,63
60	600	6,0	87,03	260	2600	26,0	377,13
65	650	6,5	94,28	270	2700	27,0	391,64
70	700	7,0	101,54	280	2800	28,0	406,14
75	750	7,5	108,79	290	2900	29,0	420,65
80	800	8,0	116,04	300	3000	30,0	435,15

Table 2.1

2.6.3 Continuous flow

2.6.3.1 Bernoulli's theory

When a fluid flows in a pipe and the pipe is completely full, due to gravity- the sum of the pressure energy, velocity energy and potential energy is always a constant. Neglect the friction factor. This means that in any section of a pipe in the piping, the sum of the three types of energy will always be the same.

2.6.3.2 Flow and cross-sectional area of a pipe

A ratio exists between the flow rate, the velocity of the fluid in the pipe and the cross-sectional area of the pipe.

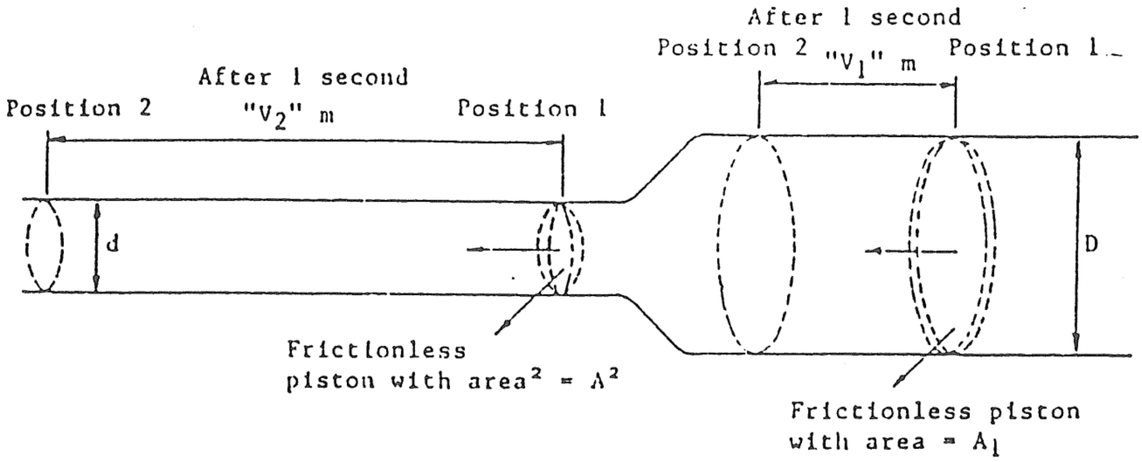


Figure 2.2

If the pipe is always full, then D > d.

When a piston with area A_1 moves over a distance of "V_1"metre in one second in a pipe, it will displace a volume of A_1V_1 metre^3, and if a second piston with area A_2 moves over a distance "V_2" metre in one second, it will displace a volume of A_2V_2 metre^3 and therefore volume 1 will be the same as volume 2.

Take a pipe with $A_1 = 1$ m^2 and $A_2 = 0,5$ m^2 with distances $V_2 = x$ and $V_1 = 1$ m.

Then Q $= A_1V_1 = A_2V_2$ $(Q = A_1V_1$
$= 1m^2 x\ 1m$ and $= 1m^2\ X\ 1m$
$= 0{,}5m^2 \ x\ v2 = 1m^3)$

$\therefore V_2 = \frac{1\ x\ 1}{0{,}5} 1\ x\ 1\ /\ 0{,}5$
= 2 metre
$\therefore V2 = 2m$

From the above, the conclusion can be drawn that when the area of a pipe decreases by half, the velocity will increase to twice as much for the same quantity. What will happen if the cross section of pipe decreases by half?

Conclusion

The flow rate or quantity in the pipe is equal to the square of the cross section of the pipe.

2.6.3.3 Flow and pressure difference

From Bernoulli's theory it is clear that the pressure of the fluid in the narrow part of the pipe is lower than the pressure in the wider part of the pipe. This is due to the greater velocity of the fluid in the narrow part of the pipe.

From the above it is clear that velocity will increase in the narrow portion of the pipe even if this portion is very short.

Primary flow gauges work on this principle. In front of the measuring plate, the pipe diameter is wider and the flow is consequently slow with a high pressure. In the narrow part the velocity will be higher with a drop in pressure.

The ratio between the flow and pressure difference is a quadratic ratio and Q = k /pressure difference.

The pressure difference is in relation to the square of the flow rate or quantity. This fact can also be proved by the formula Q = AV (or H = Os). If a fluid falls freely over a specific height, the kinetic energy is equal to the potential energy.

Potential energy = kinetic energy
$mgh = \frac{1}{2}\ m\ V^2$

$V^2 = mgh\ x\ \frac{2}{m}$

$V = \sqrt{2gh}$

If V is in the formula Q = AV is replaced by $V = \sqrt{2gh}$ then the formula becomes:

Q = $\sqrt{2gh}$ where h = height (head of fluid
= pressure height

If A x $\sqrt{2gh}$ is now used as constant "k", then Q = $k\sqrt{h}$ can be used to calculate the flow. For every system k will have a different quantity.

Worked Example 1
The diameter of a pipe is 150 mm and it transports 15m^3 fluid per minute. What will the velocity of the fluid be in m/s?

Solution:

Q = Av

$= \frac{IId^2}{4}$ V (because A = $\frac{IId^2}{4}$)

$= \frac{40}{IId^2}$

$= \frac{4\ x\ 15\ \text{metre/minute}}{II\ x\ (0{,}15)^2}$

$= \frac{848{,}8\ m/s}{60}$

∴Velocity = 14,14 m/s→

Worked Example 2
If the same pipe now transports only 5m3/min, calculate the velocity.

Q = AV

V $= \frac{AG\ \ m/s}{IId^2\ x\ 60}$

$= \frac{4\ x\ 5}{II\ x\ (0{,}15)^2\ x\ 60}$

= 4,71 m/s

What is the ratio between the two?

Ratio = $\frac{15\ m^3/min}{5\ m^3/min}$

= 3

Therefore the ratio between the velocities must also be the same.

Ratio = $\frac{14,5}{4,71}$

= 3→

Worked Example 3

When a pipe transports 30m^3/h, the pressure difference over the measuring plate is 36 kPa.

Calculate the pressure difference when the flow is reduced to 20 m3/h.

Solution:

Firstly the constant "k" must be calculated.

$$Q = k\sqrt{h}$$

$$\therefore \quad k = \frac{0}{\sqrt{h}}$$

$$= \frac{30}{\sqrt{36}}$$

$$= 5$$

With k now know, the pressure difference can now be calculated:

$$\sqrt{h} = \frac{Q}{k}$$

$$H = \left(\frac{20}{5}\right)^2$$

h = 16 kPa

It must be noted that with this formula any units can be used for the flow or pressure difference and k will adjust accordingly.

Worked Example 4

A pipe transports 25000 litres per minute against a pressure difference of 100 mm mercury (Hg).

Calculate the pressure difference when the flow is increased to 50000 l/min.

Solution:

$$k = \frac{Q}{\sqrt{h}}$$

$= \frac{25\ 000}{\sqrt{100}}$

= 2 500

Pressure difference at the higher flow value

$= \left(\frac{50\ 000}{2\ 500}\right)^2$

= 400 mm Hg (mercury→

Alternative solution:

Pressure of 100 mm Hg = pgh (use $g = 10 m/s^2$)
= 13 600 x 10 x 01
= 13 600 Pa

$k = \frac{25\ 000}{\sqrt{13\ 600}}$

= 214,37

Pressure difference at higher flow value

$= \left(\frac{50\ 000}{214{,}37}\right)^2$

= 54 400 Pa (this is in fact 4 x 13 600)

Therefore if 100 mm Hg = 13 600 Pa, then

54 400 Pa $= \frac{54\ 400}{13\ 600}\ x\ 100\ mm$

= 400 mm Hg→

2.7 Flow and loss of pressure

It must be remembered that the following tables are only applicable to the flow of water and that when other fluids are used the density and viscosity must be considered.

From **Table 2.2** it is noticed that the loss of pressure is very high when the velocity of flow increases in a specific pipe. It is advantageous to keep the linear velocity of flow within the range of 1 to 2 metres per second.

When the velocity of flow is high, for example, when a high delivery rate is required, the pipe diameter must be increased accordingly.

Take as an example the flow of 1 litre per second on **Table 2.2** and note how the friction loss (loss of pressure) decreases as the pipe diameter increases. The loss is more than 62 metre per 100 m of galvanised pipe of 20 mm diameter, whilst for a 50 mm pipe; it is less than 1m/100m.

From **Table 2.3** it is noticed that the type of pipe will also influence the friction loss. Compare the details for similar conditions on the two tables mentioned.

These types of tables are used extensively when designing and planning pipe installations.

Flow Rates				Cross sectional area of pipe									
M^2/h	l/min	l/s		20mm	25mm	32mm	40mm	50mm	65mm	80mm	100mm	125mm	150mm
0,36	6	0,1	79,2	0,75	0,23	0,05	0,02						
0,72	17	0,2	158,4	2,83	0,85	0,21	0,11	0,03					
1,08	18	0,3	237,6	6,17	1,86	0,47	0,22	0,07					
1,44	24	0,4	316,8	10,71	3,23	0,81	0,38	0,11	0,03				
1,80	30	0,5	395,9	16,44	4,96	1,24	0,58	0,18	0,05				
2,16	36	0,6	475,1	23,33	7,04	1,77	0,82	0,25	0,07				
2,52	42	0,7	554,3	31,37	9,46	2,37	1,11	0,34	0,09	0,04			
2,88	48	0,8	613,5	40,54	12,22	3,07	1,43	0,43	0,10	0,05			
3,24	54	0,9	712,7	50,82	15,33	3,84	1,79	0,54	0,15	0,06			
3,60	60	1,0	791,9	62,22	18,76	4,71	2,20	0,67	0,18	0,08			
3,96	66	1,1	871,1	74,71	22,53	6,65	2,64	0,80	0,22	0,10			
4,32	72	1,2	950,3	88,30	26,63	6,68	3,12	0,94	0,25	0,11			
4,68	78	1,3	1029,5		31,05	7,79	3,63	1,10	0,30	0,13			
5,04	84	1,4	1108,7		35,80	9,98	4,19	1,27	0,34	0,15			
5,40	90	1,5	1187,9		40,87	10,25	4,78	1,45	0,39	0,17	0,04		
7,20	120	2,0	1583,8		71,00	17,81	8,31	2,52	0,68	0,30	0,08	0,03	
10,80	180	3,0	2375,7			38,80	18,10	5,48	1,48	0,65	0,17	0,06	0,02
14,40	240	4,0	3167,6			67,12	31,44	9,52	2,57	1,13	0,29	0,10	0,03
18,00	300	5,0	3960				48,26	14,62	3,94	1,73	0,45	0,15	0,05
21,60	360	6,0	4751,4				68,49	20,74	5,59	2,46	0,64	0,22	0,07
25,20	420	7,0	5543,3				92,08	27,89	7,51	3,31	0,86	0,29	0,09
28,80	480	8,0	6335,2					36,04	9,71	4,27	1,11	0,38	0,11
32,40	540	9,0	7127,1					45,18	12,18	5,36	1,39	0,47	0,14
36,00	600	10,0	7919					55,31	14,91	6,56	1,71	0,58	0,17
43,20	720	12,0	9502,9						21,16	9,31	2,42	0,82	0,25
54,00	900	15,0	11878,6						32,48	14,28	3,72	1,26	0,38
61,20	1020	17,0	13462,4						41,30	18,16	4,71	1,60	0,48
68,40	1140	19,0	15046,2						51,13	22,49	5,85	1,98	0,60
75,60	1260	21,0	16630						61,20	27,25	7,09	2,40	0,73
90,00	1500	25,0	19797,6						86,60	38,09	9,92	3,36	1,02
108,00	1800	30,0	23757,1							54,05	14,07	4,76	1,44
126,00	2100	35,0	27716,7							72,67	18,92	6,41	1,94

Table 2.2 Friction loss in metres per 100 m, of galvanised steel pipe 10 kPa

The effect of heat

- Applying heat cause molecules to move faster, increasing the temperature.
- The physical condition can change, e.g ice to water.
- The material can expand or shrink due to the heat.
- The material can change colour, e.g a lump of iron becoming red due to the heat added.

M^2/h	l/min	l/s		20	25	32	40	50	63	75	90	110	125	140	160	200	250
0,36	6	0,1	79	2,11	034	0,17	0,05	0,02									
0,72	12	0,2	158	7,09	2,08	0,56	0,18	0,06	0,02								
1,08	18	0,3	238	14,42	4,24	1,14	0,36	0,12	0,04								
1,44	24	0,4	317	23,85	7,01	1,89	0,59	0,19	0,06	0,24							
1,80	30	0,5	396	35,25	10,36	2,79	0,88	0,28	0,09	0,04							
2,16	36	0,6	475		14,25	3,84	1,21	0,39	0,13	0,05	0,02						
2,52	42	0,7	555		18,66	5,02	1,58	0,51	0,17	0,06	0,03						
2,08	48	0,8	634		21,58	6,35	2,00	0,64	0,21	0,08	0,04						
3,24	54	0,9	713		28,97	7,80	2,45	0,79	0,26	0,10	0,04						
3,60	60	1,0	792		34,84	9,38	2,95	0,95	0,31	0,12	0,05						
3,96	66	1,1	871			11,08	3,48	1,12	0,37	0,14	0,06	0,02					
4,32	72	1,2	950			12,90	4,06	1,30	0,44	0,16	0,07	0,03					
4,68	78	1,3	1030			14,84	4,67	1,50	0,49	0,19	0,08	0,03					
5,04	84	1,4	1109			16,90	5,31	1,70	0,56	0,21	0,09	0,04					
5,40	90	1,5	1188			19,07	5,99	1,92	0,63	0,24	0,11	0,04					
7,20	120	2,0	1584			31,55	9,92	3,18	1,05	0,40	0,18	0,07					
10,80	180	3,0	2376				20,16	6,67	2,13	0,81	0,31	0,12					
14,40	240	4,0	3168				33,36	10,71	3,52	1,34	0,59	0,23	0,13				
18,00	300	5,0	3960					15,82	5,20	1,98	0,88	0,34	0,18				
21,60	360	6,0	4751					21,77	7,16	2,72	1,21	0,47	0,25				
25,20	420	7,0	5543					28,51	9,38	3,57	1,58	0,61	0,33				
28,80	480	8,0	6335					36,02	11,84	4,51	1,20	0,77	0,42	0,25			
32,40	540	9,0	7127						14,55	5,54	2,45	0,95	0,52	0,30	0,16		
36,00	600	10,0	7919						17,50	6,66	2,95	1,14	0,62	0,36	0,19		
43,20	720	12,0	9503						24,08	9,16	4,06	1,57	0,85	0,50	0,25	0,09	
54,00	900	15,0	11878						35,58	13,54	6,00	2,31	1,26	0,74	0,39	0,14	
61,20	1020	17,0	13462							16,85	7,47	2,89	1,57	0,92	0,49	0,17	
68,40	1140	19,0	15046							20,48	9,08	3,50	1,91	1,11	0,59	0,21	
75,60	1260	21,0	16630							24,40	10,81	4,17	2,27	1,33	0,70	0,25	
90,00	1500	25,0	19797							33,10	14,67	5,66	3,08	1,80	0,56	0,33	0,12
108,00	1800	30,0	23757								20,19	7,78	4,24	2,48	1,31	0,46	0,16
126,00	2100	35,0	27716								26,43	10,19	5,55	3,24	1,72	0,60	0,21

Table 2.3 Friction loss in Class 4 stiff PVC per 100 m

2.8 Viscosity of fluids

Viscosity is that property of a fluid that will resist flow. The higher the fluid's resistance against flow, then the higher the viscosity of that fluid. A low viscosity will indicate a fluid that will flow easily. Consider examples from the pulp mill - WBL vs SBL.

2.8.1 Pressure

Pressure for all practical purposes will not influence the viscosity of a fluid that is the viscosity of a fluid will not change when it is placed under pressure.

2.8.2 Temperature

Temperature will influence the viscosity of a fluid. Fluids that are heated will flow easier than fluids that are cold.

Typical examples are oil, grease and tar. All these substances will flow easier when heated and the temperature is kept high.

2.8.3 Viscosity

a) Dynamic Viscosity

The viscosity of fluids is measured in stokes or centistokes. This is determined by filling a flask with a certain fluid and then dropping a ball with a specific mass into the fluid. The time taken for the ball to travel a certain distance through the fluid is measured and this, when computed, will give the viscosity. The longer the ball takes, the higher the viscosity of the fluid.

b) Kinematic Viscosity

Viscosity can also be expressed in poise or centipoises and this is determined by the time it takes a given quantity of a fluid to pass through a small hole in the bottom of a dropping funnel. A distinction is made between dynamic and kinematic viscosity.

2.9 Typical flow systems

All factors must be considered when planning flow systems, to ensure that the system performs to expectations.

2.9.1 Hydraulic Gradient

This is the loss in pressure due to friction per 100m of pipe and is expressed in metre per metre length of pipe. This is another way of expressing friction loss and is normally determined experimentally.

Worked Example 5

Consider the following system requiring one litre per second (1l/s) to be delivered. (Remember this is for water; all other information required to determine friction loss for other fluids must be determined experimentally).

Refer to **Table 2.2**. For a flow of 1 l/s, the friction loss is 4,71m/100m of galvanised pipe with a diameter of 32mm.

The hydraulic gradient $=\frac{4,71}{100}$ = 0,0471m/m for a 32mm 100 diameter pipe. When a 80mm diameter pipe is used, the hydraulic gradient is $\frac{0,08}{100}$ = 0,0008 m/m.

The hydraulic gradient must be between 0,015m/m and 0,05m/m for an acceptable design and for economic reasons. If it is greater than 0,05m/m, the friction loss will be high and the load on the pump will increase. If it is less than 0,015m/m, the pipe diameter is too large and the cost to install these pipes becomes expensive.

The linear velocity of the water in the pipe should not exceed the range of 1 to 2m/s for economic reasons. Above 2 m/s the turbulence and friction loss will increase rapidly, resulting in increased power requirements, thus affecting costs.

The table represented in **Figure 2.4** was drawn up according to SABS standard 62/1970, showing the -factors such as pipe diameters, velocity of flow, linear velocity and hydraulic gradient that need to be considered in correct pump and pipe flow systems.

Worked Example 6

Water is to be delivered at a rate of 5l/s to a tank 200m away and 10m above the ground level. The tank pressure is 300kPa.

Determine a suitable pipe diameter (galvanised pipe) and the total equivalent pressure head (height).

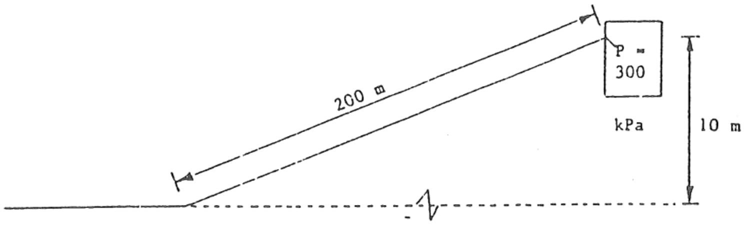


Figure 2.3

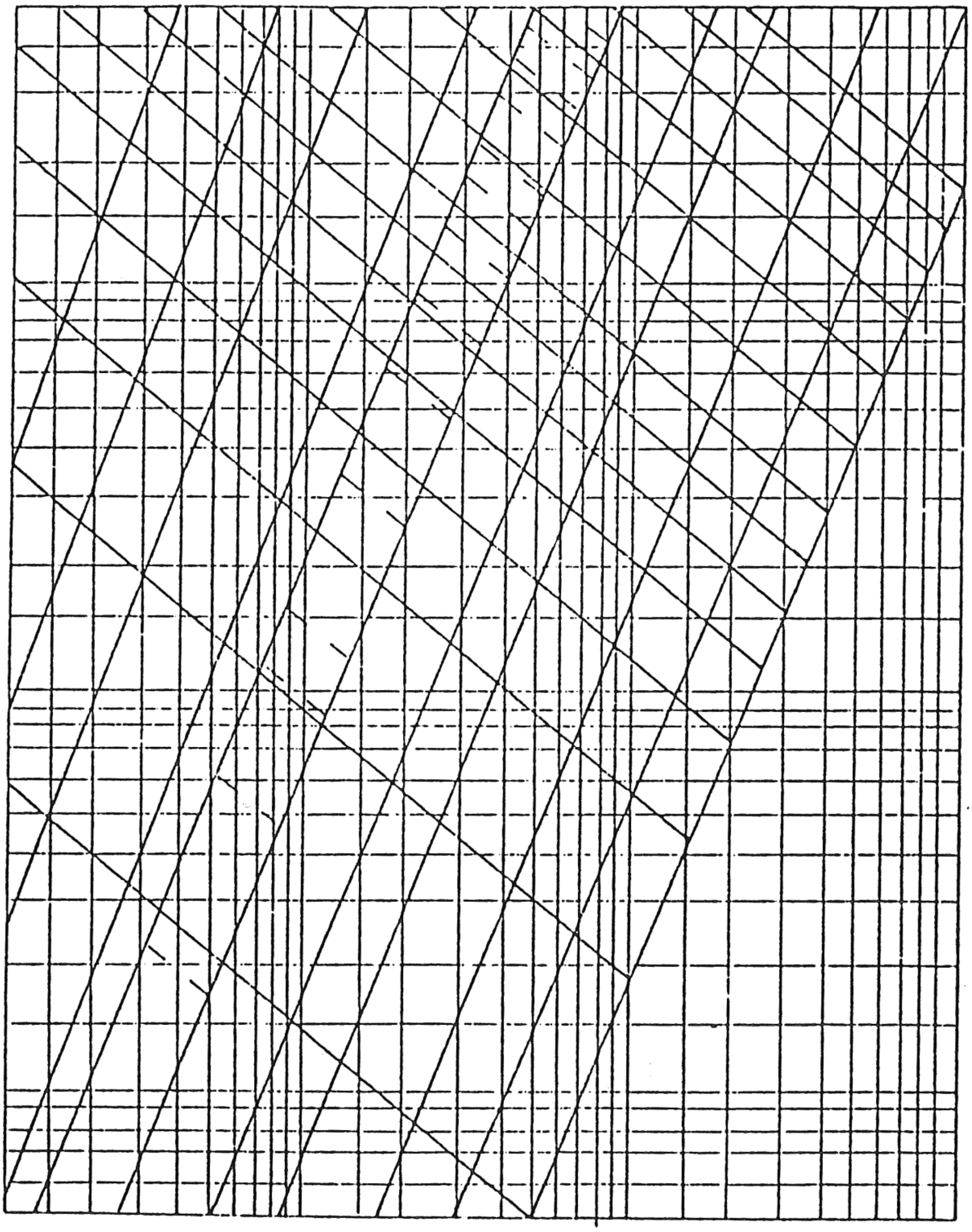


Figure 2.4 Friction in steel pipes according to SABS 62/1970

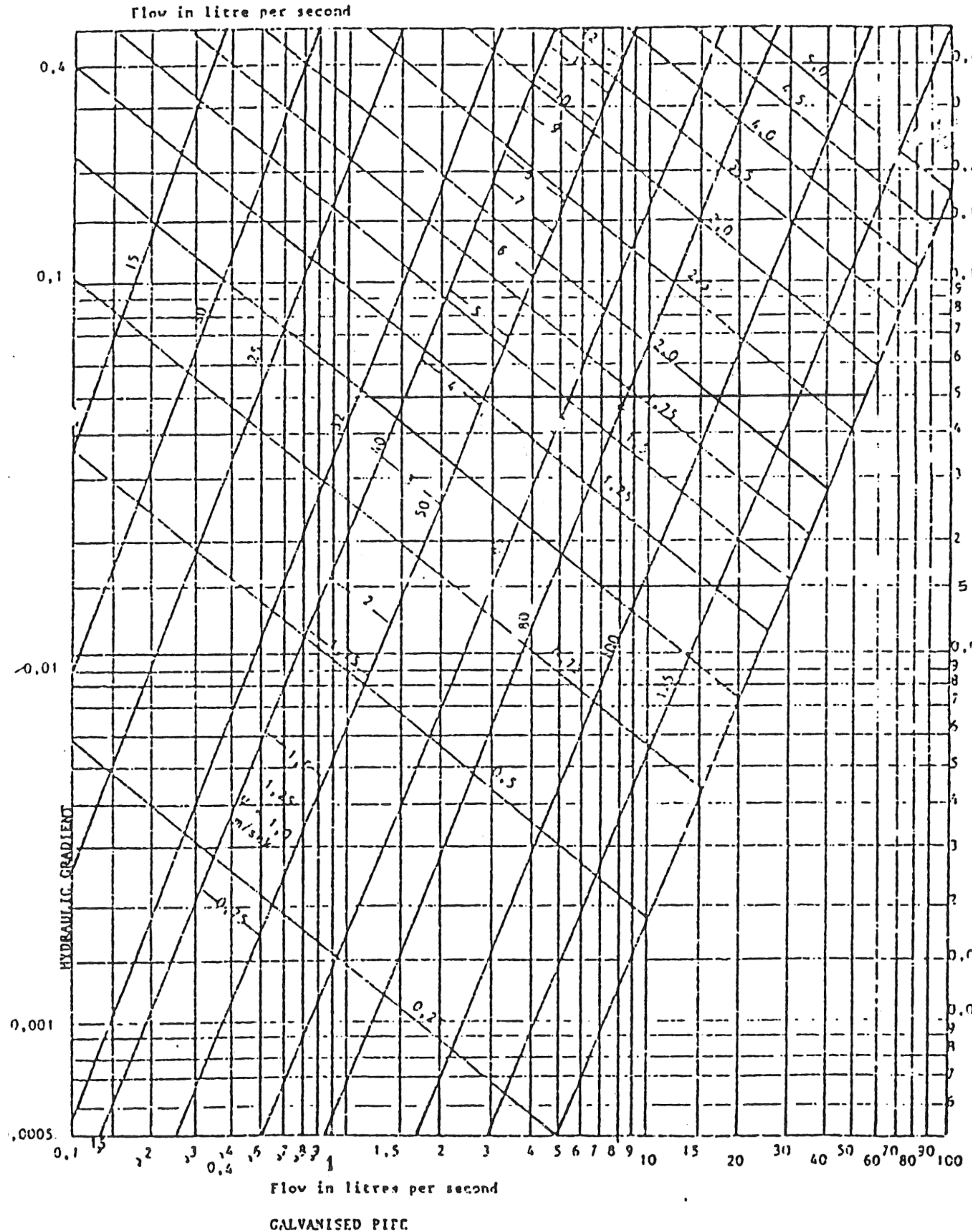


Figure 2.5 Friction in steel pipes according to SABS 62/1970

Refer to the table in **Figure 2.4**

- On the side the hydraulic gradient is read off horizontally.
- At the bottom the flow is given in l/s.
- In the table (graph) the pipe diameter in mm is found on the lines running from the left at the bottom to the right at the top corner.

- The flow velocities can be found on the lines running from the top left-hand corner to the bottom right-hand corner.

Steps

1. Determine the flow of 5l/s at the bottom of the table and follow that line upwards.
2. Draw the linear velocity for a hydraulic gradient of 0,015 (it is slightly more than 0,1m/s, but less than 1,25m/s, for a 80mm diameter pipe and between 1,25 and 1,5m/s for a 65mm pipe). The velocity is too high (2,5m/s) for the next, smaller sized pipe.

Conclusion

Pipe diameters of 66mm or 80mm will be suitable.

3. Step 3 refers to **Table 2.2**. The actual hydraulic gradient for a 65mm pipe at 5l/s is $\frac{394}{100}$ = 0,0394m/m and for a 80mm pipe it is $\frac{1,73}{100}$ = 0,0173m/m. Both are within the design criteria.
4. Step 4 - The total equivalent pressure head is the sum of the actual static head H_s plus the pressure head H_P plus the friction head H_f.
   For a 65mm pipe:
   H_f = hydraulic gradient x length of pipe
   = 0,0394 x 200m/m
   = 7,88m

   H_P = 10 metre for each 100kPa pressure head
   $= \frac{10}{100} \times \frac{300}{1} = 30m$
   ∴Equivalent pressure head H_f $= H_s + H_P + H_f$
   $= 10 + 30 + 7,88$
   $= 47,88m$

   For a 80mm pipe
   $H_T = H_s + H_P + H_f$
   $= 10 + 30 + \frac{1,73}{100} \times 200$
   $= 43,46m$

From the above it can be deduced that the 65mm pipe will be suitable, providing the flow never exceeds 5l/s and if the flow should exceed 5l/s for long periods, the 80mm pipe is the more suitable and should be used.

The flow of water into the suction of a pump positioned below a tank will have an effective pressure head less than that of the actual pressure head due to frictional losses. These factors need to be taken into consideration when designing plant layouts.

The table represented in **Figure 2.4** was drawn up from the following equation used to calculate pipe diameters:

$$Q = AV$$

Using the information in the above example:
Q = flow in m^3 per second = $5 \times 10^{-3} m^3/sec$.
A = cross sectional area of pipe in m^2
V = linear velocity in m/s

Worked Example 7

Use a linear velocity of 1m/s

$A = \frac{Q}{V}$ Area of pipe = $\frac{\pi d^2}{4}$

$\frac{\pi d^2}{4} = \frac{Q}{V}$

$d^2 = \frac{40}{\pi V}$

$d = \sqrt{\frac{4Q}{\pi V}}$

$= \sqrt{\frac{4\ x\ 5\ 10^{-3}}{\pi\ x\ 1}}$

= 0,078m

= 79,8mm or 80mm→

Worked Example 8

Use a velocity of 2m/s

$d = \sqrt{\frac{4Q}{\pi V}}$

$= \sqrt{\frac{4\ x\ 5\ 10^{-3}}{\pi\ x\ 1}}$

= 0,0564m

= 56,4mm→

As pipes are manufactured to standard diameters, it is normally the practice to select a pipe slightly larger than that calculated, to ensure the velocity of the fluid being pumped remains within the laid down specification.

Activity 2.1

1. With the aid of ***TWO*** simple sketches, illustrate the ***TWO*** flow patterns in pipelines.
2. Explain Bernoulli's theory in relation to fluid flow in a pipe.
3. Explain the influence that pressure and temperature have on the viscosity of fluids.
4. Calculate the pressure in kPa, which must be produced by a pump to deliver a liquid with a density of 1 500 kg/m^3 at a height of 30 metres above the pump. Ignore other factors.

5. Calculate the flow delivered through a 100 mm diameter pipe when the linear velocity of the liquid in the pipe is 1,53 m/s.

Activity 2.2

Indicate whether the following statements are ***TRUE*** or ***FALSE***.

1. The physical conditions do not change when heat is applied on matter.
2. Power refers to the work done per mass.
3. Change in pipe direction causes resistance of flow in pipe systems.
4. Pressure will influence the viscosity of a fluid.
5. The stripping section refers to the top section of a distillation tower.
6. Latent heat of evaporation refers to heat required to change the state of a liquid at constant temperature.
7. Work = force x distance through which the heat moves.
8. Roughness on the inside of a pipe causes resistance of flow.
9. Temperature will influence the viscosity of a fluid.
10. The density of a fluid is the quantity of the fluid per unit volume.
11. Matter is anything with a mass.
12. Kinetic energy is the energy of an object due to its state of tension.
13. Pressure will influence the viscosity of a fluid.
14. Density of a fluid is the mass of the fluid per unit volume.
15. Flow velocity resists flow in pipelines.

Activity 2.3

1. A pump delivers fluid with a density of 900 kg/m^3 into the bottom of an open container. The maximum height is 10 meters above the pump. The depth/height of the container is 2 meters. Calculate the delivery pressure of the pump. Ignore the friction and the suction pressure.
2. Explain how the density of a liquid may cause of loss of pressure in a pipe.
3. Determine the water flow in a pipe, when the differential pressure across an orifice is 12,5 kPa. When the pressure difference across the same orifice is 24,5 kPa, the flow is $15,4m^3$ per hour.
4. Name and explain ***TWO*** types of energy that bodies can have.
5. Explain ***FOUR*** effects of heat on a substance.

Activity 2.4

1. Briefly discuss tidal force and its utilisation.
2. Calculate the energy liberated by a tamper if it reaches a velocity of 8 metres per second and weights 80 kg.
3. From what height must it be dropped to generate the same amount of energy?

4. A pump delivers 280 tons of fresh water at a height of 15 metres in 90 minutes. Calculate the following:
   a. Power output of the pump in kW
   b. Efficiency of the pump with an input power of 12 kW
5. Explain how viscosity of a fluid is determined and name the unit in which it is measured.

Activity 2.5

1. A pipe transports 35 000 litres of water per minute against a pressure difference of 100 mm mercury (Hg). Calculate the pressure difference in kPa when the flow is increased to 70 000 litres per minute.
2. A pump with 75% efficiency runs for a period of 18 hours to do 16 GJ of work. Calculate the following:
   a. The power of the pump in kW
   b. The power of the source in kW
3. Define or explain the following:
   a. Latent heat of evaporation
   b. Pascal's law and state and application thereof
   c. The law of Archimedes
4. Define and explain the following:
   a. Heat
   b. One joule
   c. Matter
5. Water flows at 10 m^3/min in a pipe with a diameter of 180 mm. Calculate the velocity of the water in m/sec.
6. Determine the differential pressure across an orifice in a pipe when the flow is 25 000 litres per hour, if the same orifice creates a pressure difference of 30 kPa when the flow is 20 000 litre per hour.

Self-Check

I am able to:	**Yes**	**No**
• Explain the history of fluid flow; water		
• Explain fluid flow through gravity		
• Describe fluid flow performance		
• Identify and explain flow rate		
• Identify and describe the following types of fluid flow:		
o Equal flow		
o Turbulent flow		
• Describe and explain the following principles which influence fluid flow:		
o Pressure and pressure altitude		
o Pressure and flow rate ratio		

o Continuous flow (with problems)		
o Flow and pressure loss (with problems)		
o Viscosity fluids, statement and impact of temperature		
o The effect of pressure		
o Causes of loss of pressure, namely;		
– Size of the pipe		
– Length of the pipe		
– Roughness		
– Change of direction		
– Viscosity		
– Thickness		
o Typical flow system (with examples of problems)		
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 3

Distillation

Learning Outcomes
On the completion of this module the student must be able to:

- Describe distillation as a process of converting a simple setup to a tower
- Describe an ordinary distillation tower in terms of the following:
  - Outlet
  - Bottom product
  - Top product
  - Back flow
  - Condensation
- Explain and describe fractionation in terms of the following:
  - Separation in more than two products
  - Material balance
  - Heat balance
  - "Syrup section"
  - Fractionation part
  - Control of pressure, temperature and flow
  - Overloaded towers
  - Sorts of fractionation
  - Absorbers
  - Poachers

3.1 Introduction

Distillation is the separation of the components of a liquid mixture through stages of heating (evaporation) and cooling (condensation) until a **pure**, light product is obtained towards the top of the plant and a pure heavy product at the bottom.

The **pure**ness refers to the desired specification applicable in the particular case.

3.2 A Simple Distillation Process

Take three distillation flasks and assemble as shown in **Figure 3.1**.

Flask number 1 contains a liquid compound of 50/50 mole percent ethane and ethylene. The flask is heated in some way or other, for example by means of steam flowing through a coil in the flask.

The heating causes evaporation. The degree of heating, namely the temperature, the level and pressure should be accurately controlled. The flasks are also properly insulated against loss of heat.

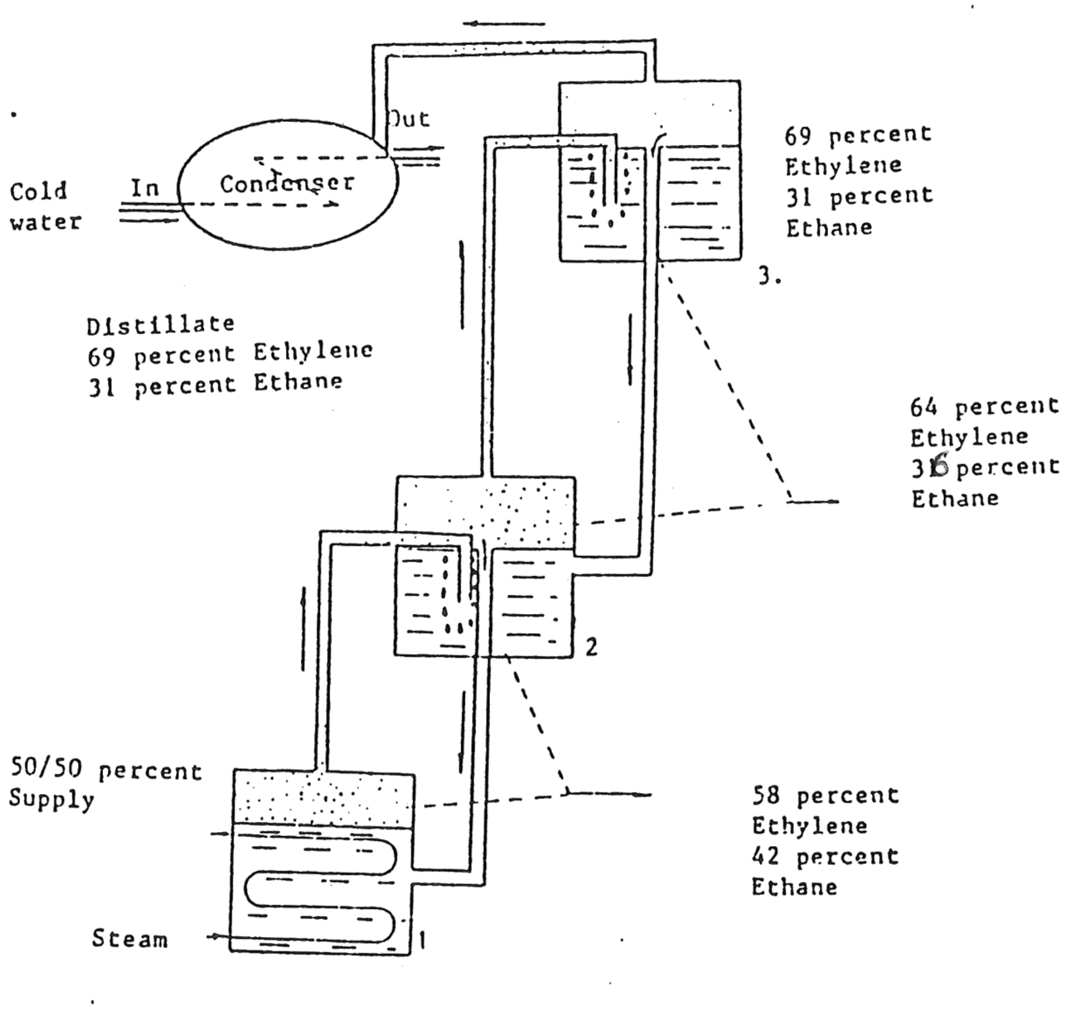


Figure 3.1

The vapour given off contains more of the light product, namely ethylene, say, 58 %, and less ethane, say, 42 %. These vapours are led through a tube (or tubes depending on the quantity) to flask number 2, where it bubbles through the liquid in that flask, giving off heat.

When the vapours cool, many of the heavier molecules condense due to the higher boiling point and a small quantity of the lighter molecules will also condense. This adds to the liquid in flask number 2 and the excess flows over into flask number 1.

The heat they give off, heats the liquid of flask number 2, causing evaporation in that flask.

In flask 2 more light vapours than heavy vapours are evaporated. Take the liquid composition in flask number 2 to be the same as that of the vapours introduced into the flask. No external heating is required.

The vapour composition will now be more or less 64/36 percent per mole of ethylene/ethane and is led to flask number 3 where the same process is repeated.

Flask number 3 now contains 64 % ethylene and 36 % ethane and the vapours present, say, 69 % ethylene and 31 % ethane, which is led to a condenser where it is cooled down to a liquid by means of cold water. This liquid is called the distillate.

As the number of flasks is increased, to the top and to the bottom, a more complete distillation is obtained, until a pure ethane is tapped off at the bottom and pure ethylene at the top.

3.3 Distillation Tower

As can be seen from the foregoing sketch, the many flasks and pipes in a distillation system of this type make it unsightly and clumsy. The whole process has been combined in one tower, with bubble caps and plates, et cetera, to perform the same task.

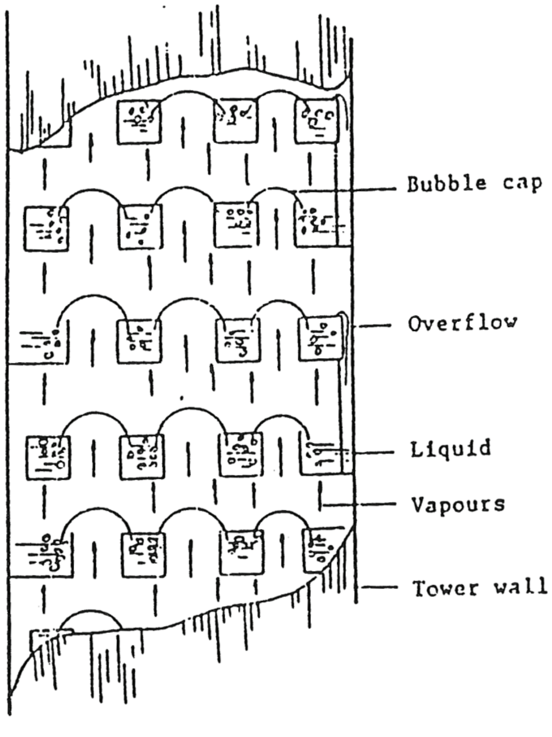


Figure 3.2 Part of a distillation tower

When part of the distillation tower, as it is now called, is cut away, it appears as shown in the following figure. Each plate with bubble caps performs the function of a flask with its pipes.

3.3.1 Description of an Ordinary Distillation Tower

The height of the tower can vary from 10 to 70 metres, depending on the product or products to be distilled. The width (cross sectional diameter) can be between 1 and 10 metres, and in some cases, even wider. The whole installation is isolated against the loss of heat.

3.3.1.1 Feed

This is the liquid mixture which must be separated into its different components and which is placed in such a position, that the temperature of the mixture is the same as the temperature of the plate onto which it goes. The composition is that of the mixture on the plate.

1. It is very important that the feed must be placed in the correct position; otherwise the heavy components may be carried to the top, if it is placed too high. It may also result in some of the lighter components flowing downwards to the bottom where they would contaminate the heavy components.

2. The process taking place in the tower, below the feed inlet, is called stripping. The light components are driven out, or stripped from the mixture by heating the liquid, or by the upward movement of warm vapours. It can also be achieved by letting in stripping steam into the tower.

   Smaller units that are exclusively used to strip are called strippers. The feed goes in at the top of the stripping tower, whilst warm gases, vapours or steam enter at the bottom.

3. On top of the feed, absorption, or rectification, occurs. The aim is to remove the heavy molecules still present in the upward moving vapour, by cooling the feed vapour and therefore condensing them.

   This is accomplished by the downward moving liquid supported by the flow back of the liquid. Smaller units called absorbers are used to carry out this function. The absorbing oil goes in at the top whilst the vapour leaves at the bottom.

4. Because the stripping and rectification must be carried out completely to ensure that the pure light products and the pure heavy bottom products are separated, it is necessary that the highest practical difference in temperature between the top products and the bottom products is maintained.

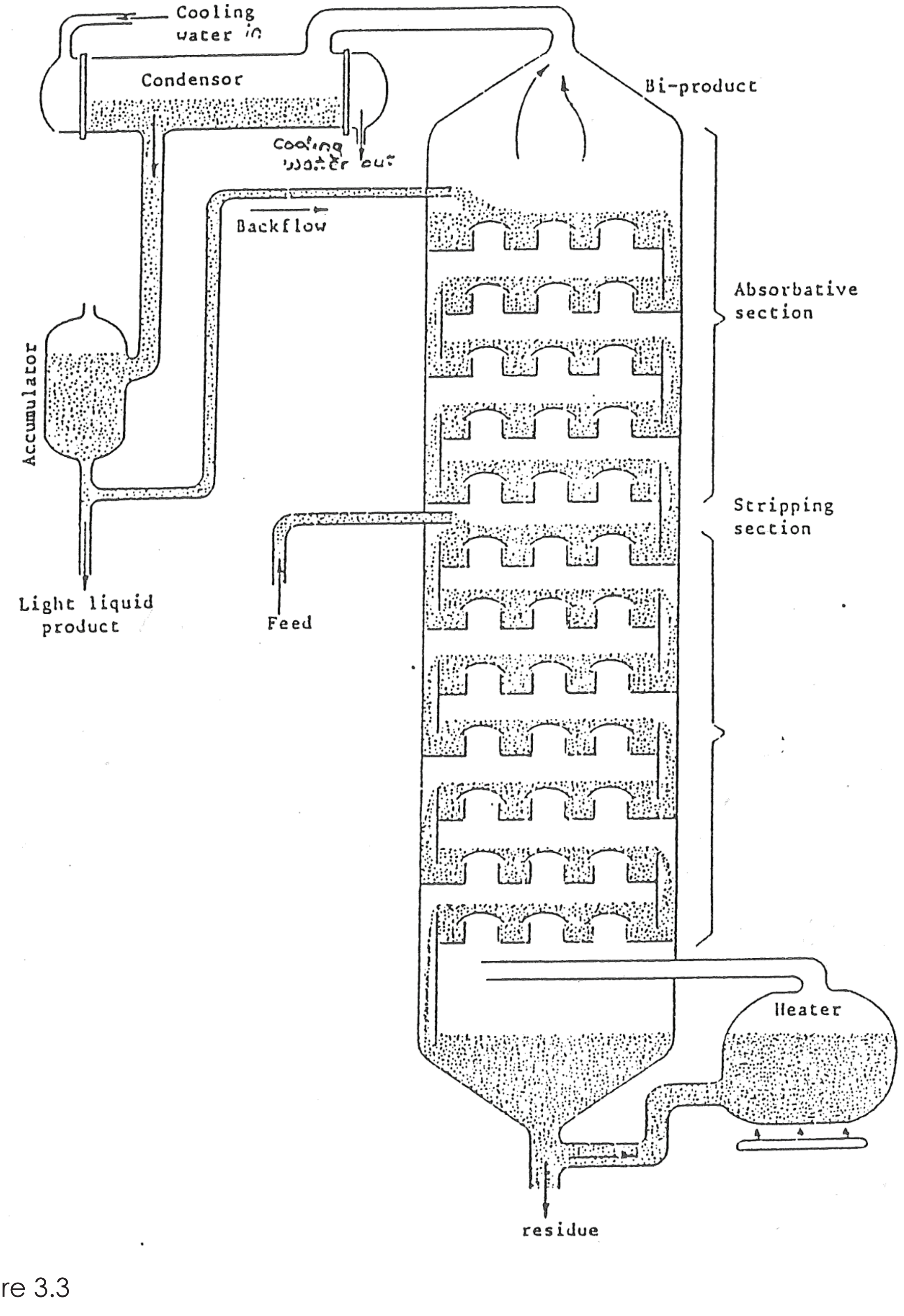


Figure 3.3

This temperature difference is called the temperature gradient and is maintained through maximum allowable bottom temperature due to back flow and uplifting heat respectively. If, however, the gradient is too great, over flowing in the tower will result and both the abovementioned factors and even the inlet flow must be reduced to control the excess liquid in the tower. Thereafter it can be gradually increased until it is in balance again.

Strippers: the feed enters the column at the top and the absorption medium enters at the bottom.
Absorbers: the gas or vapour to be purified enters at the bottom of the column and the absorption medium at the top.

The difference between the two lies in the entrance and exist positions on the column

3.3.1.2 Bottom Product

Often this is referred to as "bottoms". The bottom product is the heavy product that is tapped from the bottom of the tower and will contain very little or no light products that are present in the feed.

This residue is often a thick tar type of liquid with a high boiling point. In the case of tar, the bottom product must continuously be heated so that it will stay in a liquid form in order to flow more easily. If not, it will be difficult to remove and the tower will have to be cleaned.

3.3.1.3 Top Product (product distilled at the top)

This is the product that consists of the light components that are extracted from the feed mixture and which is normally a pure vapour or gas when tapped from the top of the tower.

From the tower it is taken to the condenser where it/is cooled down and condensates. The part that cannot be condensated, is removed as a vapour to a gas.

3.3.1.4 Back Flow

The distillate removed from the condenser flows into a level controlled accumulator. Part of the distillate is returned to the of the tower and because its temperature is lower than the top plate, it will cool down the top product and any heavy vapours still left will be condensed and will flow downwards with the products from each plate.

When the level in the drum increases, the excess liquid is removed to large containers where it is stored for later use.

3.3.1.5 Condensation

When the latent heat of a vapour is removed by cooling, it will condensate and become a liquid. The factors that will influence condensation are pressure and temperature.

The influence of pressure and temperature on condensation and evaporation.
That the measure of evaporation and the boiling point of a liquid are

dependent on the pressure exerted on the liquid and the temperature or internal energy of the liquid.

Any liquid at a certain temperature and pressurised to a specific pressure, will have a specific rate of evaporation if both temperature and pressure are kept constant.

Should the pressure on the liquid be increased, the molecules of the vapour will move closer to one another and it will condensate more readily. The result will be less evaporation.

If, however, the pressure is decreased, the reverse will happen. With an increase in temperature, evaporation will be increased, but condensation in the tray will decrease and vice versa.

Fractionation vs distillation
Fractionation is the separation of a mixture into various compounds or side fractions, while *distillation* is the separation of a liquid mixture into an overhead and bottom product only.

3.4 Fractionation

3.4.1 Separation into more than two products

While distillation is the separation of a liquid mixture into only a top and bottom product, fractionation is the separation of a liquid mixture into a number of components varying from heavy to light and termed side fractions.

A fraction consists of a number of hydrocarbons, for example, petrol is a mixture of C_4 to C_{10} of which the boiling points vary between 50°C and 190°C.

Figure 3.4 of a fractionation tower clearly indicates how crude oil is refined into fractions of light fuel oil to petrol, with heavy fuel oil as the bottom product.

3.4.2 Material balance

If a tower of this type is operated correctly, each fraction should be very pure and within laid down specification.

Samples are taken and analysed at regular intervals in order to determine faults and incorrect distribution of feed material.

When the material is correctly distributed by means of distillation, the material is in balance and according to specification.

3.4.3 Heat balance

Proper control of heat or energy, together with that of flow quantities, is necessary. As the whole system is based on evaporation and condensation and this, in turn, depends on temperature and pressure, heat or flow added to the tower will in each instance take place at a point and temperature which will allow the tower to maintain its balance and control measures will be instituted at each such point.

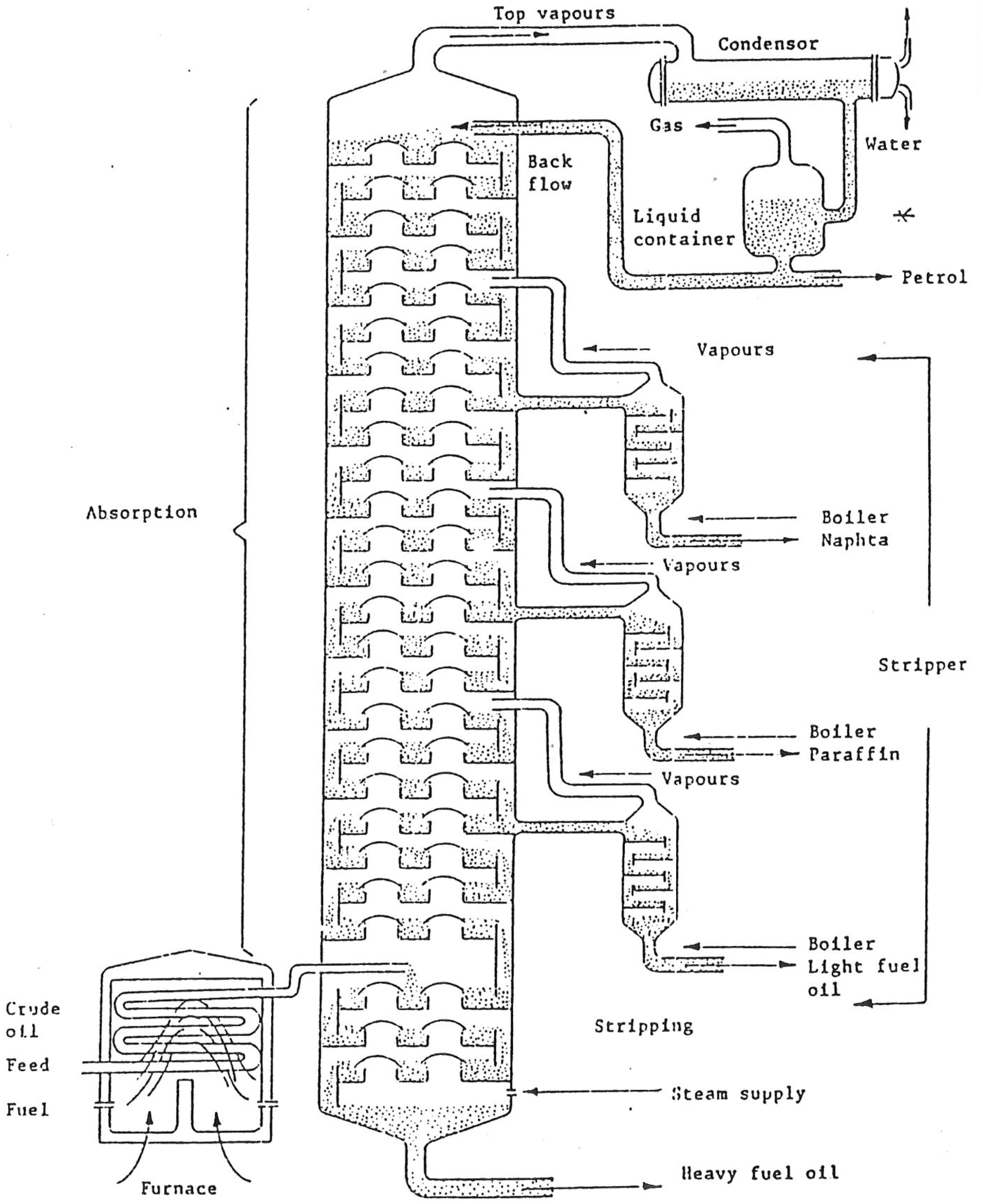


Figure 3.4 Fractionating tower

The temperature of each boiler, the flow through the various boilers, the top temperature and the bottom temperature, as well as that of the feed and steam, are controlled to maintain the temperature gradient (already discussed), of the tower within strict limits. Each point which is controlled will depend on the type of material (fraction) handled at that point in order to obtain the desired results and to remain within the specification.

By maintaining the maximum temperature gradient obtained by maximum bottom temperature and maximum back flow for cooling the top temperature (without flooding the tower), the purest bottom and top products are obtained. As the gradient diminishes, the one product is carried over to the next, both at the top and at the bottom.

3.4.4 Stripping part

In the fractioning tower figure the stripping part is clearly indicated as that part below the feed inlet, with smaller strippers on the side responsible for stripping higher up in the tower. In the absence of smaller strippers, the tower has to be higher with more plates to carry out this action completely between the fractions.

3.4.5 Fractionating part

Absorption or rectification takes place above the feed inlet and the fractions are drawn down to places where the composition complies with the required specification. Fractionation is consequently done in this part and thus the name fractionating part. Rectification indicates the rectification of each fraction by means of absorption.

3.4.6 Control of pressure, temperature and flow

When fluctuations in regard to these factors occur in the tower, fractions not conforming to the requirements will be obtained.

Any pressure and/or temperature fluctuation disturbs the energy balance of the tower and liquid fluctuations disturb the material balance.

3.4.6.1 Pressure

A number of pressure control points are fitted on a fractionating tower, for example on the gas line of the top product and on the steam line to maintain maximum steam pressure for vacuum distillation.

The pressure in the tower is lower than the atmospheric pressure, in this case, as a result of the condensation of the steam which consequently causes a marked reduction in the pressure of the tower.

In other instances a pressure controller is fitted to the bottom of the tower in order to control the steam flow through the boiler and consequently also the bottom temperature which in turn controls the vapour pressure of the bottom product.

Pressure control points are determined by the type of distillation or fractionation to be carried out and the material to be handled.

3.4.6.2 Temperature

Control points for temperature are expected to do less work than the pressure control as the sensors for temperature changes react more slowly to changes than the sensors for pressure. In order to obtain better and quicker control, the pressure control points are integrated with flow, as well as temperature control.

There are two main points for temperature control, namely half-way between the bottom and the feed and half-way between the top and the feed in order to ensure the smooth course of both stripping and absorption.

The first-named exercise control on the steam supply to the boiler of the bottom product and is set up high to ensure that the bottom products are pure.

The second exercises control on the back feed (distillate) and removes the heavy product from the vapours going upwards, halfway up the tower and ensures that the top products are pure.

Other points indicating the temperature reading across the whole tower are fixed at strategic places.

When temperature control is applied to control the composition of the fractions in the tower, the following aspects should be kept in mind:

- The pressure in the column (tower) should be kept constant.
- Temperature controls on their own are not adequate when there is a very small difference between the boiling points of the components to be separated.
- Optimum control of the changes in the process should be obtained by the correct placing of the temperature points.
- The temperature controllers should do less work than the other control points, as explained previously.

3.4.6.3 Flow

As the pressure and temperature in the column depend practically in the whole on the flow into and out of the column, they are coupled to flow control and changes in accordance with each other to ensure proper balance in the tower.

3.4.6.4 Control of difference in vapour pressure

The composition of the products in a tower will comply with the specific requirements when specific conditions are maintained on a very particular plate in the tower. When factors on other plates vary, it will be noticeable on this plate as the one is dependent upon the other.

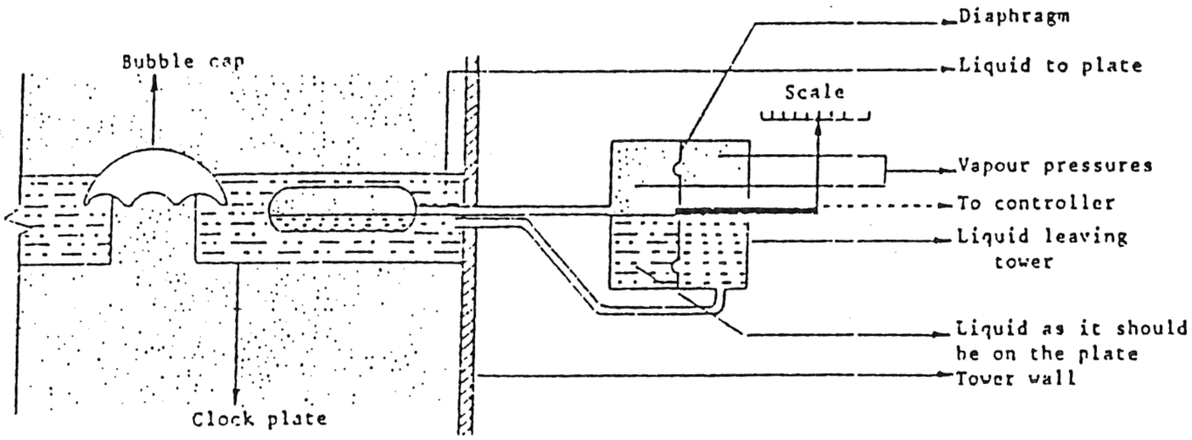


Figure 3.5 Vapour pressure difference controllers

If control is thus exercised on the vapour pressure of a liquid on a plate in the tower and that vapour pressure depends on the temperature and composition of the liquid on that plate, conditions in the rest of the tower will also be under control.

Operation: The ball of the controller, which is a sealed unit, is placed in the liquid on the chosen plate. The ball is filled with liquid which should be on the plate and is connected to a diaphragm which reads to the vapour pressure of the liquid in the ball.

Operational problems:

- Overloading
- Poor control of column temperature
- Incorrect quantities of reflux (poor control)
- Incorrect supply (feed) inlet position
- Incorrect supply (feed) temperature/or variation of feed temperature
- Poor maintenance

The other side of the diaphragm is connected to the same plate by means of a tube so that there is a constant change of liquid in accordance with the liquid on the plate. The vapour pressure of this liquid opposes the vapour pressure on the other side of the diaphragm.

When the vapour pressures are the same, the composition and the temperature of the liquid on the plate is the same as that in the ball of the apparatus. If the vapour pressures are not the same, a controller coupled to the diaphragm is activated by the movement of the diaphragm to adjust the condition on the plate.

Consequently, the apparatus reacts to the difference in vapour pressure which may arise and thus simultaneously exerts control over the temperature and composition of the liquid on the plate.

3.5 Overloading of tower

A tower will overflow when one or more the following happens:

3.5.1 Too much liquid:

A tower can only function normally when the quantity of liquid to be handled is within the limits of the tower's capacity. When too much feed is allowed in, the tower cannot handle the excess and the plates at the bottom overflow. This causes pressure and temperature in the tower to be disturbed and adjustments have to be made.

Water can also accumulate if it is not removed with the side fractions. This enhances the pressure difference of the plates and obstructs the path of the vapours.

3.5.2 Too much vapour

This is caused when the rate of evaporation is increased by too high temperatures or too low pressures. A too high pressure difference is caused through the bubble caps and the liquid which is supposed to move downwards is checked, the levels on the plates become too high and the drain pipes become full.

The result is that the liquid, instead of forming vapours, is carried to the top and then it is said that the tower "spits". The top product then contains many of the heavy components and is not pure.

3.5.3 Mechanical faults

Bubble caps may sometimes become loose and lodge in the drain pipes; or shale or other material builds up on the pipes and bubble caps in the tower, making the free passage of liquids or vapours impossible. The symptoms are the same as in the case of flooding and the working of the tower is impaired.

When mechanical faults of this type occur, the tower has to be closed down for repairs before it will function properly again.

Regarding the rectification of the other two factors, that is too much vapour or liquid or both, take note of the following:

- cut the back flow, that is, reduce the liquid entering the tower at the top
- drain the excess liquid in the bottom and overhead
- cut down the supply and reduce the bottom temperature if necessary

- adjust back flow in order to regain stable operating conditions

3.5.4 Temperature of feed

It is important that the temperature and composition of the feed should be the same as that of the liquid on the plate where the feed is introduced.

If the temperature is too high, it will also cause the measure of evaporation on that plate to be too high and the top product to be overloaded with heavy vapours. The opposite happens when the temperature is too low and too much liquid flows down to the bottom.

Consequently, it is important to choose the position where the feed enters the tower accurately and to control the temperature of the feed.

3.6 Types of fractionating towers

Fractionating towers can be divided into two main groups in accordance with their internal construction, namely:

- Clock plate or bubble cap towers
- Packed towers

The operation of the towers may further also be divided into two groups, namely:

- Distillation or
- Scrubbing towers, washing towers and absorption towers

These towers purify gases or vapours of heavy components flowing upwards, by allowing them to bubble through a downwards flowing liquid.

3.6.1 Packed towers

Instead of plates and bubble caps, this type of tower is filled with Raschig rings (short porcelain rings), charcoal, grit, etc. These towers are smaller units than the plate towers and they are used for special distillation processes. The main disadvantages of these towers are that:

- The filling material is in some cases distributed in a manner which causes the openings to be directly above each other, forming channels so that the liquid streams and vapour or gas streams make very little contact and distillation does not occur. The tower must then be repacked to eliminate the problem.
- The whole tower has to be dismantled and the packing material removed before the tower can be cleaned. The packing material can sometimes become fused together by scale and other impurities, making it very difficult to remove.

3.6.2 Absorbers

An absorber is illustrated in **Figure 3.6**. This is only one application of the absorber. Note that the gas or vapours to be purified are let in at the bottom of the tower and the absorption medium at the top. If the overhead product has to be further purified, a second smaller tower is used,

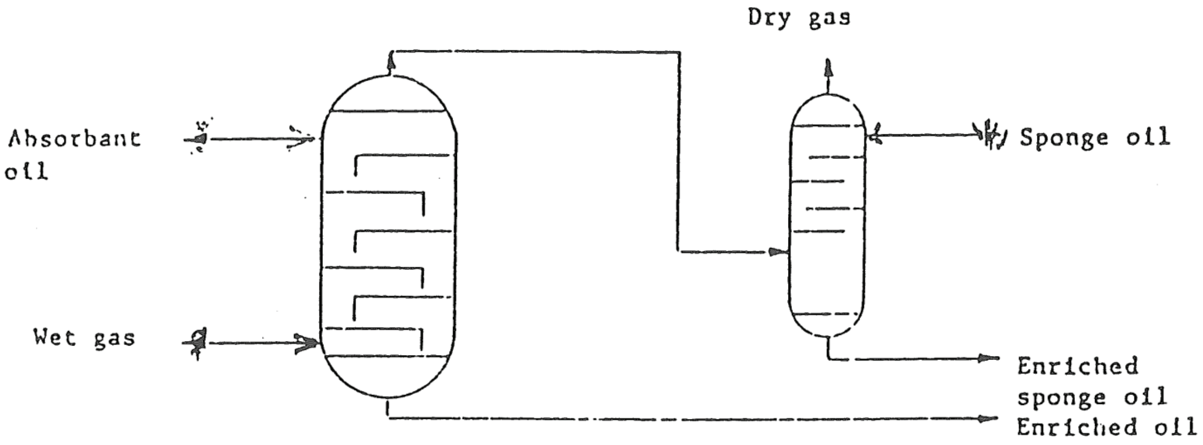


Figure 3.6 Absorber

3.7 Strippers

Their operation has already been introduced and discussed. In this case the operation is the opposite to that of the absorber and the feed is let in at the top and the gas or stripping steam at the bottom.

3.8 Vacuum distillation

Heavy components with high boiling points, for example residuals obtained as bottom products during fractionation can crack, that is break up into lighter hydrocarbons when they are over heated.

By distilling under vacuum conditions, the boiling points of the components are lowered and cracking is prevented. The difference in the vapour pressures of two constituents is also larger at the lower temperature made possible by a vacuum and consequently, a better separation is obtained.

3.9 Fractionation in petroleum industry

Crude oil is a mixture of gaseous, liquid, and solid hydrocarbons. Petroleum comes from two Latin words, *petra* meaning rock and *oleum* meaning oil. This material is well named as can be seen by studying **Figure 3.7**:

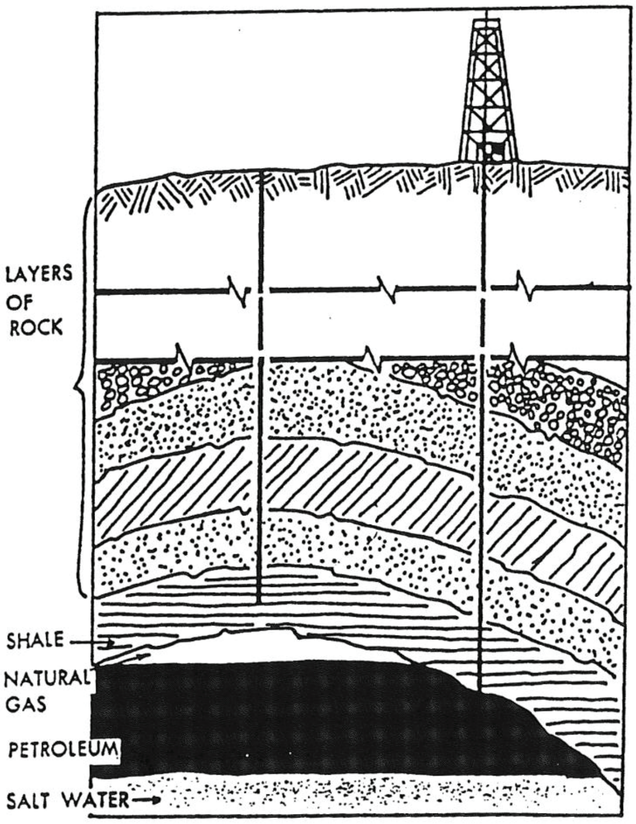


Figure 3.7 Typical structure of earth's strata in natural gas fields and oil fields

Likely oil-bearing strata are found by air photography, surface examination of rock, outcroppings, core drillings, and seismographic mapping of the earth's strata.

The latter process consists of exploding dynamite in holes in the earth's crust. The reflections of the shock waves from rock layers, on being recorded, allow a geologist to map the substrata.

In drilling an oil well a rotary rig is used. The bit, which is attached to the end of lengths of pipe threaded together, is rotated and bites its way through rock and earth.

To keep the drilled hole from caving in and to remove the drillings from the hole, a special type of mud is pumped down the pipe forming the bit stock. This mud ascends between the pipe and the sides of the hole, cementing the sides of the hole and carrying waste material to the surface.

Extra lengths of pipe for the bit stock and the machinery for lifting it out of the hole are supported by a derrick.

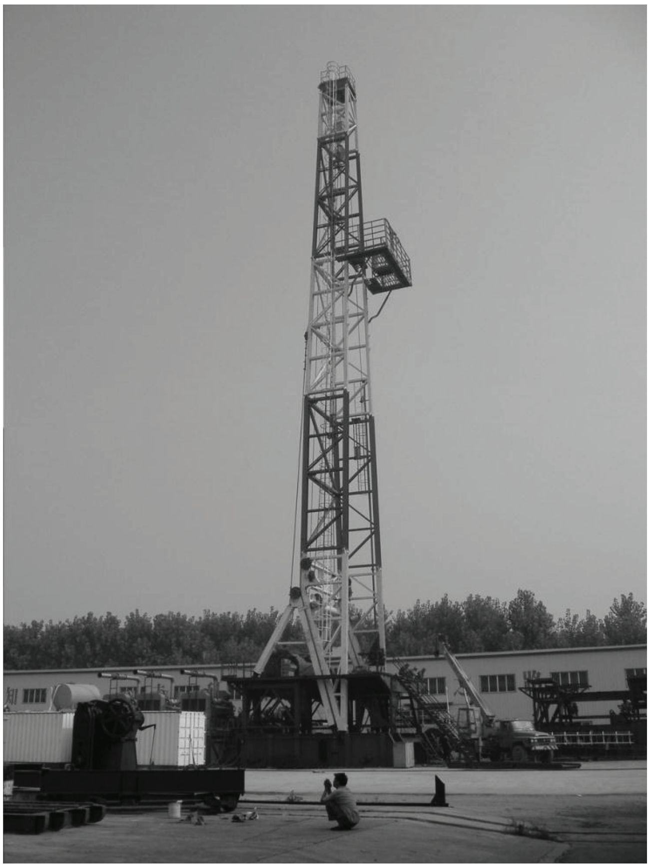


Figure 3.8 An oil drilling derrick

When a well enters oil strata, gas pressure may be sufficient to force oil to the surface. Such a well is called a gusher. Usually, however, pumps must be used to lift the oil to the surface. The oil is stored in large steel tanks until it is sent to the refinery.

3.9.1 Fractional distillation

After undesirable impurities, such as sulphur, wax and clay are removed; the crude oil is separated into fractions, which consist of mixtures of hydrocarbons having different boiling points. In this process, known as fractional distillation, the oil is heated in a pipe-still consisting of many pipes inside a gas fired furnace.

It is then discharged into the bottom of a fractionating or 'bubble' tower where the volatile components form vapours which ascend the tower.

The more volatile the vapour, the higher it rises before condensing to a liquid. In this way fractions of the hydrocarbons are sorted out according to their boiling points.

The heavier fractions with the highest boiling points condense on the lower trays. Several gases, from methane to butane, are collected at the top of the tower. The main products in descending order are: naphtha, petrol, paraffin, heating oil, lubricating oil, waxes, tars and asphalt.

The residue is petroleum coke, which is used as a fuel and for making electrodes. A 185l barrel of crude oil yields about 92l of petrol, 70l of fuel oil, 9l of paraffin, 7l of lubricating oil, and the remainder consists of other by-products.

3.9.2 Petrol

Today, petrol is the most important single product obtained from crude oil. It is a mixture consisting chiefly of hexane C_6H_{14}, heptane C_7H_{16}l and octane C_8H_{18}. The boiling point of the mixture is about 80°C.

Simple distillation produces only about 22l of petrol from 185l of crude oil. The yield of petrol is increased to about 92l per barrel by catalytic thermal cracking of heavy molecules.

If hydrocarbons of large molecular mass are heated to a high temperature in the absence of air, the molecules disintegrate or "crack" into several smaller fragments.

Example: $C_{16}H_{34} \rightarrow C_8H_{18} + C_8H_{16}$

Molecules with 16 carbon atoms cannot be used as petrol, but molecules with 8 carbon atoms can. Catalysts have been developed that allow this process to be carried out at fairly low temperatures.

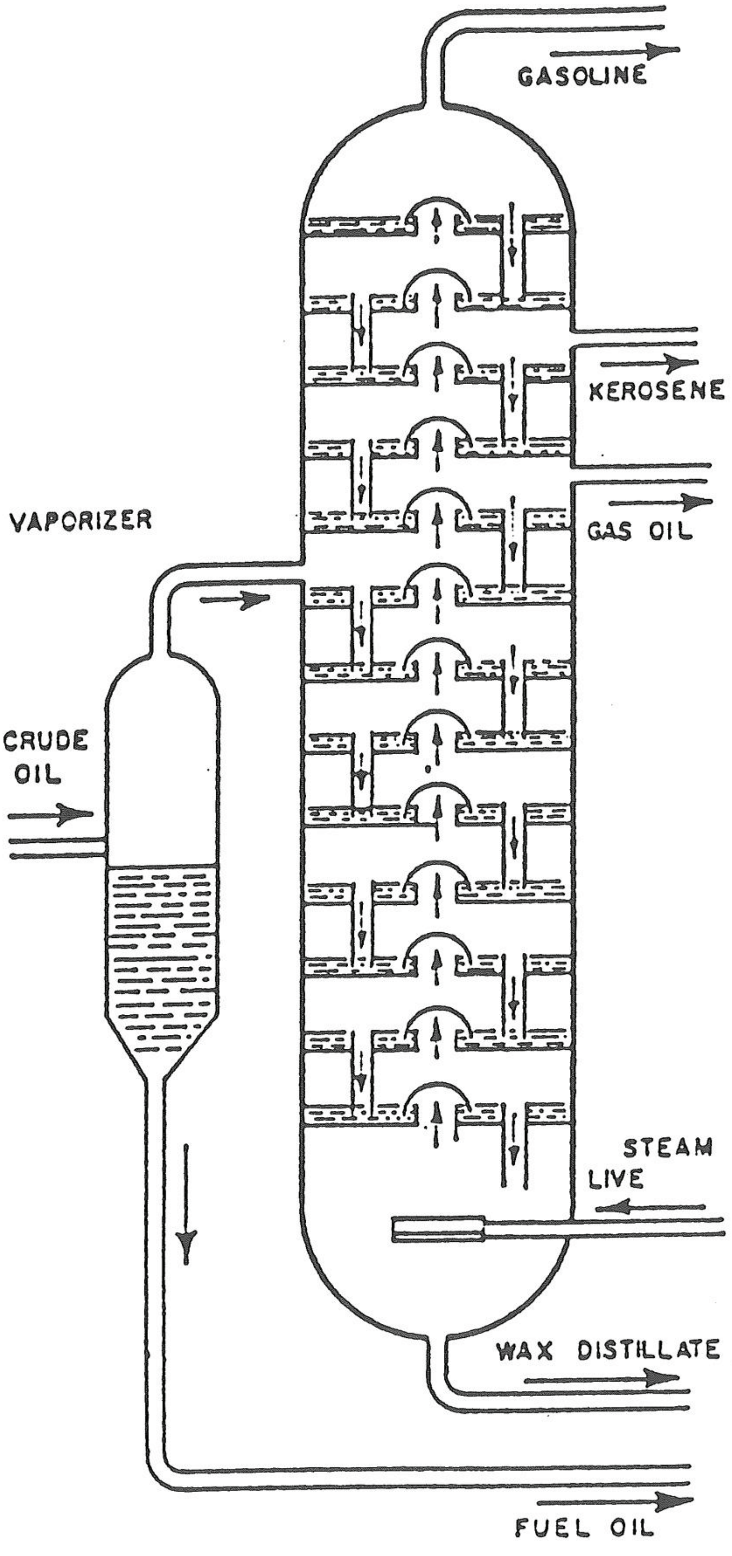


Figure 3.9 Bubble tower for the fractional distillation of petroleum

Another method of increasing the yield of petrol is polymerization, the opposite of cracking. In this process, small molecules of similar structure are jointed to form larger ones. Alkylation is a process of joining saturated and unsaturated hydrocarbons to form larger molecules.

3.9.3 Petrol as an engine fuel

Any combustible gas can cause an explosion if intimately mixed with air in the right proportions and ignited. The gaseous fuel and oxygen combine almost instantly, and the gases produced by the reaction are greatly expanded by the heat.

However, it has been found in research on the relative merits of the individual hydrocarbons as fuels for internal combustion engines that those compounds with straight chain molecules tend to explode too rapidly and burn too unevenly upon ignition.

Such rapid combustion causes fuel knock in a motor, accompanied by loss of power or damage to the motor. For maximum power, the gas-air mixture should burn quickly in a combustion wave spreading smoothly in all directions from the spark plug. This should occur only when the piston has reached to the top of its compression stroke.

In 1921 Thomas Midgely discovered that as little as 3ml of tetraethyl lead, $(C_2H_5)4Pb$, added to 5L of petrol improved it anti-knock properties greatly. Lead oxide, formed when this compound is used, may foul valves and cylinders unless a little ethylene dibromide $C_2H_4Br_2$ is added.

The ethylene dibromide forms gaseous lead dibromide and allows the lead to pass out with the exhaust. "Ethyl fluid", an additive that allows higher compression in engines and greater economy of engine operation, is now used in most motor fuels.

3.9.4 Octane numbers

The octane number refers to the anti-knock quality of a motor fuel. A branched-chain isomer of octane is an excellent motor fuel, whereas straight-chain heptane is a very poor motor fuel, as mentioned above.

By mixing these liquids and using the resultant fuel in a test engine, it is possible to compare the anti-knock qualities of this mixture with those of any other petrol.

The particular mixture of heptane and octane which has the same anti-knock qualities as the petrol being examined is noted. The percentage of octane in the reference mixture is called the octane number, and this number is affixed to the petrol being compared.

Petrol with an octane ration of 90 ("90 octane") means that it has the same anti-knock quality as a mixture of 90 percent octane and 10 percent heptane.

Aviation fuels may have an octane rating of 100 or more. These fuels are composed, for the most part, of carefully selected branched molecules, and their octane number may be increased still more by the addition of "Ethyl Fluid".

3.9.5 Petrochemistry

Natural gas and petroleum are now used in increasing amounts to make organic compounds; included among these are ethanol, glycerol, acetone, ethylene glycol, benzene, and toluene. Such compounds are used to be obtained from a variety of sources but are now available directly or indirectly from petroleum.

Rubber, plastics, detergents, insecticides, and synthetic fibres, like orlon, dacron and nylon, are synthesised from the above compounds. The industry based on converting petroleum by-products to useful substances is called the petrochemical industry. South Africa's largest such industry is situated at Sasolburg.

3.10 Fractional distillation of crude tall oil

Fractional distillation may be accomplished in either a batch or a continuous system. Either system may be operated with or without an inert carrier gas. The yield and composition of the products are dependent upon the distillation process used as well as the quality of the crude tall oil. The basic products obtained by fractionation are:

1. Heads (or light ends)
2. Fatty acids
3. Distilled tall oil (DTO)
4. Rosin
5. Pitch

Several grades of fatty acids and rosin may be produced by different fractionation procedures.

Many equipment configurations for continuous fractionation of crude tall oil have been employed. One process using four columns is illustrated in greatly simplified form.

The objective of this system is to obtain a rosin fraction having characteristics similar to wood rosin, a fatty acid fraction light in colour and low in rosin content, a pitch fraction high in unsaponifiable materials, and various other fatty acid products.

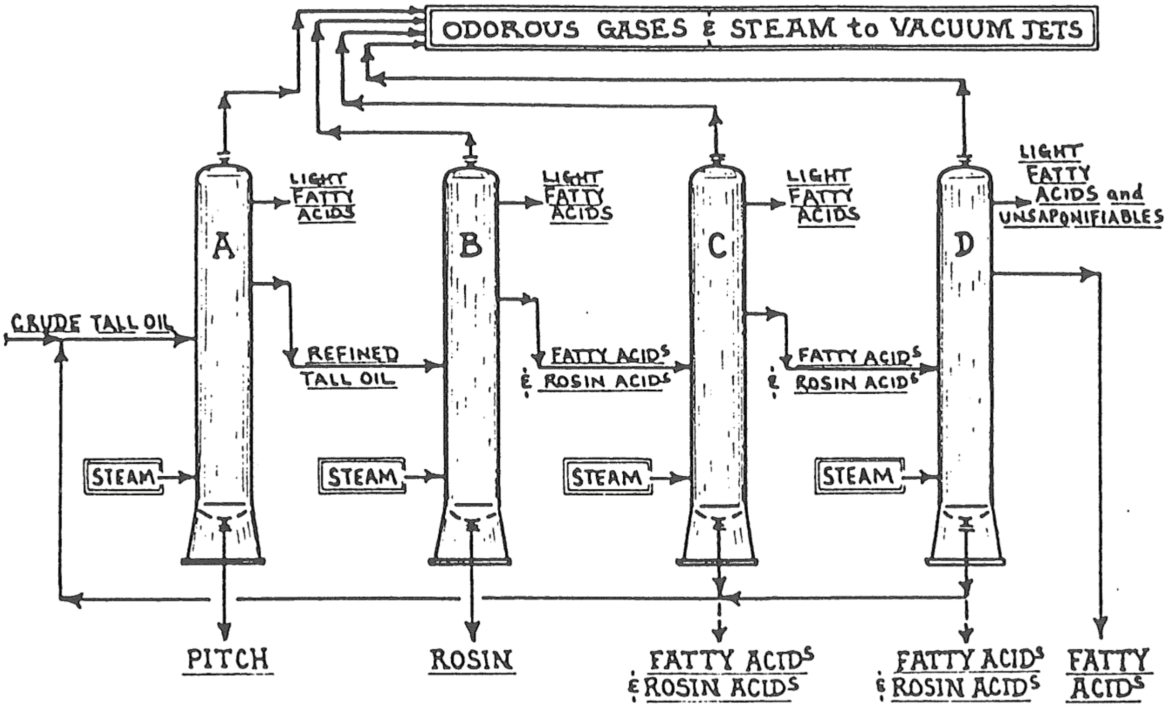


Figure 3.10 Equipment Configuration for Continuous Fractionation Process-Model 1

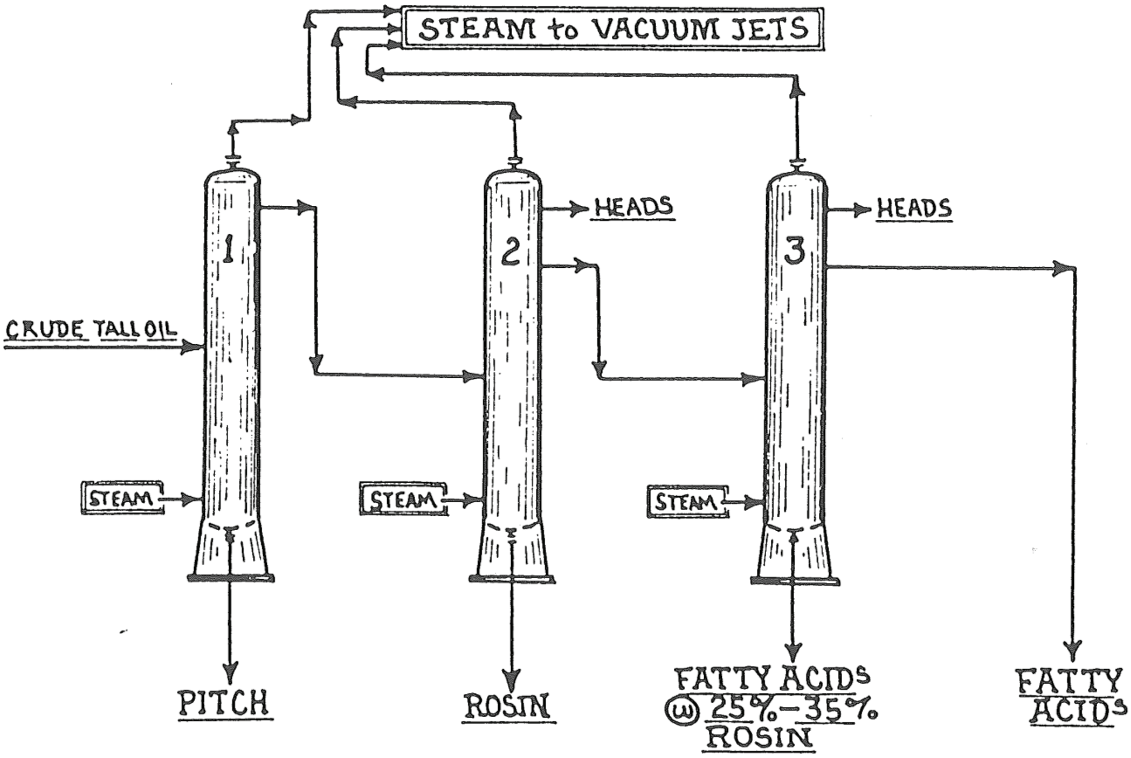


Figure 3.11 Fractionation Process- Model 2

Thermal degradation is avoided by using high flow velocities and a steam carrier to reduce temperatures. An alternative configuration using three columns to obtain a similar separation is presented in the second figure, also in simplified form.

In this system the bottom stream from Column 3 is not recycled to the crude feed. It is necessary to remove this fraction to purge the system of fatty acids having vapour pressures closer to the resin acids than the bulk of the C_{18} fatty acids.

3.11 Technical considerations

3.11.1 Chemical

Essentially all of the fatty and resin acids in crude tall oil are heat sensitive and/or capable of isomerisation.

If crude tall oil contained only these components, the distillation would be complex enough. In addition to these, however, the neutral materials - including sterols, other alcohols, esters, terpenes, and stilbene derivatives - have boiling points throughout the ranges of the fatty acids and rosin.

Some of these neutrals also react with the fatty and rosin acids under distillation conditions; this results in additions to the pitch streams and poorer quality in other bottom products.

In recent years, the kraft mills have increasingly stored their wood supplies in the form of chips rather than roundwood and have either mixed chips from hardwoods with pine chips or mixed the spent hardwood pulping liquors with the spent pine pulping liquors.

These practices have reduced the volume and quality of crude oil available to the distillers and forced the distillers to produce higher percentages of low value products in order to meet specifications for fatty acids and rosin.

Crude tall oil to be distilled is normally transported and stored in mild steel. This presents little problem unless:

(a) the crude oil contains excessive quantities of spent sulphuric acid or
(b) the storage is prolonged at elevated temperatures

In the latter case, the rosin acids tend to be isomerized and partially decarboxylated resulting in either higher pitch yields or lower quality rosin. In each case the presence of iron salts in the feed to the distillation plant catalyses the decomposition of both fatty and rosin acids, increasing the yield of pitch and heads at the expense of the primary products.

The heat degradation of the unstable resin and fatty acids in tall oil is a time-temperature reaction. Every effort must be made to keep the distillation temperature as low as practical and the retention time at these temperatures as short as possible. Since the distillations must be carried out at reduced pressures it is imperative to minimise air leakage.

3.11.2 Paper

The second largest end-use category for rosin, and probably the largest single use of rosin, is in the sizing of paper. In practice, the sodium salt is made first and added to pulp in the beater.

Subsequent reaction with paper-maker's alum (aluminium sulphate) under the proper pH conditions results in deposition of aluminiumresinate complex on the pulp in suspension.

Today much of the rosin size is "fortified" by the addition of 3-5% maleic anhydride. This decreases the amount of product necessary to achieve a given sizing level.

This development accounts for much of the decline in rosin size usage in recent years, even though the production of paper is increasing. More recently, the advent of "emulsion" sizes has accelerated this trend.

Activity 3.1

1. Explain the reflux process in a distillation tower.
2. Explain partial evaporation and partial condensation
3. Explain how fluctuation of internal pressure and temperature affect the operation of a fractionation column.
4. Briefly explain the following parts in a fractionation column:

4.1. Stripping part
4.2. Rectification part

5. Sketch an absorber column system.

Activity 3.2

1 Indicate whether the following statements are ***TRUE*** or ***FALSE***.
1.1 Evaporation is the opposite of distillation.
1.2 The rectification section refers to the top section above the feed inlet of a distillation tower.
1.3 The top product is often a thick tar type of liquid in a distillation tower.
1.4 Too much water condensate can cause flooding of a fractionation tower.

1.5 Absorbers are classified as a type of packed tower.

1.6 In the stripping section of a distillation tower the heavy products also become vapour.

1.7 When a vapour mixture is cooled and only a part is condensed and the condensate contains a greater quantity than the one fluid then the other is referred to as partial evaporation.

1.8 Bottom products refer to the heavy product that is tapped from the bottom of a distillation tower.

1.9 An increase in pressure in a fractionation tower has the opposite effect and therefore requires less energy to obtain the same amount of vapour.

1.10 A packed tower is a typical example of a fractionation tower.

1.11 Distillation refers to the separation of components of liquid mixture through stages of heating and cooling.

1.12 To ensure that the purist products are produced during distillation, it is important that the maximum heat output through the re-boiler is applicable.

1.13 The bottom product during distillation is often a thick tar type of liquid.

1.14 Poor temperature control in fractionation towers can cause operational problems.

1.15 Absorption towers are not considered as part of the fractionation process.

Activity 3.3

1. Explain the difference between strippers and absorbers.
2. Explain heat balancing.
3. Explain the control and effect of pressure in a fractionation column.
4. State ***FOUR*** possible problems encountered when operating a fractionation tower.

Activity 3.4

1. Explain temperature gradient as control variable for effective operation of a distillation tower to produce high quality products.
2. Explain the difference between fractionation and distillation.
3. Draw a controller operating on the principle of vapour pressure.
4. Discuss the causes and consequences of too much vapour in a fractionation tower.

Activity 3.5

1. Explain the terms rectification and stripping as part of the distillation

process.
2. Briefly discuss general mechanical causes for flooding during fractionation.
3. Discuss, with the aid of a sketch, the pressure control in a column where vacuum fractionation is applied.

Activity 3.6

1. Explain temperature gradient as a control variable for effective operation of a distillation tower to produce a high quality product.
2. Give a detailed description of what happens when pressure in a distillation column increases at a constant temperature.
3. Explain the operation procedure that can be followed to ensure proper fractionation, while arrangements are being made to take the tower out of commission for mechanical repairs.
4. Sketch a complete, fully labelled typical fraction tower.

Self-Check

I am able to:	**Yes**	**No**
• Describe distillation as a process of converting a simple setup to a tower		
• Describe an ordinary distillation tower in terms of the following:		
o Outlet		
o Bottom product		
o Top product		
o Back flow		
o Condensation		
• Explain and describe fractionation in terms of the following:		
o Separation in more than two products		
o Material balance		
o Heat balance		
o "Syrup section"		
o Fractionation part		
o Control of pressure, temperature and flow		
o Overloaded towers		
o Sorts of fractionation		
o Absorbers		
o Poachers		
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 4

Instruments

Learning Outcomes
On the completion of this module the student must be able to:

- Describe the history of instruments and controls
- Process the following variables with their measurements:
    - Energy variables: pressure and temperature
    - Number and temperature variables: fluid flow, liquid level and weight
- Identify and describe the following elements of measurement:
    - Primary e.g. pH electrode or thermometer ball
    - Transfer element e.g. a small tube or electrical wire
    - The instrument itself e.g. a manometer or potentiometer
- Identify and name indicator and recording instruments
- Describe the measurement of pressure (negative and positive) using:
    - Open U-tubes
    - Differential U-tubes
    - Manometers
    - Barometers
    - Bourdon tubes
    - Diaphragm meters
    - Bellow Gauges
- Explain the calibration of pressure meters
- Describe temperature measurement using the following:
    - Bi-metal thermometers
    - Liquid and glass thermometers
    - Pressure type thermometers
    - Thermocouples
- Describe flow measurement using the following:
    - Positive transfer meters
    - Flow rate meters
    - Hole plates
        - Normal
        - Ventura tube
        - Piton tube
    - Rota meters
- Describe liquid level measurement in terms of the following:
    - Silk glass, float, pressure difference and metal expansion
    - Float

- Pressure difference
- Metal expansion

4.1 Introduction

The rapid progress of instruments and control during the last few decades is amazing, especially since the development of electronic components such as the transistor and the solid state type of diodes.

Later, microtechnology became a factor and powerful machinery could be operated and controlled by means of small components of which the network of currents cannot be distinguished with the naked eye. Without micro-technology, electronic computers and space travel would have remained a dream.

4.2 Variables and the measurement thereof

As far as instrumentation is concerned, a variable is anything of, or in, a process which is subject to variation and which can be measured and controlled.

Variables can be divided into two main groups, namely energy and rate variables.

4.2.1 Energy variables

These are the variables such as pressure and temperature concerning the internal energy of materials (substances).

4.2.1.1 Temperature

This is measured by means of various types of thermometers and only two scales are acceptable for examination purposes that are the absolute or Kelvin scale and the Celsius scale.

Figure 4.1 shows that the scales correspond as far as the magnitude of the graduations are concerned, but not as far as the scale range is concerned.

On the Kelvin scale for example, there are no negative readings, but on the Celsius scale readings can be less than 0°C. Temperature is an indication of the degree of heat energy an object possesses.

If you were to accept that cold only indicates the absence of heat, then nothing can be colder than when there is absolutely no heat and this then is the absolute zero, that is 0 Kelvin or-273,16°C. 0°C = 273 Kelvin.

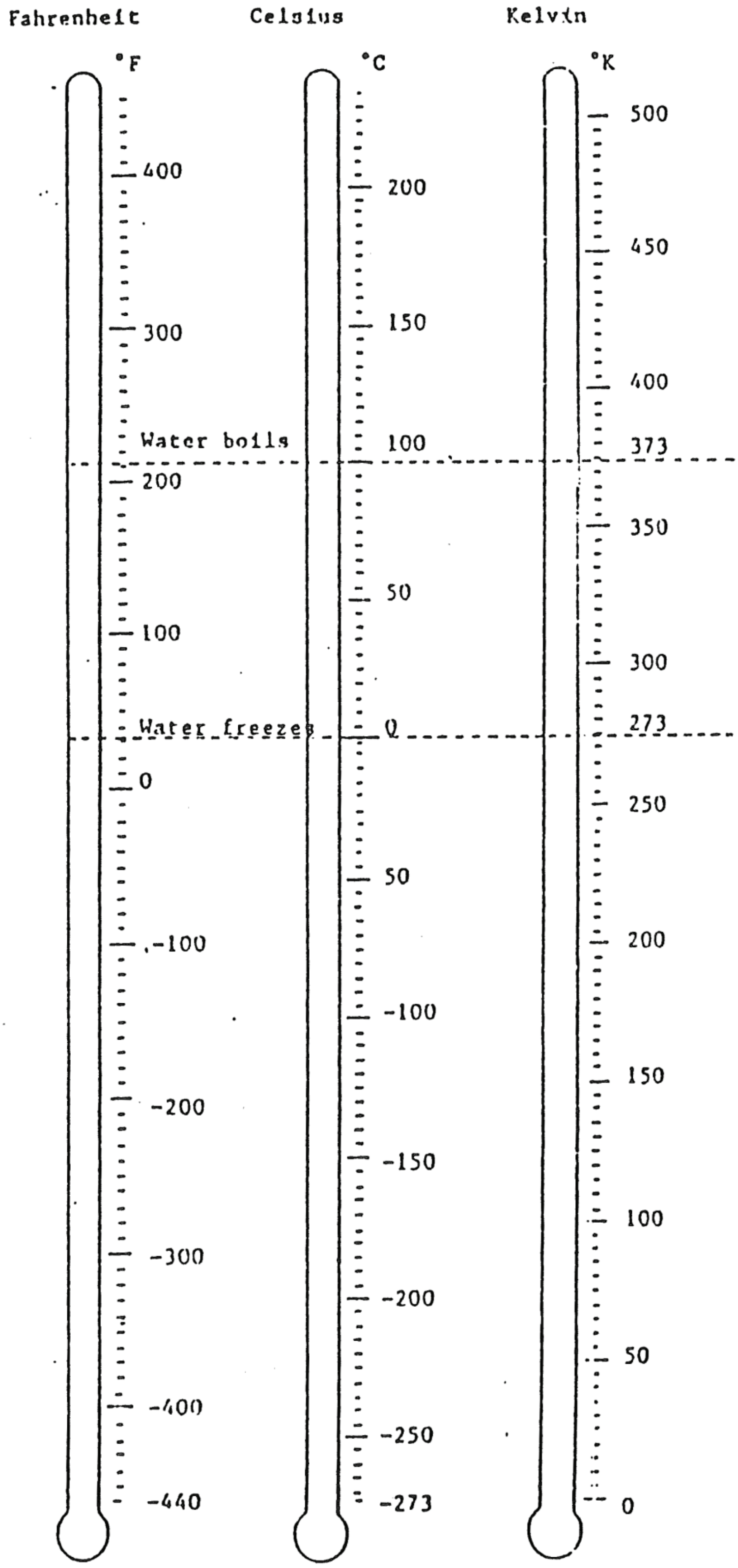


Figure 4.1 Temperature scales

4.2.1.2 Pressure

In many cases this is directly related to the temperature of the relative type of material.

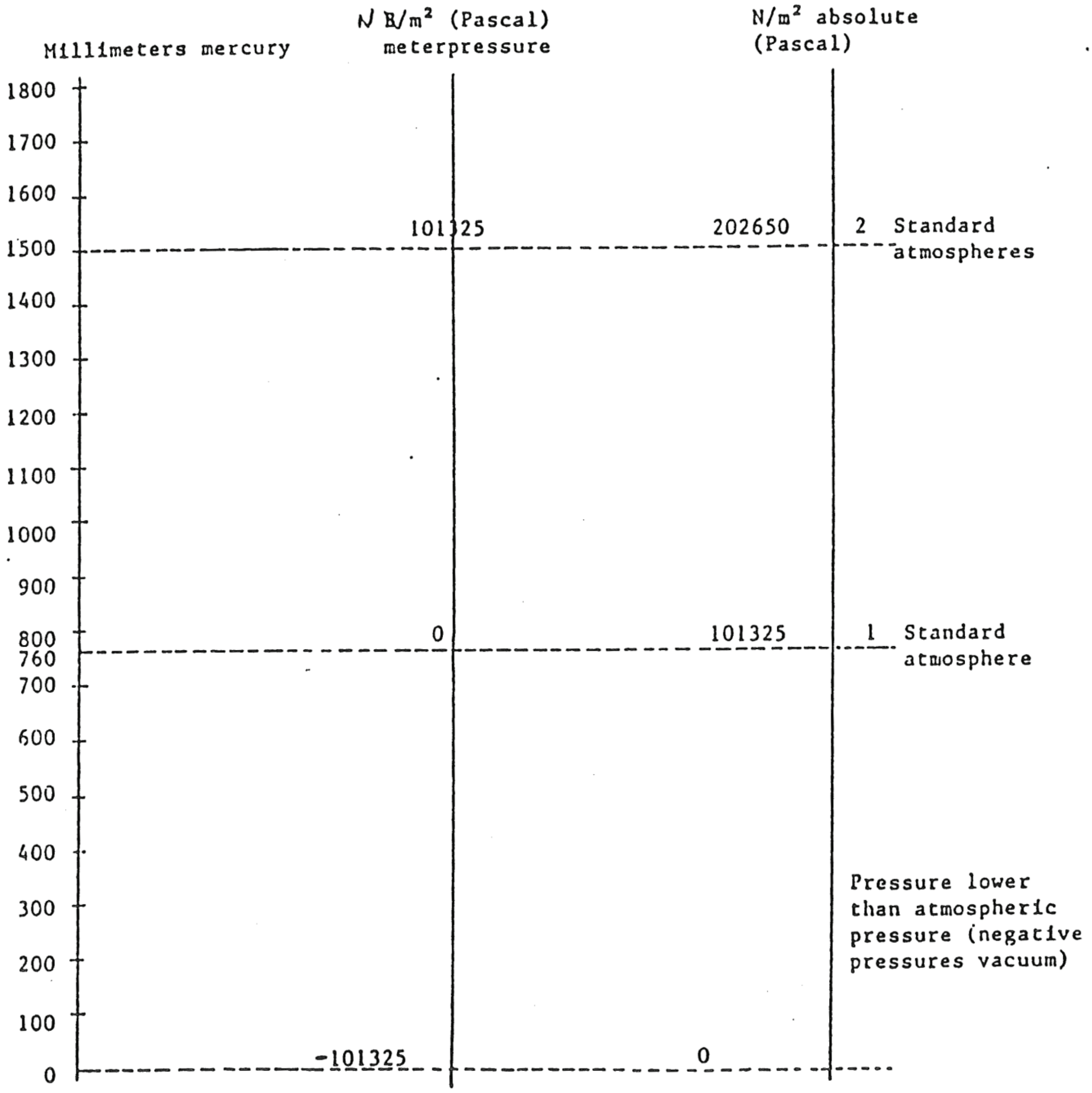


Figure 4.2 Pressure scales

Various types of pressure meters are used to measure pressure and these are discussed in detail later.

Once more you will have noticed that there are no negative values on the absolute pressure scale. There is no other name by which this scale can be distinguished from the other scale and consequently it is only written as N/m^2 (abs).

4.2.2 Quantity and rate variables

Quantity variables relate to changes in quantities and are measured by units of mass. (m^3, litres). Rate variables are energy quantities per time unit, for example litres per second, cubic metres per minute.

4.2.3 Potential and kinetic energy

The well-known English scientist, Isaac Newton, after whom the Newton unit of force was named, did a lot of work in the field of force, distance, velocity, mass and momentum and the influence of the one on the other.

For our purposes we confine ourselves to mass, force, distance and velocity.

Energy cannot be created or destroyed, but that it can only be changed from one form to another, for example, electric energy to heat or actuating energy, chemical energy to actuating or electrical energy. Energy can also be defined as the power to do work.

Potential energy: the energy of an object due to its *position or state of tension*.
Kinetic energy: the energy of an object due to its state of *movement*.

4.2.3.1 Potential energy

An object, or mass or quantity of liquid or gas, has potential energy as a result of the position it occupies, or as a result of the tension under which it is. For example, a shotgun bullet or a bomb has potential energy confined in them as a result of the chemical composition of the gunpowder or explosives.

A spring which can be compressed or stretched has potential energy as a result of the state of tension in which it is.

In the same manner, fuel, a hanging drop-hammer, a hammer held aloft, all have potential energy. When there is movement or velocity, we can say that the object or mass has kinetic energy.

4.2.3.2 Kinetic energy

An object or mass has kinetic energy as a result of its movement or velocity.

Thus water flowing from a pipe has kinetic energy as a result of the movement and velocity of it. Sprinklers, paddle wheels, water turbines for electricity can only do the work as a result of the movement of the water.

This principle is also applied to drive certain types of tools with gas and compressed air. Energy is proportional to mass (force), distance and/or velocity.

Take an object with mass "m" hanging at a height "h" above the ground or any other horizontal plane. The force exerted on it by gravity or by the rope or clamp which keeps it in place is mass x gravitation = m x g.

The work or labour it can do is in relation to the height "h" (distance).

As the work or labour is thus force x distance, the energy this mass has, will be equal to mass x gravity x height or distance - mgh (g = gravitation = 9,81 m/s^2).

The units for energy are consequently exactly the same as for work done that is joule and multiples thereof.

When the object is falls, the velocity with which it falls increases in proportion to the lapse of time while the height it still has, decreases in accordance with the time lapsed.

It thus means that as the kinetic energy increases as a result of the velocity increase, the potential energy decreases as a result of the height decrease, but the original potential energy is exactly equal to the final kinetic energy at that point when the height is made zero by stopping the object.

Kinetic energy = work done force x distance.

The force is equal to mass x velocity + time and the distance is equal to mean velocity x time.

The formula is thus:

$$\text{Kinetic energy} = \frac{mv}{t} \times \frac{vt}{2} = \frac{mv^2}{2} \text{ or } ½mv^2$$

where m = mass in kg; v = mean velocity in metres per second; t = time in seconds.

The mean velocity of a falling object is taken as half of the initial velocity + the final velocity =$\frac{v_1+v_2}{2}$.

It has already been stated that the potential energy is exactly the same as the kinetic energy and thus we can equate the two in a formula: potential energy = kinetic energy.

$$\begin{aligned} mgh &= \frac{mV^2}{2} \\ v^2 &= \frac{2mgh}{m} \\ v &= \sqrt{2gh} \\ \text{and } h &= \frac{mV^2}{2mg} \\ h &= \frac{V^2}{2g} \end{aligned}$$

Power = force x distance + time and this is kinetic energy + time (and also potential energy+ time where applicable: as for example, when potential energy can be equated to kinetic energy).

Worked Example1
Calculate the potential energy a boulder of 1 tonne(1000Kg) has, lying on a cliff with a height of 30 metres.

Solution:
Potential energy = mgh
= 1000 X 9,81 X 30
= 294 300 J
= 294,3kJ (Answer)→

Worked Example 2
Calculate the kinetic energy the boulder in **Example1**would have if it fell freely through a distanceof 20m.

Solution:
Kinetic energy = potential energy
= mgh
= 1000 x 9,81 x 20
= 196 200 J
= 196,2 kJ (Answer)→

Worked Example 3
A projectile with a mass of 6Kg is projected (shot) vertically upwards with an initial velocity of30m/s.

Calculate:
1. the initial kinetic energy of the projectile
2. the height the projectile will reach

Solution 1
Kinetic energy (KE)
$= \frac{mv^2}{2}$
$= \frac{6\ x\ (30)^2}{2}$
= 2 700 J
= 2 ,7kJ (Answer)→

Solution 2
As potential energy = kinetic energy the formula for potential energy can be used.

Potential energy (PE) = mgh
∴2 700 J = 6 x 9,81 X h
∴h $= \frac{2\ 700\ metres}{6\ x\ 9{,}82}$
= 45,87m (Answer)→

Worked Example 4

A turbine is driven by water from a vertical height of 140m at a rate of 30 cubic metres water per second flowing through it. Take the density of water as 1000Kg/m^3 and the efficiency of the system as 70% and determine the power made available by the turbine.

Solution:

Power = $\frac{force\ x\ distance}{time}$ x degree of efficiency (n)

With first principle

P $= \frac{volume\ x\ density\ x\ gravitation\ x\ distance\ x\ n}{time\ in\ seconds}$

$= \frac{vol\ x\ p\ x\ q\ x\ distance}{t}$ x n

$= \frac{30\ x\ 1000\ x\ 9{,}81\ x\ 140}{1}$ x $\frac{70}{100}$

= 41,202 x 10^6 x 0,7

= 28,84 MJ/s

∴P = 28,84 MW (megawatts) (answer)→

and/or power $= \frac{kinetic\ energy}{time}$ x n $= \frac{potential\ energy}{time}$ x n

$= \frac{mv^2}{2}$ $= \frac{mgh}{t}$

As velocity is not given, we use the potential energy.

P = $\frac{PE}{t}$ x n $= \frac{mgh}{t}$ x n

$= \frac{30\ x\ 1000\ x\ 9{,}81\ x\ 140}{1}$ x $\frac{70}{100}$

P = 28,84 x 10^6 W (Answer)

and/or power $= \frac{kinetic\ energy}{time}$

P $= \frac{mv^2}{2t}$

but V $= \sqrt{2gh}$

= $\sqrt{2}$ x 9,81 x 140

= 52,41 m/s

∴ Power P $= \frac{30\ x\ 1000\ x\ (52{,}41)^2}{2}$ x $\frac{70}{100}$

= 28,84 x 10^6 W (answer)→

4.3 Elements of Measurement

Measuring instruments consist of three parts:

- The **primary measuring element** or **sensory element** which is in contact with the variables being measured and which detects the change. This is, for example, pH electrodes when the pH is being measured or a thermometer bulb, when temperature is being measured. The primary element should be sensitive enough to react to any change that occurs without significant time delay.

- The **transfer element** transfers the change which was detected to the next element known as the indicating element.
- The i**ndicating element** which reacts to the change that was detected and transferred. A well-known indicating element is the Bourbon type of pressure meter with a "c" shaped tube of which the free end moves as a result of the change and then indicates this change by means of a gear and lever mechanism and indicator on a calibrated scale.

Figure 4.3 illustrates the three elements of measurements.

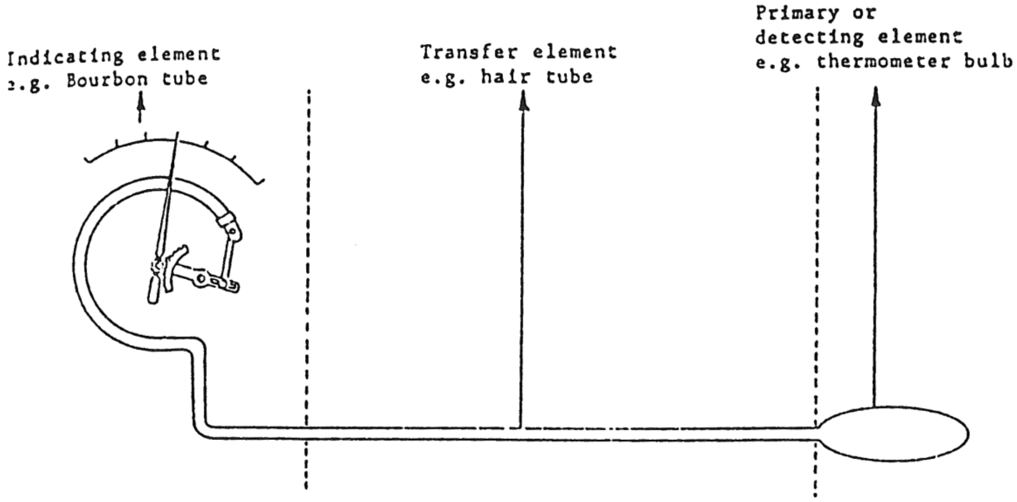


Figure 4.4 A typical measuring instrument

4.4 Indication and Registration Instruments

The indication instruments are now discussed separately under the headings of the variables being measured.

It is often necessary not only to have an indication of the state of the variable, but also to have a record or report which makes it possible to see what the reading is at a given moment and over a specified period of time.

A registration element of this type also consists, in addition to the measuring instrument, of a mechanism such as an electric clock, or small motor, which runs at a constant slow speed and which rotates a card or disc on which a pen notes the reading of the variable.

A chart or roll of this type can be of great value for the tracing of faults, costing, planning, etc.

4.5 Measurement of pressure

The basic metric unit in which pressure is measured is the Newton per square metre (N/m^2). One N/m^2 is one Pascal (Pa).

Compare the units for pressure measurement with atmospheric pressure and you will notice that when the pressure being measured is larger than the atmospheric pressure, we say it is positive meter pressure and when it is smaller than atmospheric pressure, we say it is negative meter pressure or vacuum.

A very efficient instrument for the measuring of pressure, is the U-tube manometer.

4.5.1 Open U-tube

As the name indicates, the tube is U-shaped with a downwards bend. The tube is partially filled with a liquid such as water, paraffin, light oil or mercury, according to the magnitude of the pressure acting upon it. This is called the sealing liquid as it seals the pressures from each other.

Before coupling the pressures to the U-tube, the levels in the two legs will be the same and this is the zero point on the scale fitted between the legs.

The high pressure presses the sealing liquid downwards until a point of balance is reached. The downwards displacement in the one leg is the same as the upwards displacement in the other leg and this is added together to calculate the pressure.

Pressure measured with atmospheric pressure as a reference pressure is known as gauge pressure. It can be positive or negative.

In **Figure 4.5(b)** the pressure is positive and it will be negative if the levels are reversed - then the measured pressure will be lower than the atmospheric pressure and we will have a vacuum.

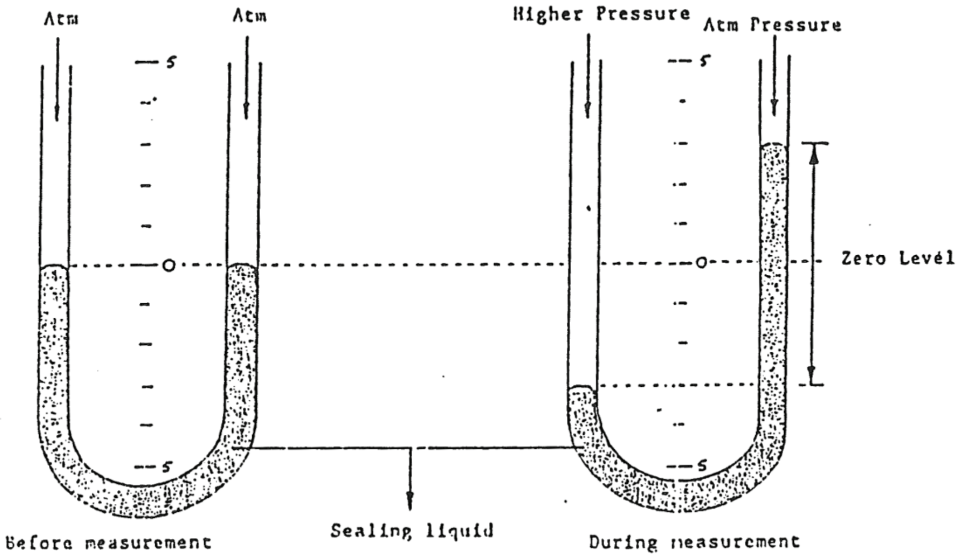


Figure 4.5Before and during measurement

The pressure is measured by measuring the difference in levels and using the formula:

Pressure = Density of liquid x gravitation x height (P = pgh)
P = pressure in N/m^2
p = density of sealing liquid in kg/m^3
h = level difference in metres

Worked Example 5:

An open U-tube is filled with paraffin with a density of 850 Kg/m^3 and the difference between the levels is 235mm. Determine the pressure applied.

P = ?
p = 850 Kg/m^3
g = 10 m/s^2
h = 235mm = 0,235m
p = pgh
= 850 x 10 x 0,235 pascal (N/m2)
= 1 997,5 Pa
P = 1,998 kPa (Answer)→

Worked Example 6:

The difference in the levels of an open U-tube is 350mm. The pressure applied is 2 kilopascal. Calculate the density of the sealing liquid.

P = pgh (P = 2kPa = 2000Pa
$= \frac{p}{gh}$ g = 10m/s^2
$= \frac{2000}{10\ x\ 0,350}$h = 350mm = 0,35m

p = ?)
density= 571,43Kg/m^3 (answer)→

Worked Example 7:
Calculate the difference in mercury level in an openU-tube when a pressure of 85kPa acts on it. (Density ofmercury = 13 600 Kg/m^3)

P = 85kPa = 85 000Pa (N/m^2)
p = 13 600Kg/m^3
g = 10 m/s^2
h = ?
P = pgh
H = $\frac{p}{g}$
= $\frac{85000}{13600 \, x \, 10}$
h = 0,625m (answer)
Difference in level = 625mm→

4.6 Differential U-tube

In this case two differing pressures are applied to the U-tube and the difference between the two pressures is measured. The method of measuring remains the same and the formula is practically the same as the previous one, namely:

Pressure difference = density x gravitation x level

(The actual magnitude of the pressures is of no consequence).
P_1 - P_2 = pgh where P_1 - P_2 is the pressure difference (with P_1 the higher pressure).

The calculations are basically the same as the previous ones.

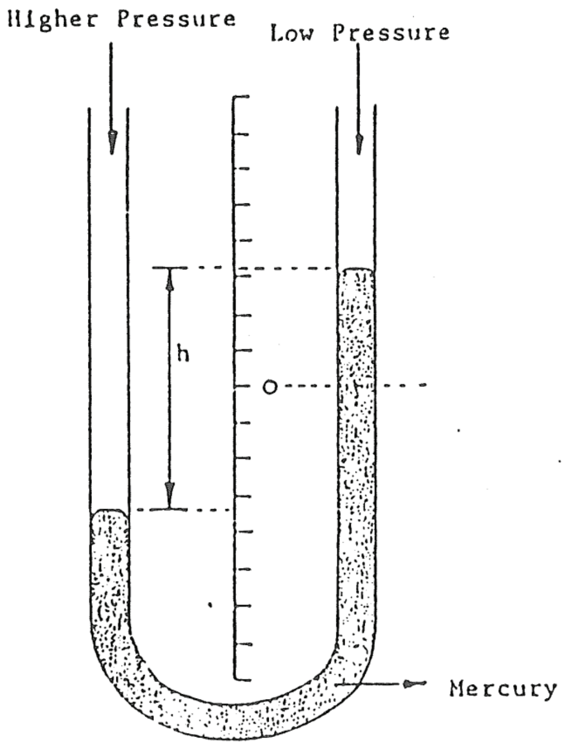


Figure 4.6 Differential U-tube

4.7 Closed leg U-tube

The leg of this type of tube is sealed so that it contains a complete vacuum after the mercury has been placed in it and the tube is held upright. The legs of the U-tube are at least Im long and the tube is illustrated in **Figure 4.7.**

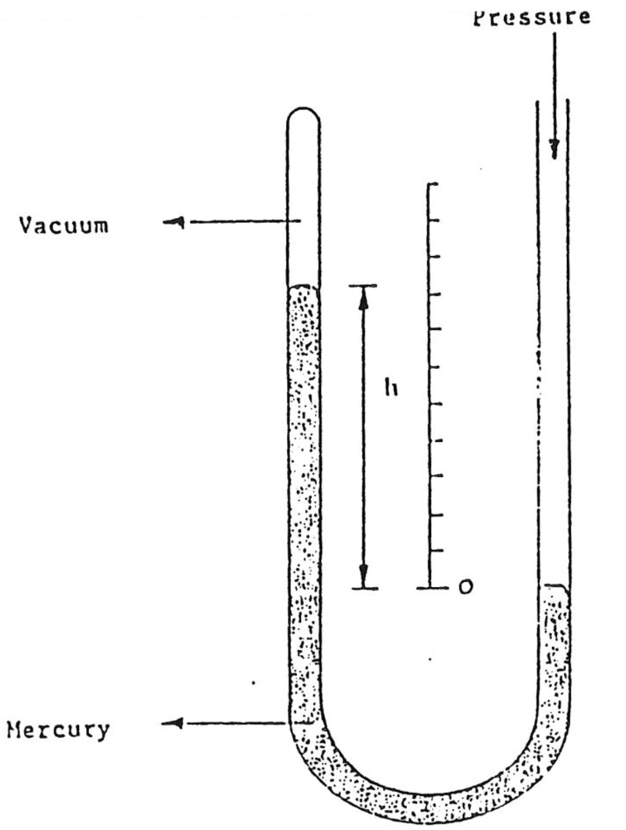


Figure 4.7 Closed leg U-tube

TAKE NOTE:

1. The zero point of the scale is at the bottom and not in the middle.
2. The levels will be the same only when the pressure being measured is also a complete vacuum.
3. The pressure measured in this manner with a complete vacuum as reference pressure, is known as absolute pressure.
4. 4. Absolute pressure cannot be negative.

Another definition for absolute pressure: Absolute pressure is gauge pressure plus atmospheric pressure.

The formula for the calculations is once more the same, that is
P(abs) = pgh

4.7.1 Other Calculations

Worked Example 8:
The pressure of the atmosphere at a certain place is 88kPa. What is the absolute pressure when a gauge registers a pressure of 175kPa (gauge pressure)?

Absolute pressure = gauge pressure + atmospheric pressure

= 175 + 88 kPa
P(abs) = 263 kPa (abs) (Answer)

Worked Example 9:
A gauge indicates the pressure in a system to be 30 kPa. Calculate the absolute equivalent of that pressure if it is measured at sea-level.

P(abs) = (P(atm) + P(gauge))
= 101,325 + (-30) kPa
P = 71,325 kPa (abs) (answer)→

4.8 Barometers

These are apparatuses used to measure the atmospheric pressure and can be of a mechanical type (discussed later on) or of the glass tube type constructed as illustrated.

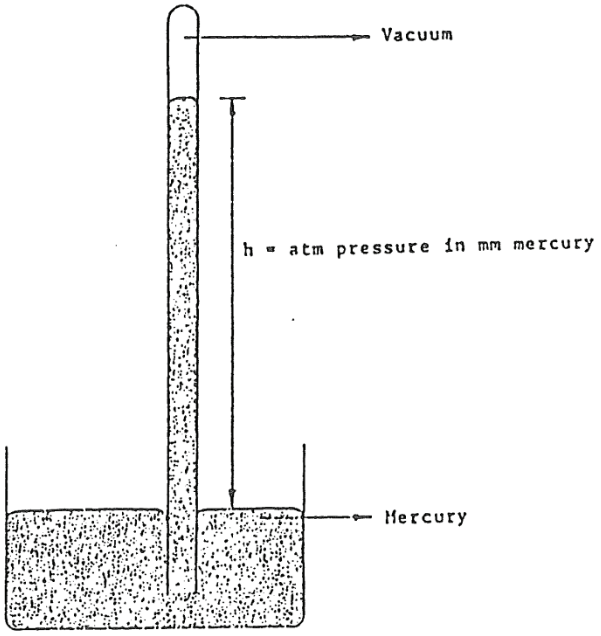


Figure 4.8 Barometer

Worked example 10:
The reading on a mercury barometer at a specific place is 715mm. What is the atmospheric pressure at that place?

P atm = pgh
= 13 600 x 10 x 0,715
= 97 240 Pa
= 97,24 kPa (answer)→

Worked Example 11:

What will the barometer reading at a place be in mm of mercury, if the atmospheric pressure at that place is 85 kPa?

$$\begin{aligned} P\ atm &= pgh \\ h &= \frac{p}{pg} \\ &= \frac{85\ 000}{13\ 600\ x\ 10} \\ &= 0{,}625\text{m} \\ \text{reading} &= 625\text{mm (answer)}\rightarrow \end{aligned}$$

When readings of liquid levels in tubes are taken, the following should be kept in mind:

1. With mercury the reading is taken at the top curve of the mercury.

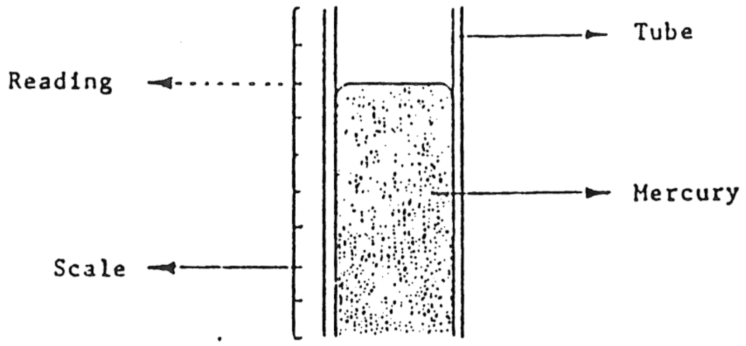


Figure 4.9

2. In the case of other liquids the readings are taken in the depressions of the surface (meniscus).

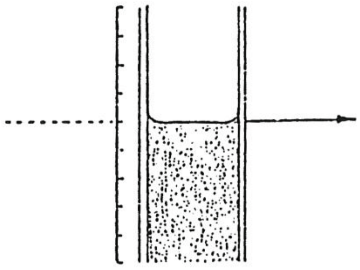


Figure 4.10

3. The eye must be kept on horizontal plane with the liquid and the tube vertical.

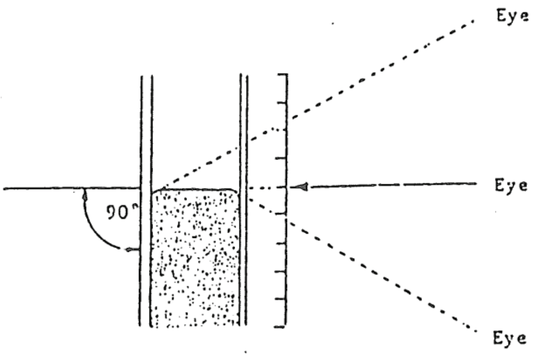


Figure 4.11

4.8.1 Measurement of small pressure differences

It often happens that the difference between two pressures is very small. It then becomes difficult to measure the difference with the ordinary U-tube manometers.

To facilitate the measurement and enlarge the scale length, the leg of the manometer is held at a slant so that the mercury has a longer distance to move in that tube. The other leg of the manometer forms a bowl.

As the angle between the inclined leg and the horizontal plane becomes smaller (the angle of inclination), the scale graduations become longer. The result is that more accurate readings can be taken with it.

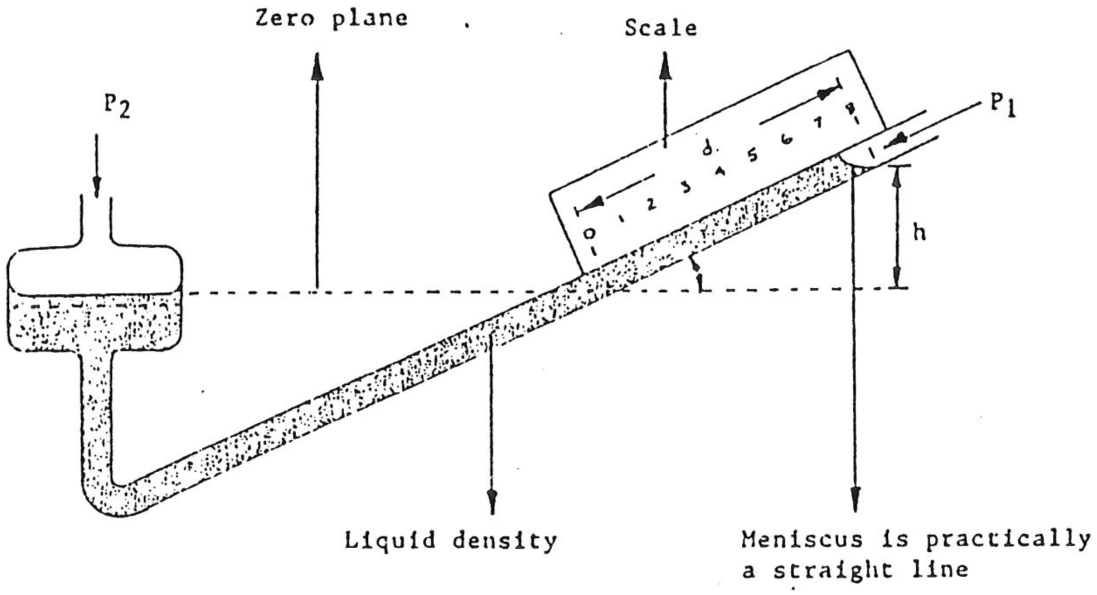


Figure 4.12 Slant leg manometer

As the angle of inclination becomes smaller, the scale becomes longer.

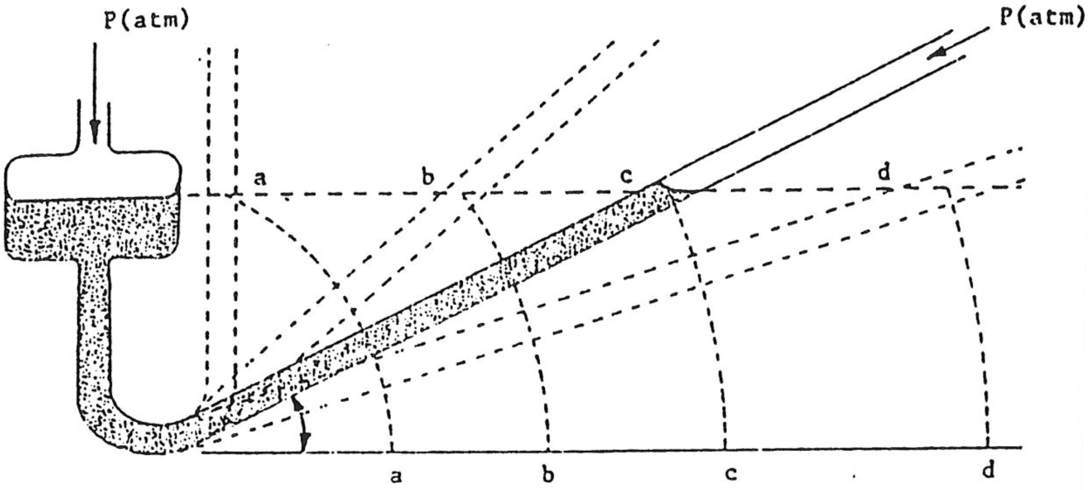


Figure 4.13 Angle of inclination and the scale

4.9 Measurement of pressure

The meters which we are now going to discuss, are known as mechanical pressure meters and are much stronger than the glass type of meters.

They can also withstand much rougher handling and shocks, but should, however, be handled with care. The pressure readings are shown on calibrated clock plates by means of pointers.

4.9.1 1.1. Bourdon tube meters

These tubes were named after the French inventor Bourdon, who in 1849 discovered that a bent flat tube tends to straighten when pressure is applied within the tube. This principle is now applied generally for pressure measurement and even in the well-known toy where a rolled paper tube straightens out when air is blown into it.

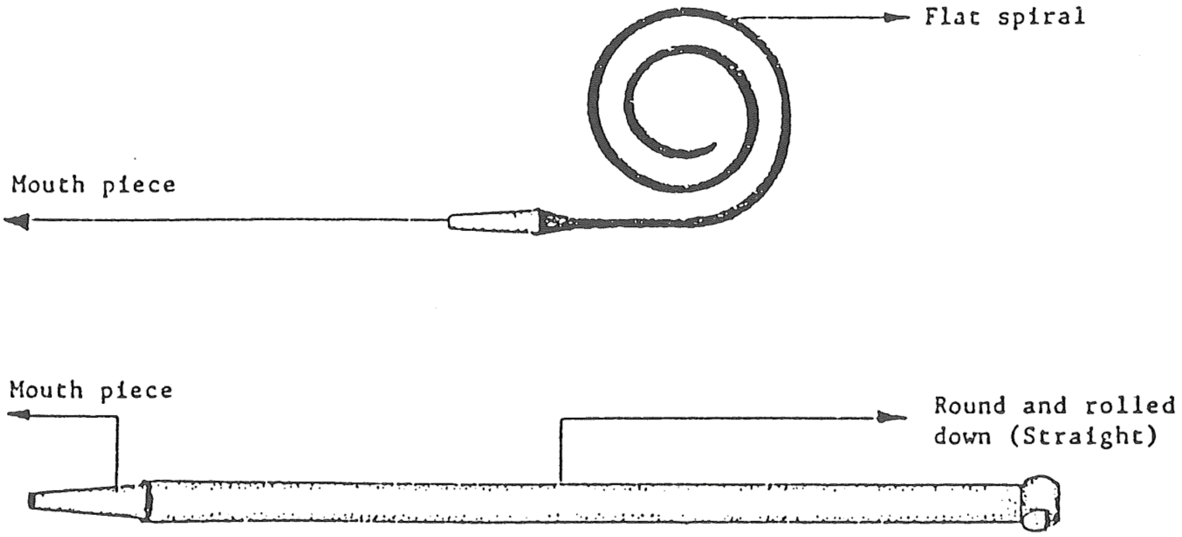
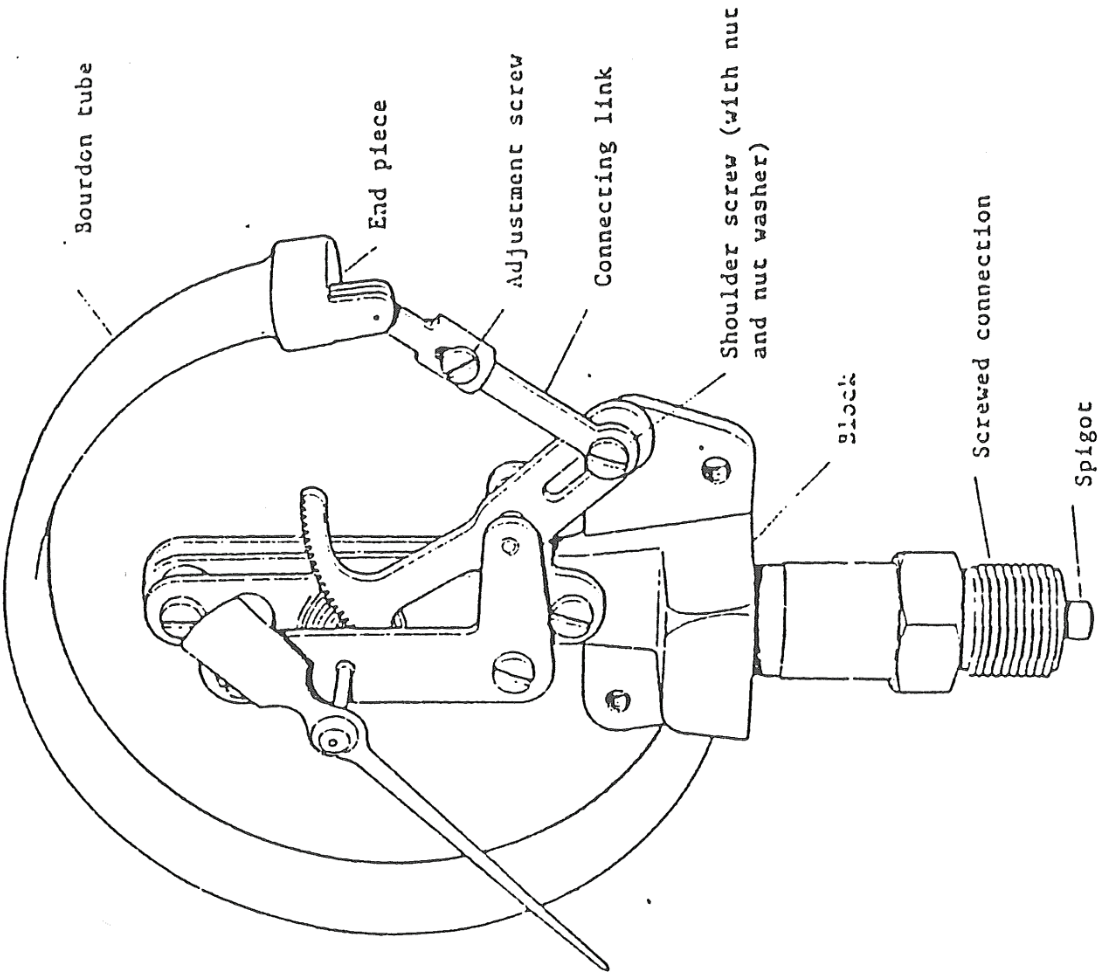
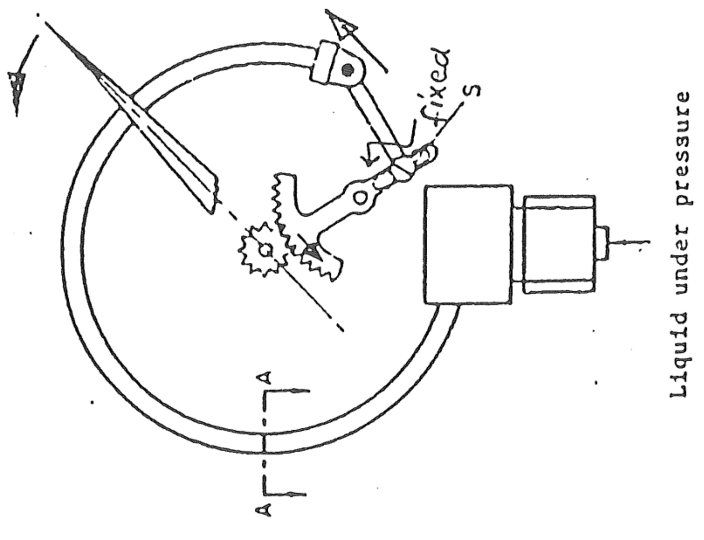


Figure 4.14



BASE-FRAME OF BOURDON GAUGE (BY COURTESY OF BUDENBERG GAUGE CO LTD)



THE C-TYPE OF BOURDON TUBE

Figure 4.15

The strength of the tube depends on the thickness of the material and the type of material and also on the actual internal surface area of the tube. This determines the resilience of the tube.

As the outer part of the tube has a larger circumference than the inner part, it exerts more force and the tube tends to straighten out in accordance with the pressure exerted on it. The amount the mobile and piece of the tube moves, depends on the circumference (length of the tube).

The mobile end piece of a tube of the same type and diameter as another second tube, but with twice the length of the second one, will, under the same pressure, move twice as far as the second one. For this reason (to enlarge the scale and thus to make the tube more sensitive), we have the spiral type of tube.

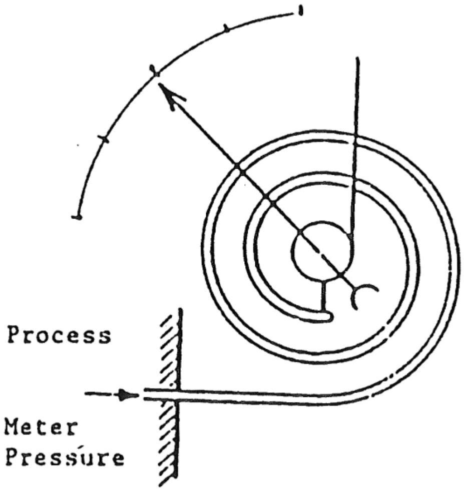


Figure 4.16

Still another type of Bourdon tube is the helical type. They are used to measure high pressures.

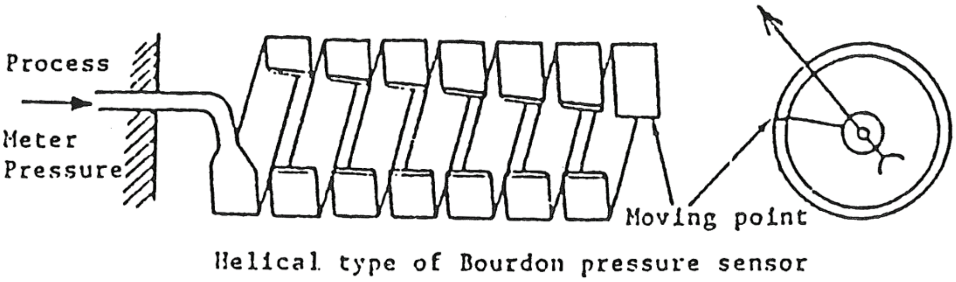


Figure 4.16 helical type of bourdon tube

In general, it can be said that the C-type tubes are used for pressures from 0 to 700 atmospheres; the spiral type from 0 to 7 atmospheres and the helical types from 0 to 5 500 atmospheres.

It is obvious that the various tubes should be used for various measuring ranges. Each tube is manufactured to serve only a specific range of measurement and the normal use of the meter should not exceed the 50% of the gauge. If the tubes are used at the higher gauge readings for lengthy periods, the tubes tend to become permanently deformed as a result of the mechanical tensions prevalent in them and they then have to be tested and reset or recalibrated on a regular basis.

4.10 Diaphragm Meters

This type of meter has already been in use for more than a century and has been improved to such an extent in the last few decades that an accuracy of ±0,1% of the measuring range is not exceptional.

The diaphragms of these meters are thin, strong, elastic, metal discs. They are flat or concentrically corrugated and have accurate gauges for the purpose for which they are applied.

The diaphragm moves or bulges at the centre as a result of the pressure applied to it and often has a calibrated spring to enlarge its range and to bring it back to zero. It is obvious that the flat (uncorrugated) type of diaphragm's movement is very limited. The corrugations and forms of the diaphragms are designed in a manner which allows sufficient movement for specific pressures.

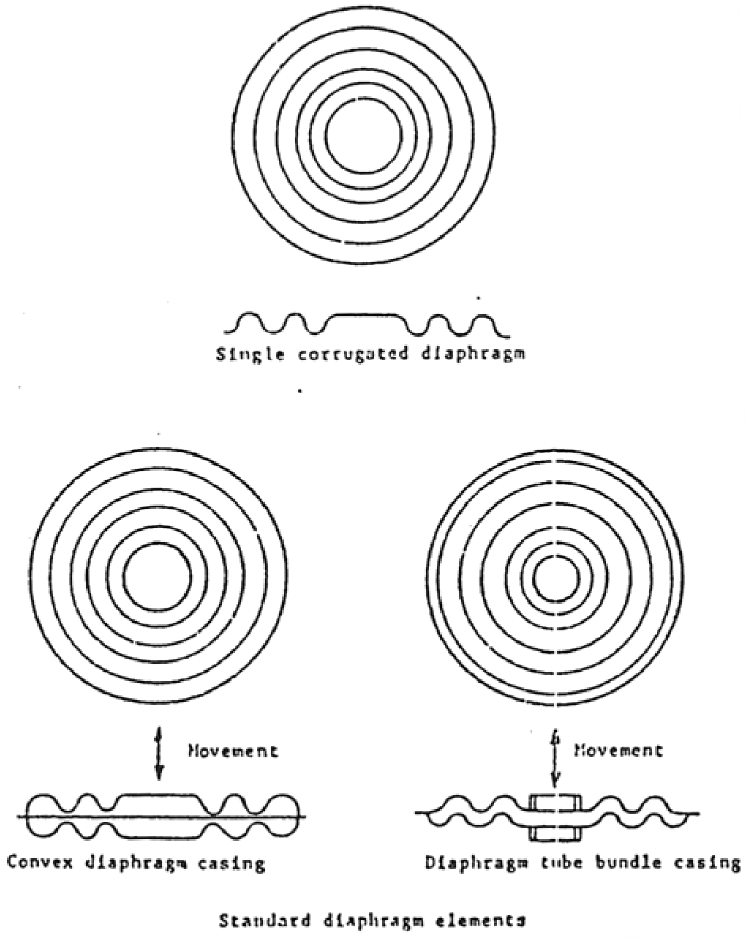


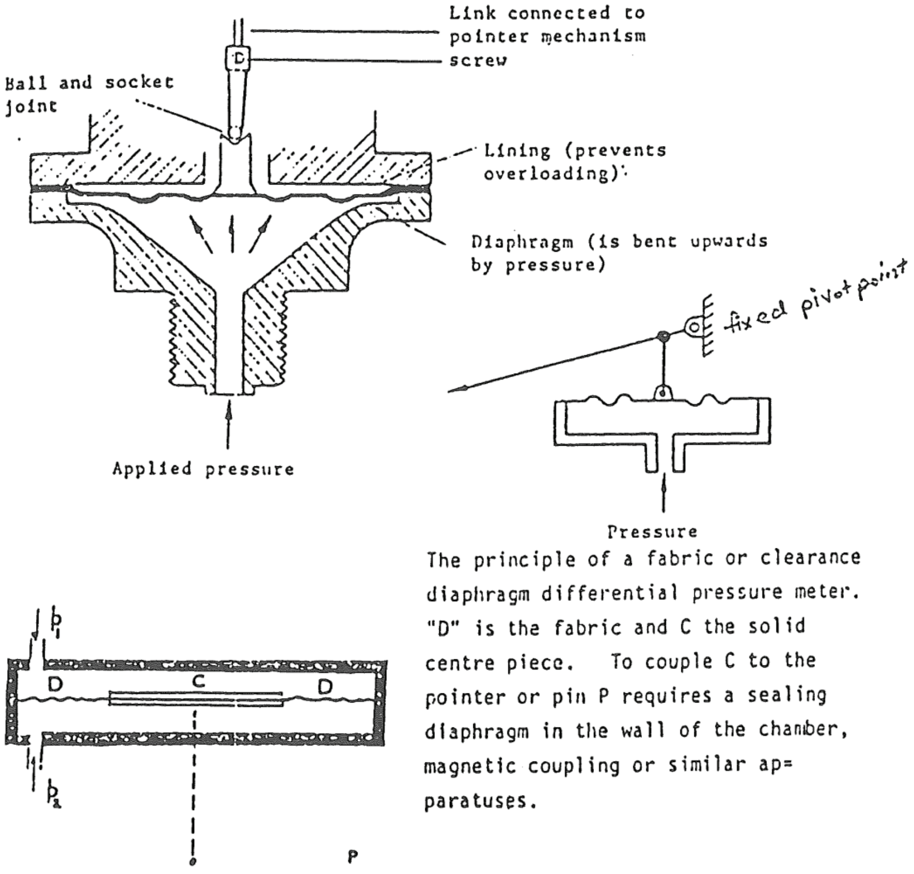
Figure 4.17 Different forms of diaphragms

The movement is transferred to gear mechanisms which allow a pointer to move over a suitable scale and the reading can then be taken from this.

The following sketches show how some of the diaphragms are formed. Large forces can be transferred by the diaphragms as a result of their surfaces and consequently they are not influenced by friction between the moving parts as is the case with many other meters.

Diaphragms are very popular when it comes to the measurement of pressure differences. The diaphragm is placed in a strong box with a pressure connection at each side of the diaphragm. The high pressure causes the diaphragm to move against the lower pressure.

Diaphragm type of barometers (to measure atmospheric pressure) is also very popular. The one side of the diaphragm is then completely under vacuum (no pressure) and the other side is open and points to the atmosphere.



The principle of a fabric or clearance diaphragm differential pressure meter. "D" is the fabric and C the solid centre piece. To couple C to the pointer or pin P requires a sealing diaphragm in the wall of the chamber, magnetic coupling or similar apparatuses.

Figure 4.18 Diaphragm meters used for the measurement of the difference between two pressures

When the movement of one diaphragm is not sufficient, the movement can be increased by increasing the number of diaphragms. The movement of the following arrangement is six times that of the movement of a single diaphragm.

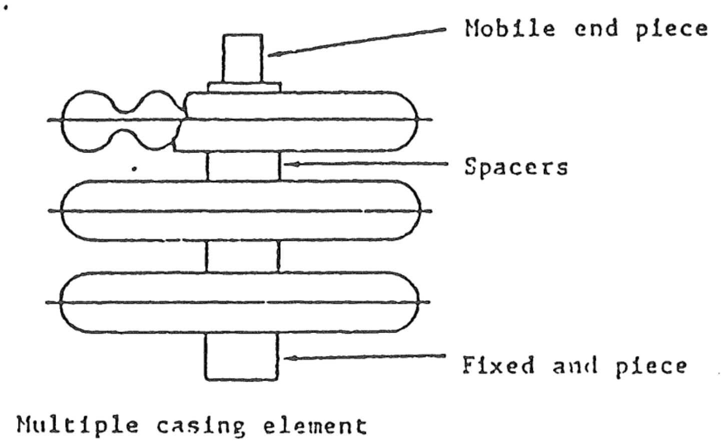


Figure 4.19Multiple diaphragms (stack diaphragms)

4.11 Bellows type of meters

As can be seen from the following sketches, the bellows resemble a corrugated tube which becomes longer when pressure is applied to it.

They are also used to measure atmospheric pressure, difference between two pressures and absolute pressure.

The sensitivity of the meter depends on the diameter and thickness of the bellows and also on the type of material.

The following sketches are self-explanatory and show the construction and purpose of the meters.

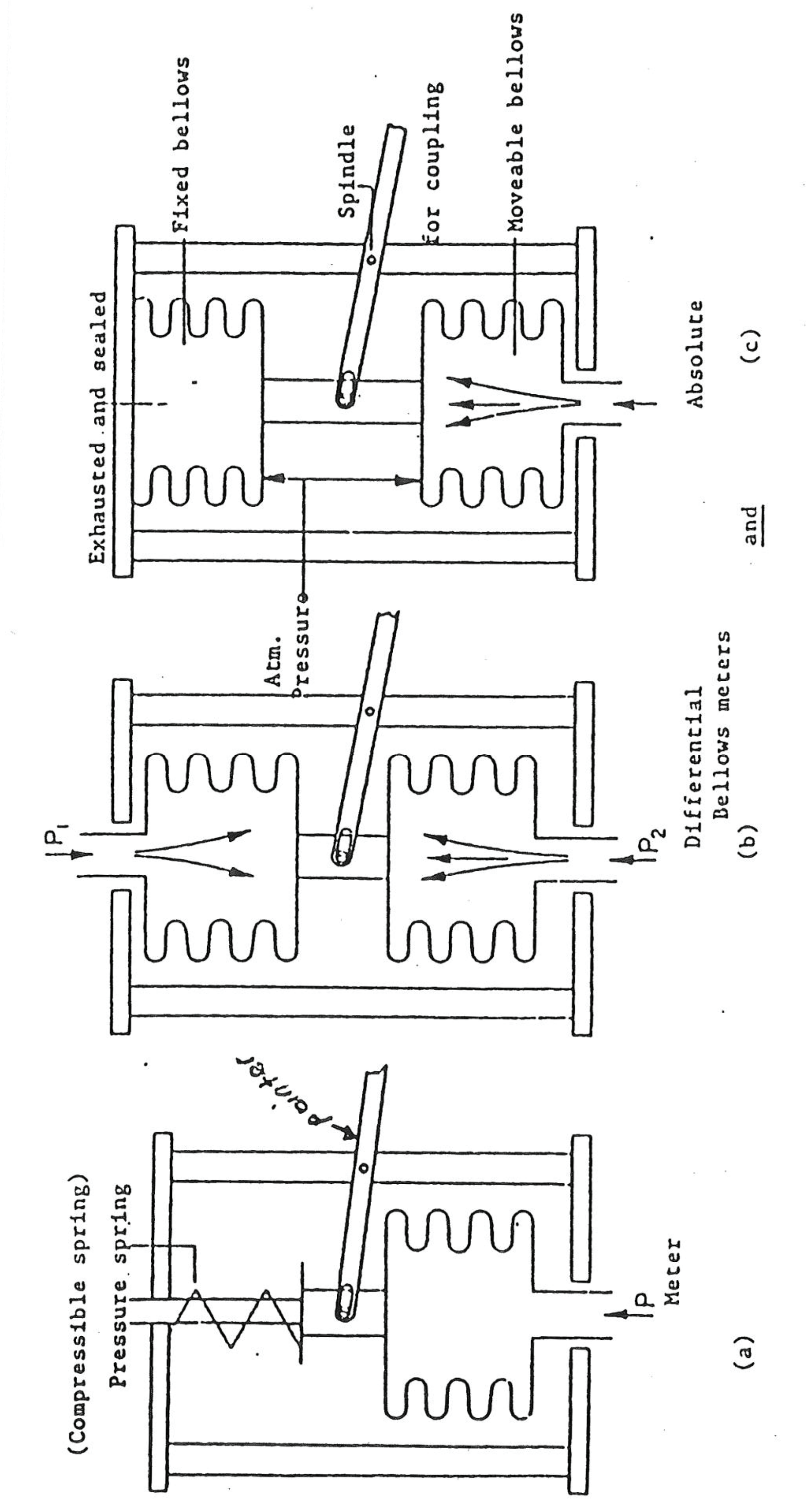


Figure 4.20 Bellows meters

4.12 Calibration of pressure meters

It often happens that meters, after having been used for a long time, give faulty readings and they then have to be tested and recalibrated.

In order to test meters, meters which have already been set are used to compare the readings. If the reading is incorrect beyond limits, the meter will have to be replaced and reset.

For this purpose (calibration) two appliances can be used, namely a mercury type U-tube manometer or a dead mass tester (sometimes also known as a hydrostatic balance apparatus).

In the case of the U-tube manometer, the faulty meter is joined to the high pressure side of the manometer and the reading on the manometer serves as the reference pressure reading. The meter is then set accordingly.

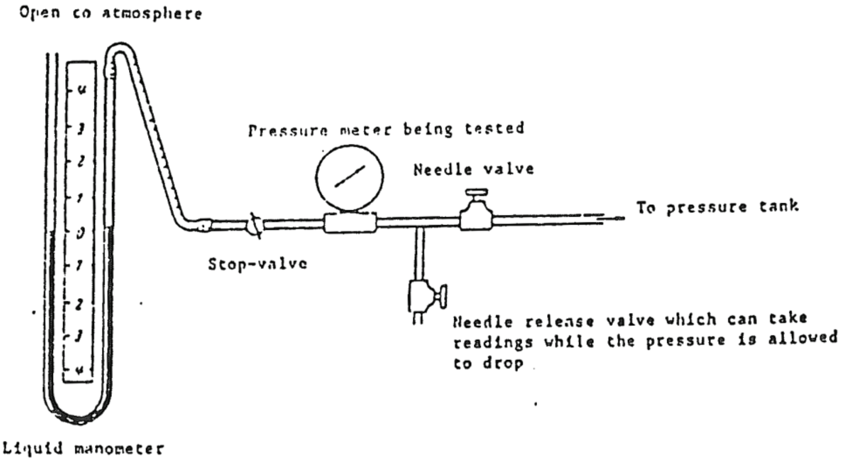


Figure 4.21 Calibration by means of U-tube manometer

4.12.1 The dead mass tester

This apparatus works on the principle of Pascal's law which reads as follows: When pressure is applied to an enclosed liquid, the pressure will be transferred proportionally in all directions by the liquid.

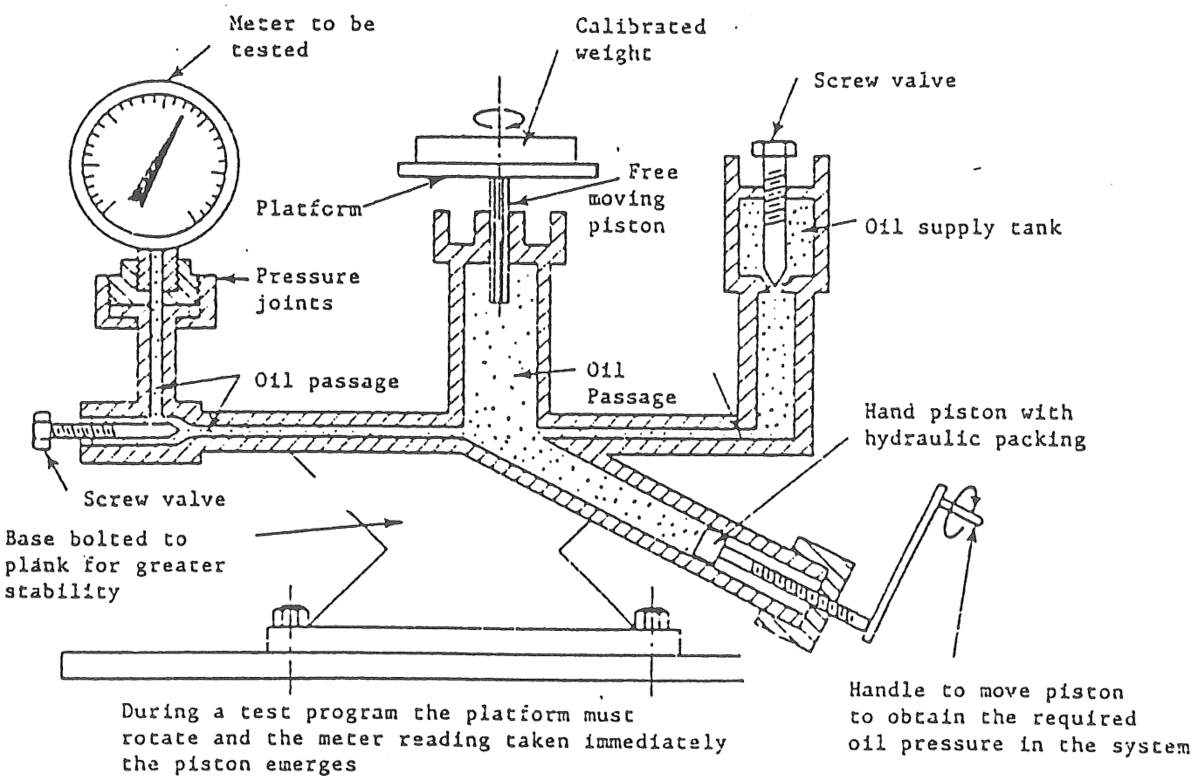


Figure 4.22 Dead mass tester

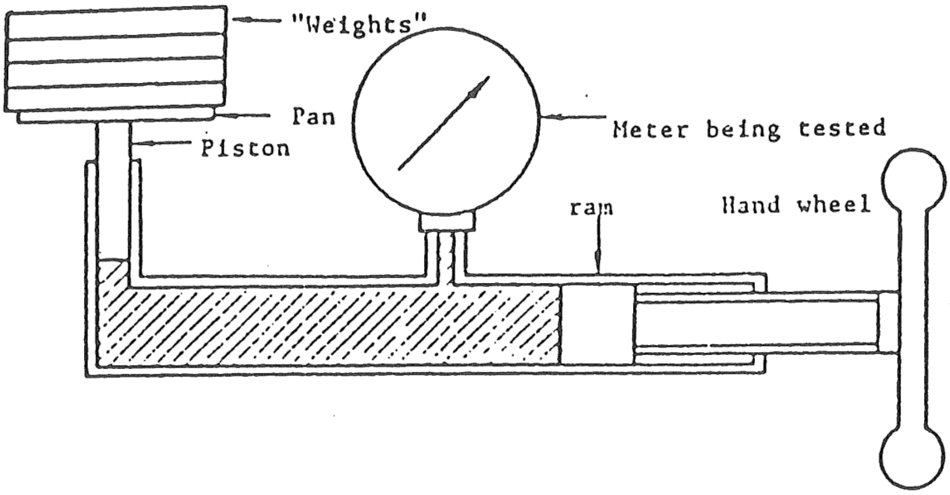


Figure 4.25 Dead mass tester

Use of Dead Mass Tester

- Ensure that the apparatus is filled with oil and that there are no air bubbles present.
- Screw the meter to be tested down properly so that there are no leaks.
- Place suitable quantities of calibrated mass on the platform first 10%, then 50% then 90% of the meter's scale.
- Turn in the hand wheel so that pressure is applied to the oil and
- Rotate the platform with the mass on it so that friction between the piston and cylinder wall is decreased.

- As soon as the platform with masses lifts to such an extent that the specific mark becomes visible, the downwards pressure of the mass is the same as the pressure on the liquid and this is compared with the meter reading.

The meter is then set and retested.

⚠ This work is done by the instruments technician and does not form part of the duties of the process controller (operator).

The relative formula in this case is:
Pressure on liquid x surface of piston plus platform mass (including the mass of the piston and platform) x gravitation, that is $P \times A = M \times g$.

A = area of piston with platform
M = mass including the mass of piston and platform.

4.13 Measurement of temperature

A clear distinction must be made between heat and temperature.

Temperature is an energy condition and indicates the degree of heat of a substance in degrees Celsius or Kelvin. These temperature scales have already been discussed.

Warmth (heat) is a form of energy and is measured in units of energy.

The more heat a substance possesses the higher its energy contents while its temperature will also be higher, except in cases where the substance(s) change(s) condition and no change in temperature is noticeable, although the amount of energy (heat) of the substance increases.

The opposite is, of course, also true when the substance is cooled and the energy content decreases.

It is thus wrong to say that the temperature (instead of the heat) is removed. A substance always has a temperature, regardless of the amount of heat it possesses.

This aspect will be discussed in more detail in the N3 course when the effect of heat on substances is dealt with.

To determine the degree of heat of substances, we use thermometers which indicate the degree of heat (temperature) in calibrated units on the scales. We are now going to discuss a number of these types of temperature.

4.13.1 Bimetal thermometers

They consist of two flat strips, each of a different type of metal and are secured to each other with the flat sides touching. The one metal, for example, copper, expands more than the other metal, for example iron, and the strip bends.

The degree of expansion of the metals is proportional to the temperature thereof and if the expansion is thus measured, it will be an indication of the temperature of the bimetal strip.

One end of the strip is fixed and the other allowed to move freely as a result of the bending. The free moving end is connected to a gear mechanism which causes a pointer to move.

The pointer indicates the temperature on a suitable scale. When the temperature decreases, the strip bends back and the pointer indicates the new temperature.

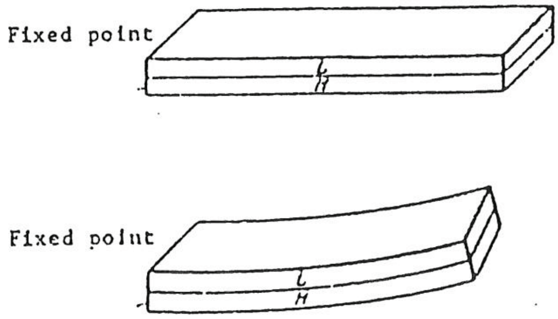


Figure 4.26 Principle of bimetal thermometer

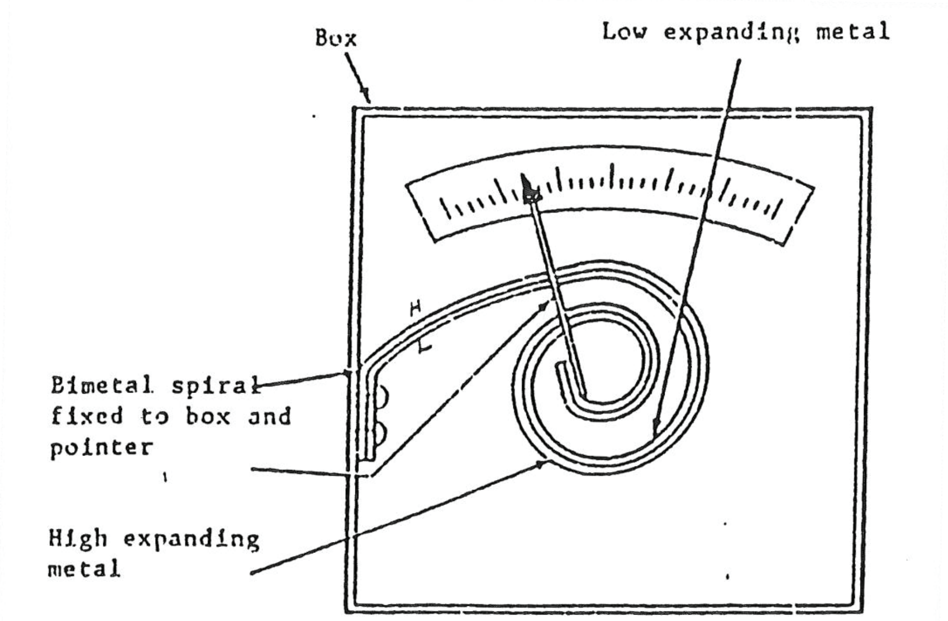


Figure 4.27 Bimetal thermometers for the measurement of temperature of environment

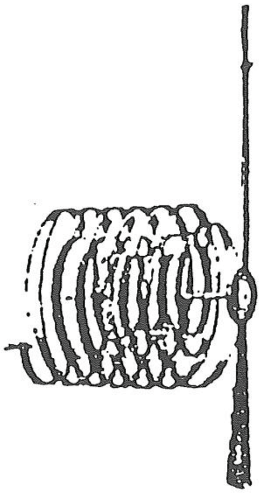


Figure 4.28 Helical form of bimetal thermometer

They are accurate to within 2 and 5% of the scale and are not influenced by atmospheric pressure.

4.13.2 Liquid-in-glass thermometer

These are of the well-known clinical thermometer type. A glass tube with a very small internal diameter (hair tube) and a thin glass bulb at the bottom end is filled with a liquid, for example mercury, coloured alcohol or something similar.

The liquid expands, ie its volume increases, and pushes up into the hair tube until it reaches a position proportional to the temperature. A scale is affixed to the tube.

It is difficult to take a reading on this type of thermometer, especially when it is filled with mercury. The liquid also drops as soon as the thermometer is removed from the source of heat and, consequently, the reading has to be taken quickly unless it remains in contact with the source. The glass bulb also breaks easily.

However, this type of thermometer is considerably cheaper than most of the other types and is not influenced by atmospheric pressure changes.

4.13.3 Pressure type of thermometers

They are divided into three groups and usually, although not necessarily, have a bourdon type of pressure meter as reference element:

4.13.3.1 Gas pressure thermometers

When the temperature of a gas changes, but the volume of the gas remains the same, the pressure of the gas also changes. (Charles' law).

A sealed unit consisting of a bourdon tube element, connected to a hair tube which, in turn, is connected to a hollow metal ball, is filled with nitrogen which expands when the temperature is increased and pressure is applied to the bourdon tube.

The bourdon tube reacts to this, as explained under pressure meters and the pointer indicates the temperature on a scale calibrated in degrees Celsius or Kelvin.

Changes in atmospheric pressure affect this type of thermometer and when accurate readings have to be taken; this has to be taken into account.

Special provision also has to be made for changes in the environmental temperature at the bourdon tube which is sensitive to changes of this type.

Gas pressure thermometers are suitable for readings between -50°C and 538°C. Helium gas is used for lower temperatures. The temperature scale is directly proportional pressure (the scale is thus linear).

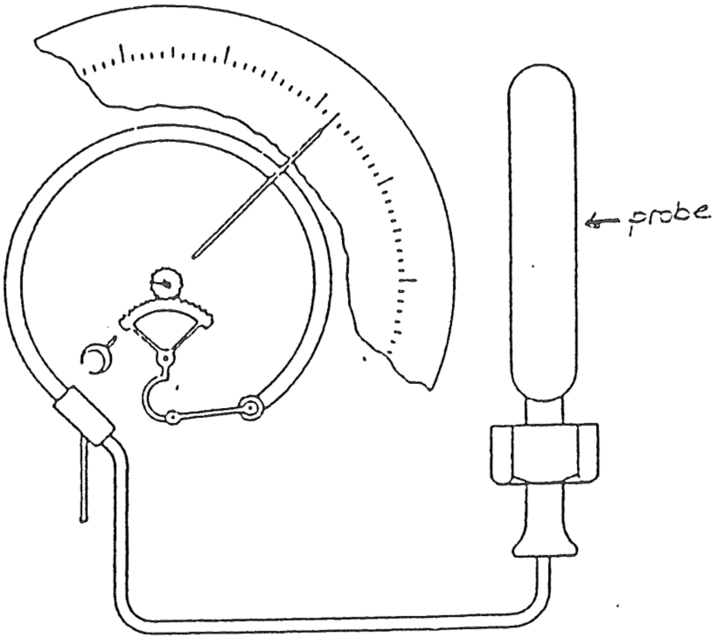


Figure 4.29 Typical gas pressure thermometers

4.13.3.2 Liquid pressure thermometers

The construction of this type of thermometer is the same as that of the gas pressure type, but the thermometers are completely filled with liquid.

Filling liquids are mercury (-38°C to 538°C), xylene (-400°C to 400°C), alcohol (-46°C- 150°C). The scale is also linear.

4.13.3.3 Vapour pressure thermometers

In this case the system is partially filled with liquid and partially with the liquid's vapour.

It is important that the liquid should be volatile and that there should always (at any temperature it measures) be a quantity of vapour and a quantity of liquid in the ball. As soon as all the vapours have condensed at low temperature, there is no vapour pressure left and the reading is incorrect.

In contrast, the readings will be incorrect as soon as the liquid has evaporated completely. The temperature scale is not linear.

Suitable filling liquids for vapour pressure thermometers are methyl chloride, freon, sulphur dioxide, ethyl alcohol, tolud and ether. The measuring range is also in the vicinity of -50°C to 500°C.

Environmental temperature changes have no effect on this type of thermometer (vapour pressure) as the vapour pressure is independent of the volume of liquid in the system.

In the case of the liquid and vapour pressure thermometers, the level of the bulb above or below the pointer, has to be taken into account (head pressure faults), but this is unnecessary in the case of the gas pressure type, as the density of the gas is very low and can practically not cause errors.

4.13.4 Thermocouples

When two different types of metal wires (conductors), for example copper and iron are connected at the ends, forming an electric circuit, an electromotive force (emf measured in millivolts) is set up in the circuit and a small current flows if the two joins are at different temperatures.

The emf is proportional to the difference in temperature between the two joins. The larger the difference in temperature the larger the emf.

A very simple thermocouple can be constructed as shown, but it has certain shortcomings. It is necessary to keep the one join at a fixed temperature, for example 0°C, so that the temperature of only the other join changes and the emf is thus only attributable to that temperature.

This is impractical and the emf of a thermocouple is measured by means of a potentiometer for practical reasons.

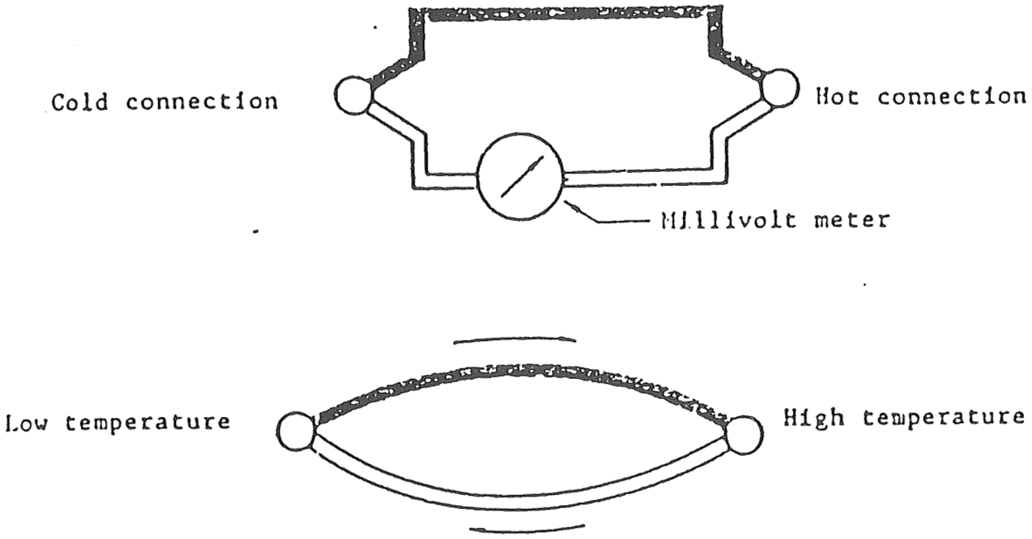


Figure 4.30 Simple thermocouple circuits

The following table gives an indication of a couple of types of metal used for thermocouples and also the recommended maximum working temperature of the couples.

(a)Metal		**(b)Recommended Maximum working temperature**
alloy of platinum and rodium	platinum	1 400 °C
copper	constantan	400 °C
iron	constantan	850 °C
chromel	alumel	1 100 °C

Table 4.1

Chromel is an alloy of chromium and nickel and alumel is an alloy of nickel and aluminium with traces of manganese and silicon. Various compositions of this type are available.

Thermocouples must be used judiciously, as some of them oxidise (rust) at high temperatures and thus should be used in neutral or reducing atmospheres. Consequently, the choice of the type of thermocouple depends on various factors which should be examined carefully.

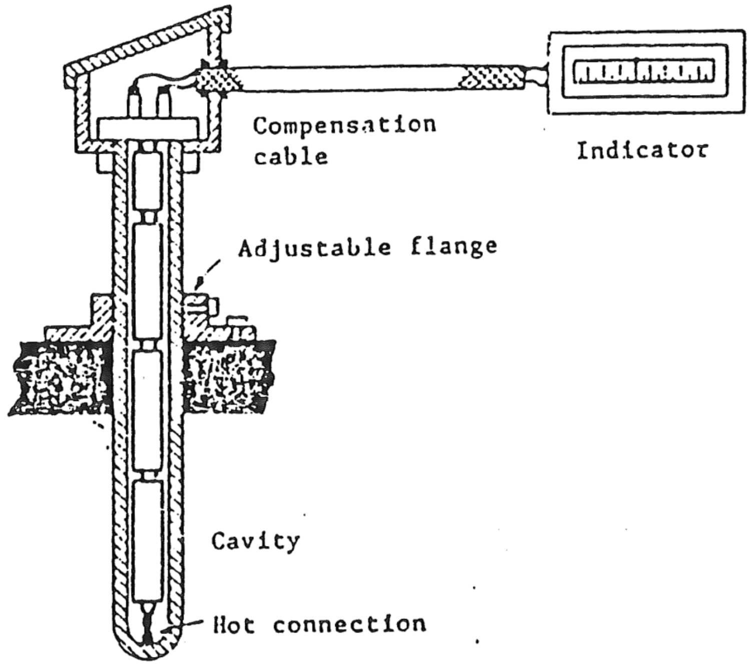


Figure 4.31 Basic arrangements for installation of thermal couple in industrial plant

4.14 Measurement of flow

Many different systems and meters are used to measure flow or flow rate. It is necessary for a variety of reasons to make an accurate determination of the quantity of liquid used in processes. Through the years new systems (meters) have been developed while others have been extended and improved.

However, many of the old tried methods have remained basically unchanged. To try to discuss all the methods and types of meters is attempting the impossible and consequently we only deal with the few meters and methods stipulated in the contents. The material of which the meters are manufactured depends on the type of liquid to be measured.

4.14.1 Positive displacement meters

These meters measure the actual quantity of liquid flowing through the meter, and through the gear mechanisms, a counting apparatus rotates, which indicates the quantity.

4.14.1.1 The rotating vane type of meter

In these meters the liquid stream drives a blade wheel. The blades are close to the walls of the meter so that it can still rotate freely. The volume of liquid caught and displaced between the blades is known and the number of rotations is registered as a volumetric quantity, for example cubic metres or litres.

These meters are consequently also known as volumetric flow meters.

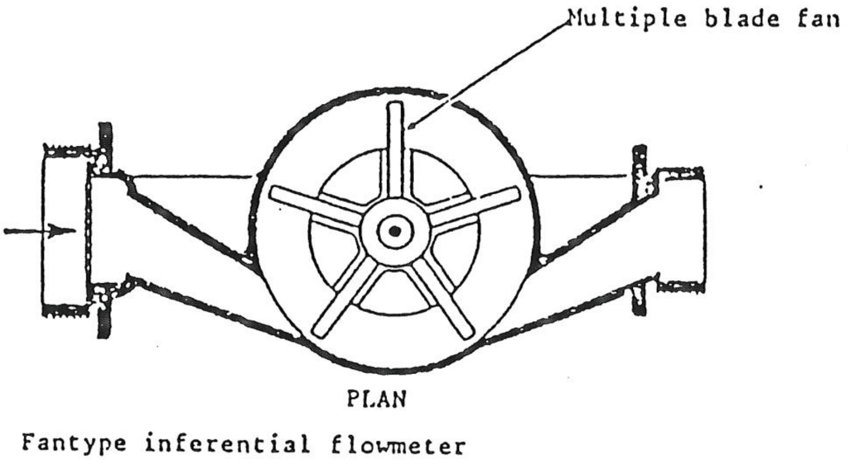


Figure 4.32 Rotating vane flowmeter

4.14.1.2 The screw (helical) type of meter

The liquid flowing through the meter causes the screw to rotate in the same manner the wheel of a windmill is rotated by the wind. However, it is more positive with the liquid than with the wind and practically no, or very little, movement is lost. The helix or screw also rotates a gear and counting mechanism which indicate the readings in volumetric quantities.

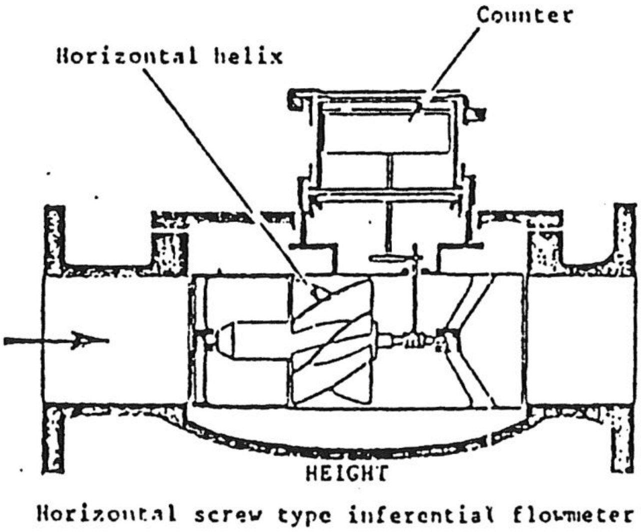


Figure 4.33 The screw (helical) type of flowmeter

4.14.2 Flow rate meters

In the above flow meters the time it takes a certain quantity of liquid to flow through the meter is not important. In the case of flow rate meters, both quantity and time are important and both have to be indicated.

Using stop watches, the meters just figured, could well be used to measure flow rate, but then somebody will continuously have to take readings of the quantity and time and record them, or otherwise the information has to be noted on a card on which time is also indicated by a registering mechanism.

It has been established by trial and error that the flow rate in flow meters is in one respect, proportional to the linear velocity at which the liquid moves in the pipe, which, in turn, is related to the internal diameter of the pipe, and in the second respect to the pressure difference introduced across a constriction in the pipe.

Actually, the flow rate is proportional to the square root of the pressure difference.

This principle of pressure difference and flow rate was evidently explained for the first time by the Italian scientist Venturi, in 1797 and summarised in a practical design by Herschel in 1887.

Bernoulli's theory is also applicable in this respect. Bernoulli's theory states that: When a liquid flows in a pipe and the diameter of the pipe changes, the velocity of the liquid changes and also the pressure of the liquid. Flow rate meters operate on this principle and we are now going to discuss some of these meters.

The meter by which the pressure difference is caused is known as the primary flow meter or element and the meters used to measure the pressure difference across the primary element are known as the secondary flow meters.

A primary and secondary flow element has to be used in conjunction with each other to measure flow rate and cannot be used separately for this purpose. We have already discussed the pressure difference meters (manometers).

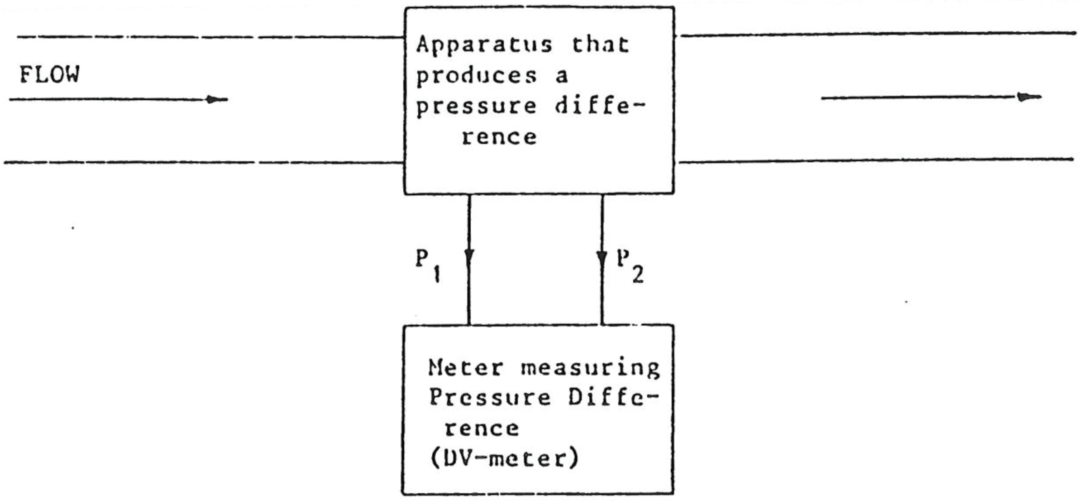


Figure 4.34 Block diagram of flow rate meter

4.15 Orifice plates

4.15.1 Ordinary orifice plates

These consist of flat machined metal discs with a hole in the middle. They are mounted between two flanges in the pipe for measurement purposes. The following diagram shows the pressure difference at various points on both sides of the orifice plate.

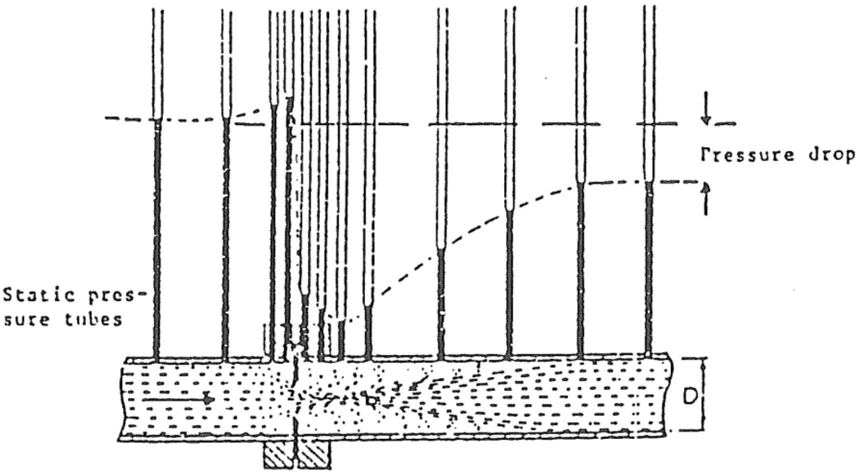


Figure 4.35 Difference in pressure on both sides of orifice plate

Note that there is a considerable permanent loss of pressure to (downstream from) the orifice plate.

Suitable points, depending on the characteristics of the pipe system, are chosen for the pressure difference meters and flow rate can be measured.

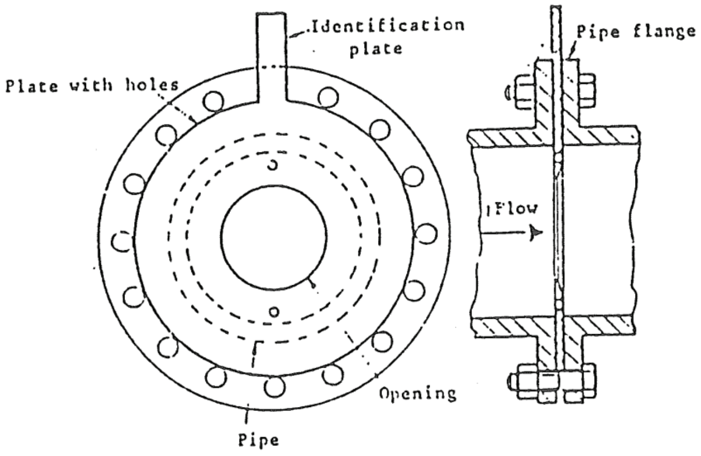


Figure 4.36 Concentric thin orifice plate

Note that the orifice plate has a tongue or protuberance on which particulars regarding the plate are punched.

The holes above the larger hole are intended for gas or vapour flow when liquids containing such substances are measured with it and the hole at the bottom is for condensate (liquid) when wet gases are measured with it.

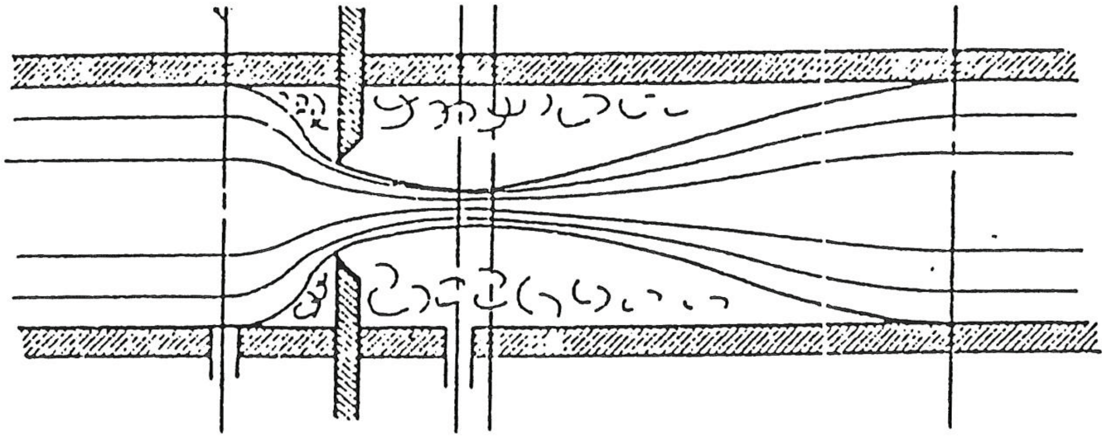


Figure 4.36 Flow pattern with orifice plate in the "line"

4.15.2 Venturi tube

This type of tube is illustrated in the following diagram and consists of a short tapered part and a long tapered part, of which the two constricted ends are connected by means of a short tube that is the cone. The whole apparatus is attached to the pipe by means of flanges. Note the direction of flow and the pressure connections.

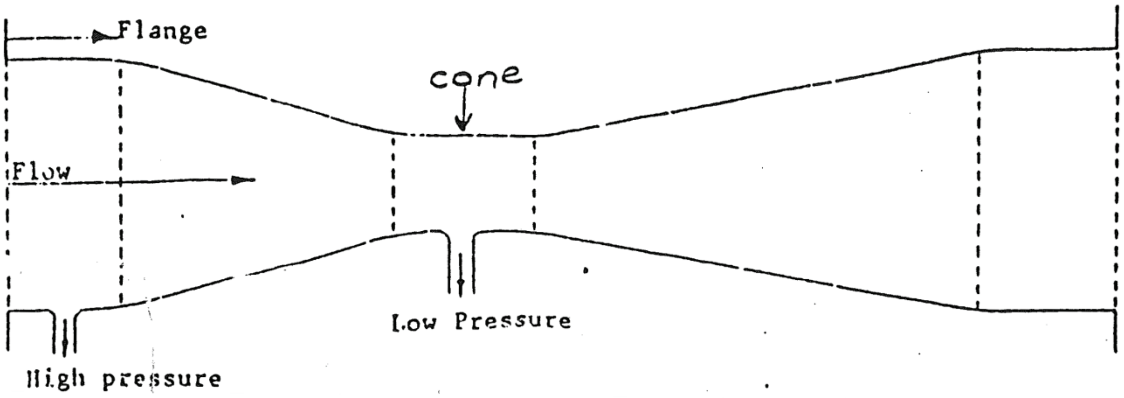


Figure 4.37 The venturi tube

Advantages of the Venturi Tube

- As a result of the slanted shape which allows solids through more easily, the tube does not easily become blocked.
- No special provision has to be made for vapours and/or liquids as in the case of the orifice plate.
- The pressure loss across the meter is less than in the case of the orifice plate.
- If accurately manufactured, it gives very accurate readings.

Disadvantages of the Venturi Tube

- As a result of its size and shape, it is more difficult to install than the orifice plate.

- Accurate machining is essential and the characteristics of each of the tubes have to be determined experimentally. Sharp corners and ridges affect the flow.
- The cost of the tube is higher than that of the orifice plate.

Other very similar primary meters are the Dall tube and the flow nozzle.

4.15.3 The pitot tube

It has already been stated that the pressure of a liquid in a pipe will increase when the velocity thereof is reduced. Thus a high pressure will build up when an obstruction, even in the shape of a squarely bent tube with its opening against the direction of flow is placed in the pipe.

The kinetic energy of the liquid is converted or transformed into pressure energy. The difference between the pressure of the liquid against the wall of the pipe (the static pressure) and the velocity pressure (or kinetic pressure) gives an indication of the flow rate.

With the bent tube in the liquid stream where the velocity is the highest (this must be determined experimentally for each system), and the other tube on the internal wall of the tube, the largest difference in pressure can be measured and this measurement will be more accurate.

A simple pitot tube is illustrated in the following sketch. Other shapes are also available, but the results do not differ much.

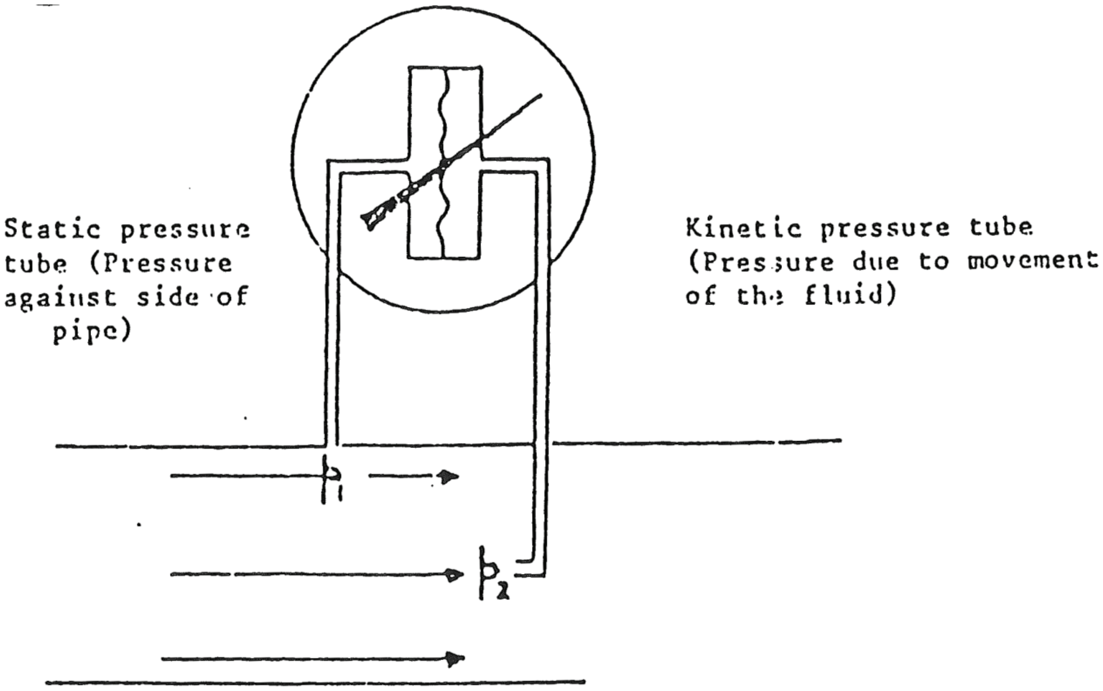


Figure 4.38 A simple pitot tube installed

Advantages

- It is cheaper than most other meters.
- It is easier to replace.
- It gives a very small pressure loss.
- Depending on the type of liquid, any type of metal tube can be used for it.

Disadvantages

- The pipe blocks up easily if the liquid contains solids.
- The high pressure tube must be placed exactly parallel in the pipe, otherwise it will affect the reading.

4.16 Rotameters

The name of the meter creates the impression that it has something to do with rotation, but this is not the case. The internal cross-sectional area of the tube changes as the tube tapers and the flow is determined as follows:

The tapered tube is mounted vertically in the line with the wide side up. The tube is graded, that is a scale is affixed to it and a small weight or heavy "float" is lifted by the liquid stream to a position where the downward pressure of the float balances the upward pressure of the liquid.

The reading is then taken on the scale, directly opposite to the float.

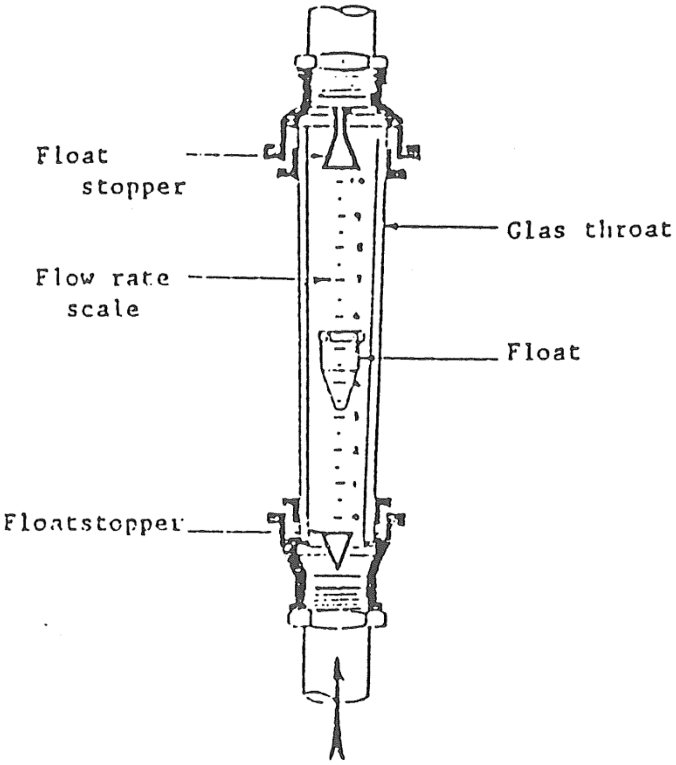


Figure 4.39 Diagram of glass shell adjustable surface meter

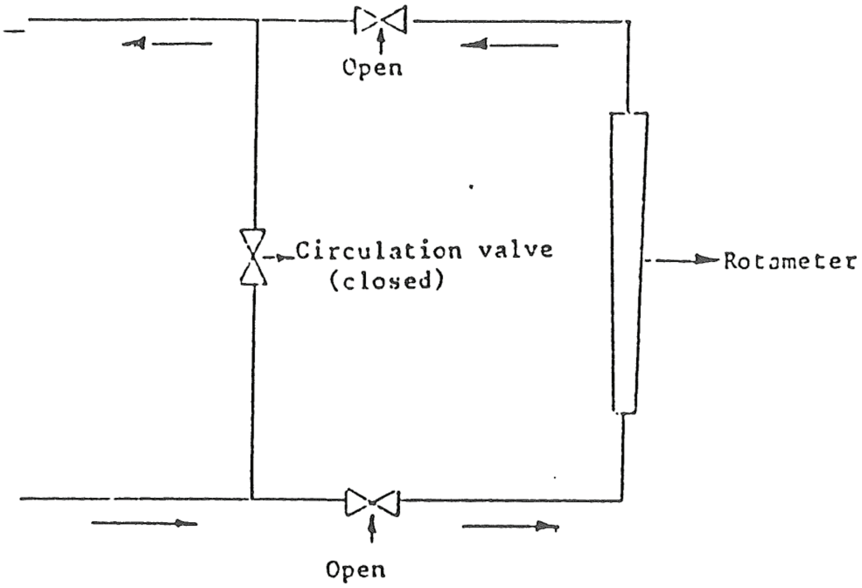


Figure 4.40 Installation of rotameter

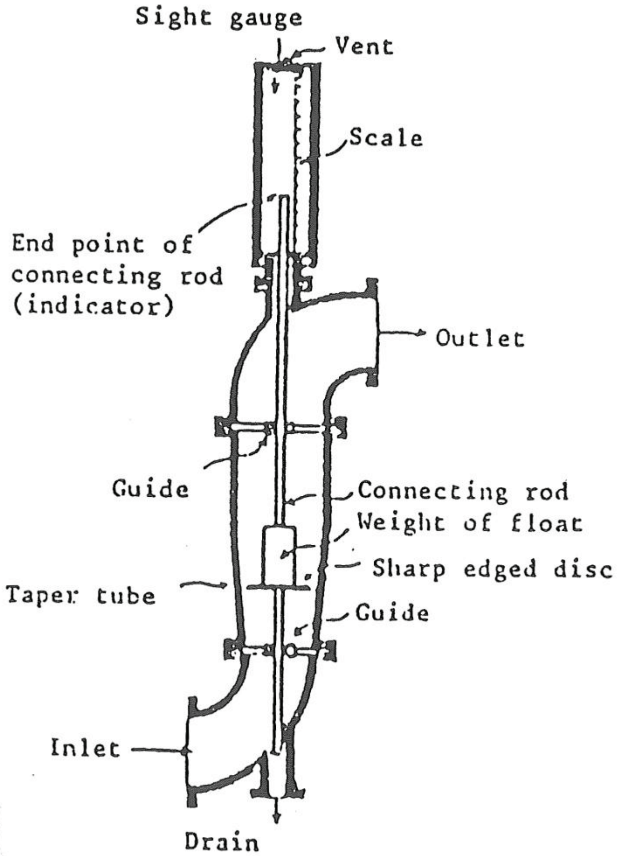


Figure 4.41 Rotameter with metal tube

This type of rotameter is used where the pressure of the system is high or where the liquid flowing through it is not transparent. The float of some of the types is heavy or spring-loaded when thick viscous liquids are handled.

The scale and float should be adjusted for each of the liquid types. Various sizes are available for various rates of flow.

4.17 Measurement of liquid level

Measurement of the liquid levels in containers can be classified into five groups:

1. Mechanical and general
2. Pneumatic (air)
3. Electric
4. Electronic
5. Nucleonic

The method to be applied naturally depends on the characteristics of the liquid, for example acid, base, viscosity, colour or transparency, density, and also on the type of container, its height and shape.

The best known method of measuring level is by means of the dip-stick, of which at least one is to be found in each motor, lorry or tractor.

Other simple methods are the float system and sight-glass methods.

For the purposes of this course, we confine ourselves to two methods of direct and two methods of indirect level measurement.

4.17.1 The sight-glass

There is a large variety of shapes and types of sight-glasses on the market, the most important being the tube type and window type.

It is essential that the isolating valves in **Figure 4.42** should both be open to obtain correct readings. Should the top one be closed, the liquid will not be able to rise freely in the glass tube as a quantity of gas or air in the glass will exert pressure on it, leading to a faulty reading.

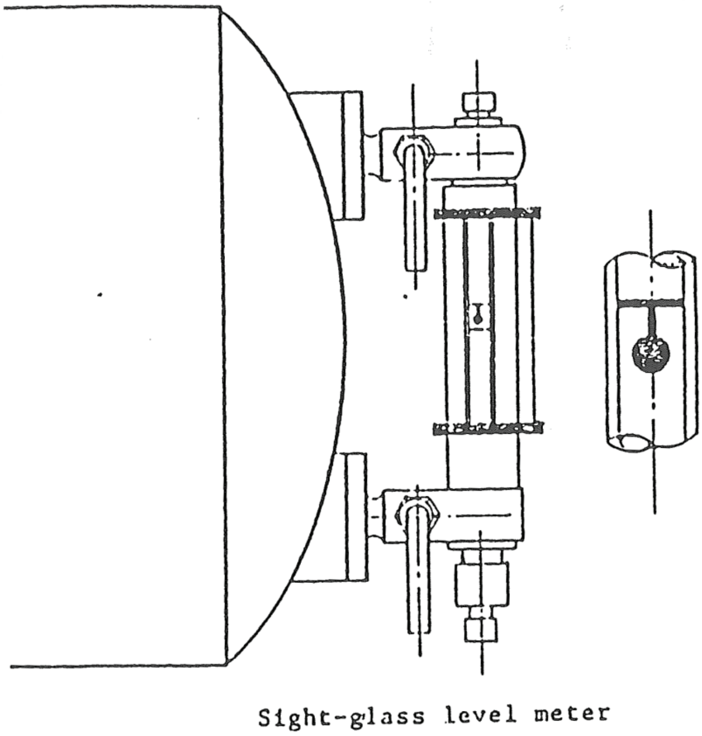


Figure 4.42 Tube type of sight glass

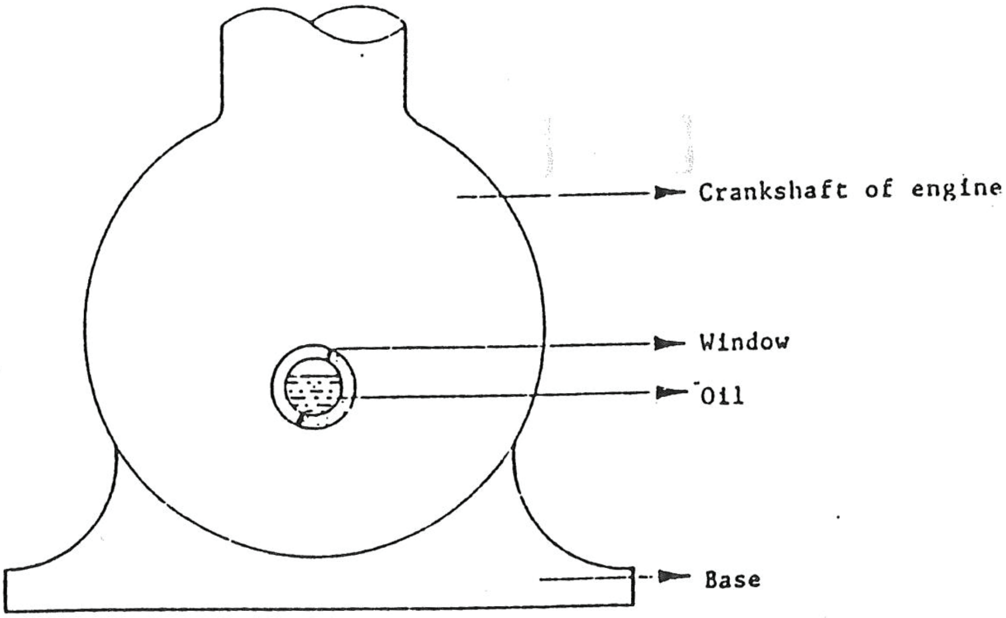


Figure 4.43 Window type of sight glass

If the bottom valve is kept closed, the liquid cannot move up the tube through the valve and the reading will again be wrong.

Long glass tubes are seldom used as they break very easily. When clear, transparent liquids are measured, it is sometimes difficult to see the level in the tube and, consequently, a small float is introduced into the tube. This floats on the liquid and makes it easier to take the reading.

4.18 Float Systems

There are many types and we are going to discuss a type suitable for open containers and a type which can be used for closed containers, usually under internal pressure.

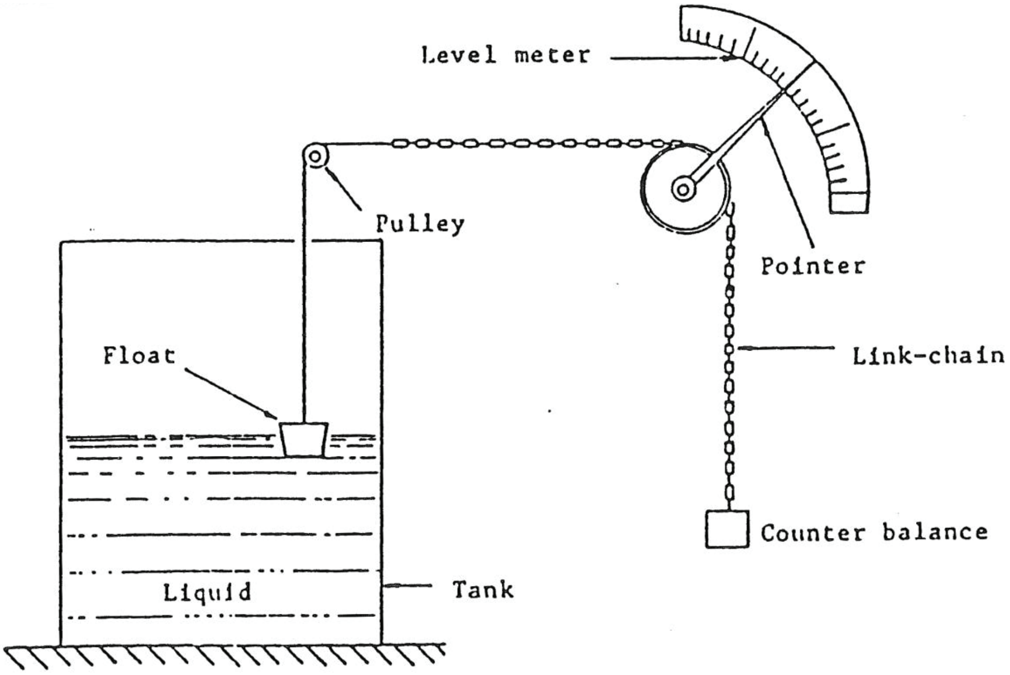


Figure 4.44 Float level meter

The cable to which the float and counterbalance are attached is wound round a drum to eliminate slip and while the float moves up and down, the drum with pointer turns, indicating the level.

The counter balance keeps the cable tense and cancels the weight of the floating float. The float is heavier than the counter balance.

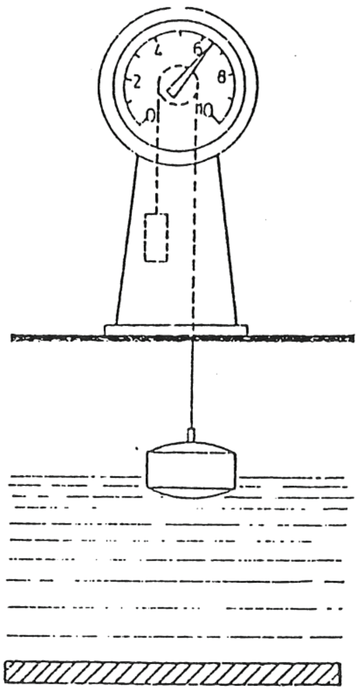


Figure 4.45 Open tank float type meter

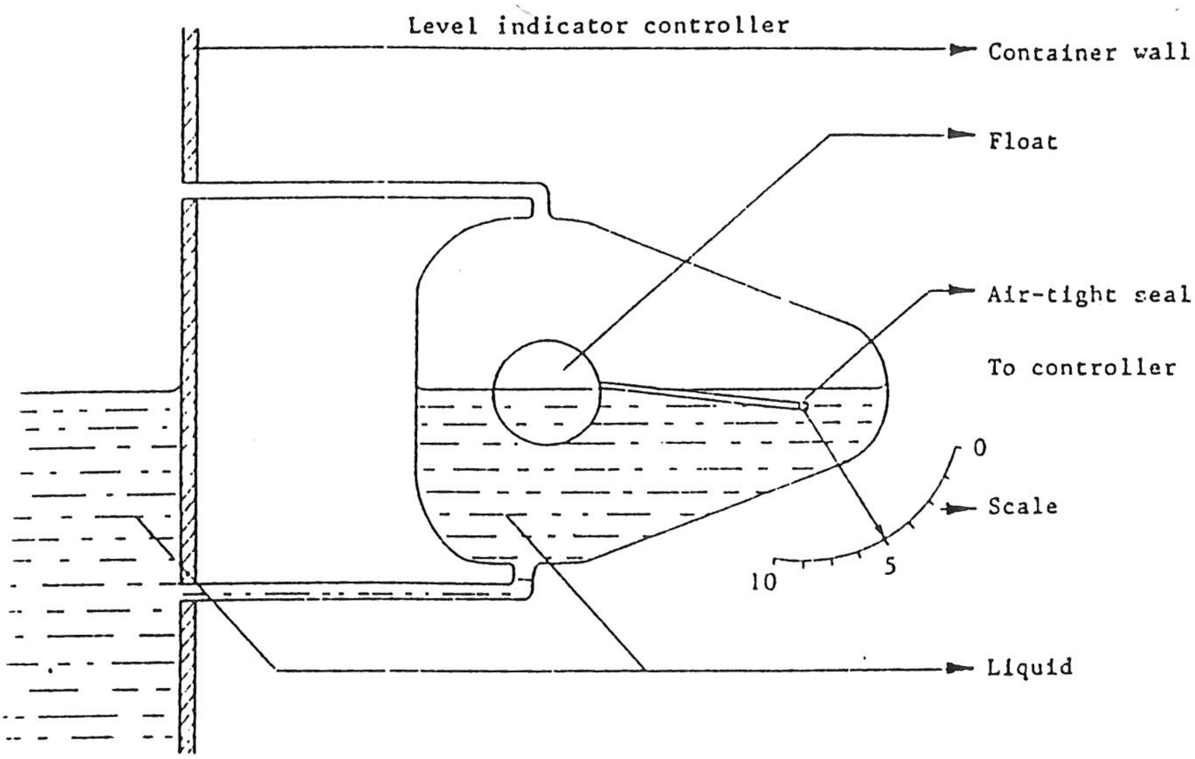
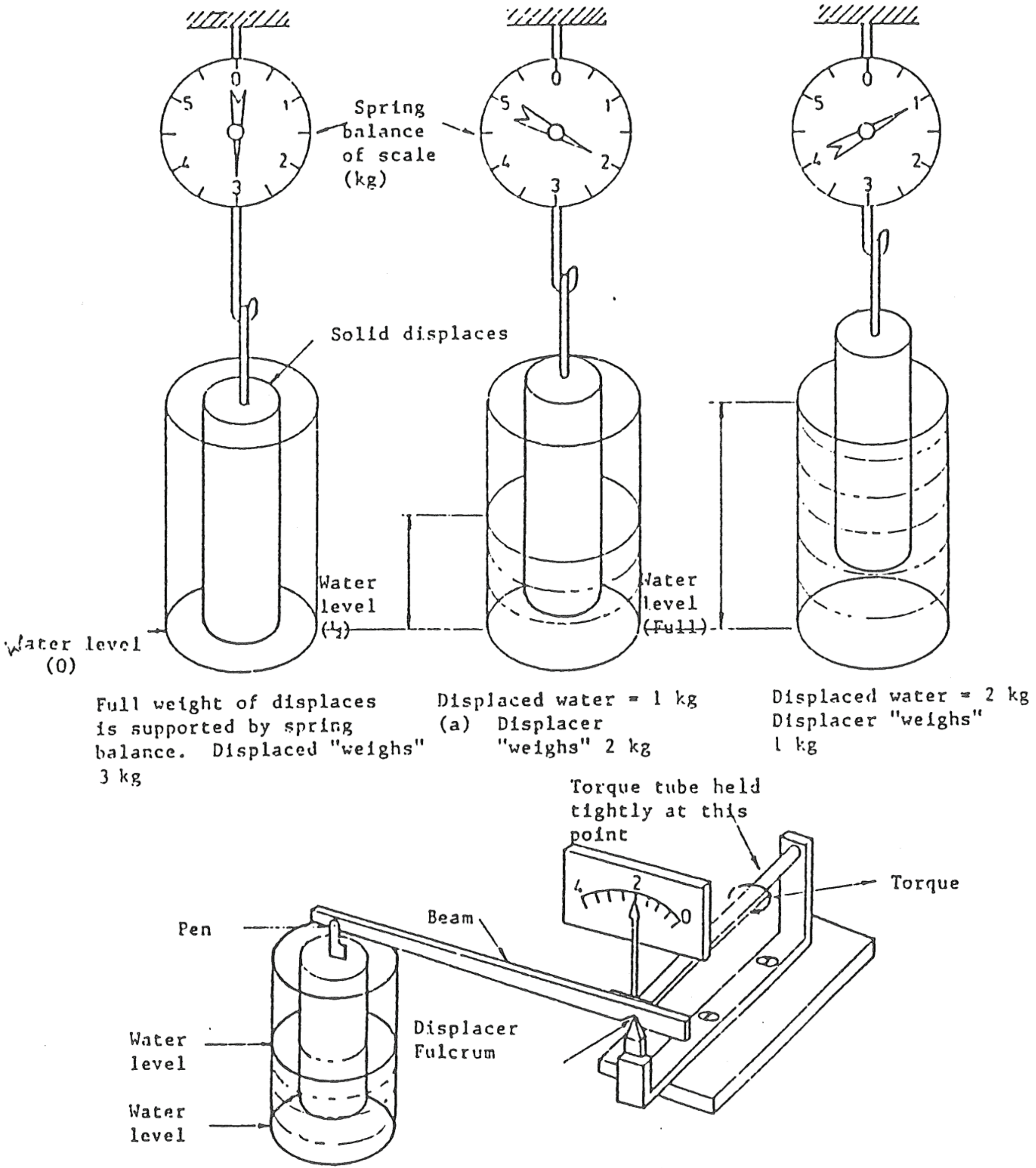


Figure 4.46 Float system closed container

In this system the level can be indicated electrically if the float changes the resistance of a resistance element while the level changes, or if the float rotates a small shaft to which it is coupled; a pointer moving across a scale is attached to the small shaft. When the container is under pressure it will make no difference to the operation and the whole should be properly pressure tight.



(a) Principle of adjustable displacement meter
(b) Basic operation of adjustable displacement meter
(Mason-Neilan Division of Worthington (Canada) Ltd)

Figure 4.47 Displacement type level meter

When a heavy object is immersed into a liquid it experiences an apparent loss of mass as a result of the upward pressure of the liquid against the object. The loss of mass is equal to the liquid being displaced (Law of Archimedes).

The more displacement there is, the larger the apparent loss of weight, consequently the apparent mass of the float in the liquid will be an indication of the level in the container.

If the float is long and fairly heavy, a change in level of a few metres will only entail an upward displacement of a few centimetres of the float.

The indicator can be an ordinary spring-balance type of instrument if the container is open, or a torsion bar which is fixed at the side furthest from the float while the other end is passed through a seal and a bush to the outside to turn a pointer.

The scale will change when the density of the liquid (type of liquid) changes.

4.19 Measurement of level by means of pressure difference

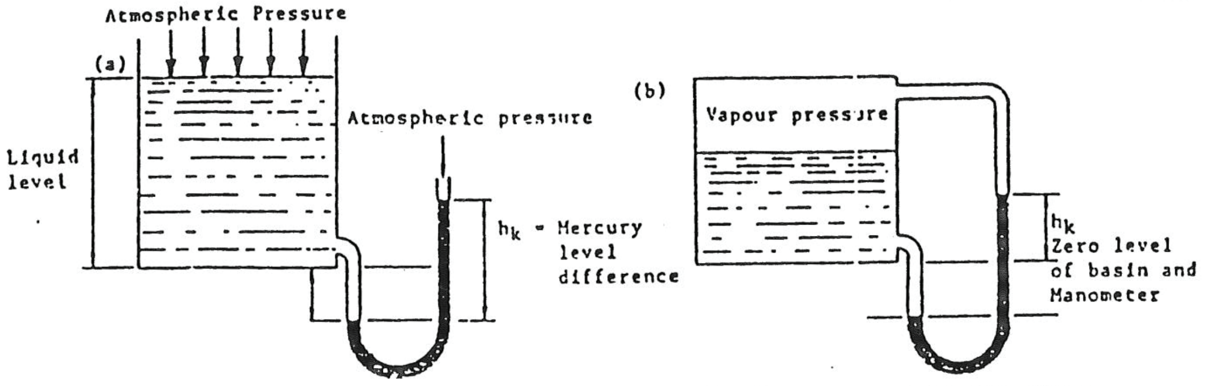
You have already seen that the pressure a column of liquid exerts depends on the density of the liquid and the height of the column.

(The formula $P = pgh$)

In **Figure 4.48 (a)** the container, as well as one leg of the manometer is open to the atmosphere.

Figure 4.48 (b) the container under pressure is the vapour pressure of the liquid in the container. The one leg of the manometer is then connected to this pressure at the top so that the pressure acts on both legs and thus cancels it.

Provision is made for the height between the bottom of the container and the manometer liquid so that the reading is only in respect of the level in the container.



Static pressure operating system (Simple)

Static pressure operating system (Closed system)

Figure 4.48 Measuring of level by means of manometers

As the U-tube manometer breaks so easily, it is not unusual to substitute a mechanical type of meter for it, for example, a diaphragm type.

One side of the diaphragm is connected to the bottom of the container with the result that the liquid presses against it and the other side is handled according to the system's requirements. A pointer which is manipulated by the diaphragm indicates the level.

4.20 Metal Expansion

When a metal is heated, it expands, one end of a bar can thus be attached inside a boiler in such a manner that it is partially in the water and partially in the steam above the water. The free end is attached to a valve or regulator which controls the level of the liquid.

As the level rises or drops, the length of the bar changes as a result of the part of the bar which is in contact with the higher temperature steam so that it can expand or contract, thus manipulating the regulator.

4.21 Nucleonic type of level meter

It is often necessary to measure the level of dangerous liquids, ie. acids. The conventional methods are then not always suitable and a less dangerous system has to be used.

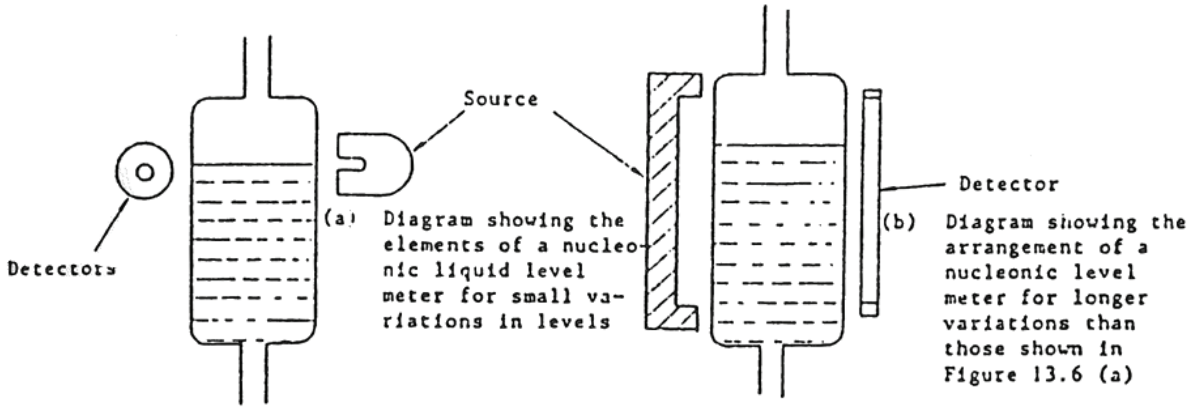


Figure 4.49 Nucleonic level meter

The system consists of a radio actived source, for example, cesium or cobalt which radiates beta or gamma rays which are intercepted by a tracer or receiver.

The container is completely opaque and the rays penetrate it. The liquid absorbs some of the rays so that the quantity or density of the rays reaching the receiver depends on the height of the liquid.

	Activity 4.1
1. Name the elements of measurement with an applicable example of each element.	

2. State the relative advantages and disadvantages of venture tubes.
3. Explain the principle of operation of the rotameter as flow meter.
4. Sketch a pressure type thermometer and briefly explain the operation.
5. A pressure gauge indicates the pressure in a system to be -26,3 kPa. Calculate the absolute equivalents of that pressure in mm. Hg if it is measured at sea level

Activity 4.2

1 Indicate ***TRUE*** or ***FALSE***

1.1 pH measuring refers to a quality variable.
1.2 The electrodes of a pH meter refer to a transfer element.
1.3 A bourdon tube can be used to measure pressure.
1.4 A manometer can be used for calibration of an orifice.
1.5 263 K equals 10 °C.
1.6 m^3/sec refers to a rate variable.
1.7 A dead mass tester is based on the principles of Dalton's law.
1.8 A pressure type thermometer is based on Charles' law.
1.9 A nucleonic type level meter is suitable to measure the steam level of high pressure boilers.
1.10 280 Kelvin = 10°F.
1.11 Diaphragm meters are highly suitable to measure pressure differences.
1.12 The dead mass tester works on the principles of Archimedes law.
1.13 Flow rate meters are based on Bernoulli's theory.
1.14 A rotameter is a good example of a positive displacement meter.

Activity 4.3

1. Explain with examples, what absolute pressure and absolute temperature mean.
2. Explain the most importance requirement for effective control of any process.
3. Explain how the linear expansion of metals is used for measuring temperature.
4. Sketch the thermometer as it would be constructed in question 3.
5. Sketch and explain the operation of a rotameter.

Activity 4.4

1. Explain what flow rate meters are.
2. State the advantages and disadvantages of the pitot tube.
3. Sketch a spiral type bimetal thermometer and briefly explain its operation.

Activity 4.5

1. Process energy variables refer to the internal energy of materials. Name and explain this internal energy of materials as process variables. Give an applicable secondary measuring element and give a unit of measurement.
2. Convert 263 Kelvin to °C.
3. State the law of Archimedes.
4. Sketch a level gauge operating on the principle of Archimedes. Indicate its position at ***TWO*** levels.
5. Calculate the scale reading on the inclined leg of a manometer if the angle of inclination is 40°C and the vertical mercury level differs with 160 mm. Use the following information to do the calculation. Sin 40°C = 0,643.
6. Sketch a spiral type bimetal thermometer and briefly explain its operation.

Activity 4.6

1. Calculate the difference in mercury levels of a U-tube manometer if the differential pressure is 85 kPa.
2. Sketch a pressure type thermometer and briefly explain its operation.
3. Sketch a venturi tube indicating the flow direction with installation.
4. State the advantages of using venture tubes.
5. Name the ***TWO*** well-known methods that are used to calibrate pressure gauges.

Self-Check

I am able to:	**Yes**	**No**
• Describe the history of instruments and controls		
• Process the following variables with their measurements:		
o Energy variables: pressure and temperature		
o Number and temperature variables: fluid flow, liquid level and weight		
• Identify and describe the following elements of measurement:		
o Primary e.g. pH electrode or thermometer ball		
o Transfer element e.g. a small tube or electrical wire		
o The instrument itself e.g. a manometer or potentiometer		
• Identify and name indicator and recording instruments		
• Describe the measurement of pressure (negative and positive) using:		
o Open U-tubes		
o Differential U-tubes		

o Manometers		
o Barometers		
o Bourdon tubes		
o Diaphragm meters		
o Bellow Gauges		
• Explain the calibration of pressure meters		
• Describe temperature measurement using the following:		
o Bi-metal thermometers		
o Liquid and glass thermometers		
o Pressure type thermometers		
o Thermocouples		
• Describe flow measurement using the following:		
o Positive transfer meters		
o Flow rate meters		
o Hole plates		
– Normal		
– Ventura tube		
– Piton tube		
o Rotameters		
• Describe liquid level measurement in terms of the following:		
o Silk glass, float, pressure difference and metal expansion		
o Float		
o Pressure difference		
o Metal expansion		
If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Past Examination Papers

higher education
& training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

NOVEMBER 2011

NATIONAL CERTIFICATE

PLANT OPERATON THEORY N2

(**11040012**)

15 November (X-Paper)
09:00 – 12:00

REQUIREMENTS:

Candidates will require drawing instruments, pens and a ruler.

Calculators may be used.

This question paper consists of 5 pages and a 1-page formula sheet.

TIME: 3 HOURS
MARKS: 100

INSTRUCTIONS AND INFORMATION

1. Answer ALL the questions.
2. Read ALL the questions carefully.
3. Sketches must be large, neat and fully labelled.
4. 100 marks: 100%.
5. Number the answers correctly according to the numbering system used in this question paper.
6. Write neatly and legibly.

QUESTION 1: CHEMISTRY

1.1 Indicate whether the following statements are TRUE or FALSE. Write only 'true' or 'false' next to the question number (1.1.1 - 1.1.5) in the ANSWER BOOK. (5)

1.1.1 Atoms with the same number of protons and neutrons in the nucleus are called isotopes.
1.1.2 The atomic mass of Ca is 40 amu.
1.1.3 Electrons have a positive charge.
1.1.4 An electrovalent bonding refers to covalent bonds.
1.1.5 CO is slightly soluble in water.

1.2 Determine the molecular mass of CH_3OONa and show your calculations. (5)

1.3 With the aid of an appropriate chemical reaction, explain a method for the preparation of hydrogen by means of an acid. (6)

1.4 Give the IUPAC name of paraffin and acetylene and give the formula for each. (4)

1.5 Explain what the following formula represents: $3C_2H_6$. (3)

1.6 State **TWO** characteristic properties of Hydrogen. (2)

[25]

QUESTION 2: ENERGY AND FLUID FLOW

2.1 Indicate whether the following statements are TRUE or FALSE. Write only 'true' or 'false' next to the question number (2.1.1 - 2.1.5) in the ANSWER BOOK. (5)

2.1.1 Latent heat of evaporation refers to heat required to change the state of a liquid at constant temperature.
2.1.2 Work= force x distance through which the heat moves.
2.1.3 Roughness on the inside of a pipe causes resistance of flow.
2.1.4 Temperature will influence the viscosity of a fluid.
2.1.5 The density of a fluid is the quantity of the fluid per unit volume.

2.2 Briefly discuss tidal force and its utilisation. (4)

2.3

2.3.1 Calculate the energy liberated by a tamper if it reaches a velocity of 8 metres per second and weighs 80 kg. (3)

2.3.2 From what height must it be dropped to generate the same amount of energy? (3)

2.4 A pump delivers 280 tons of fresh water at a height of 15 metres in 90 minutes.

Calculate the following:

2.4.1 Power output of the pump in kW (4)
2.4.2 Efficiency of the pump with an input power of 12 kW (2)

2.5 Explain how viscosity of a fluid is determined and name the unit in which it is measured. (4)

[25]

QUESTION 3: DISTILLATION AND FRACTIONATION

3.1 Indicate whether the following statements are TRUE or FALSE. Write only 'true' or 'false' next to the question number (3.1.1 - 3.1.5) in the ANSWER BOOK. (5)

3.1.1 In the stripping section of a distillation tower the heavy products also became vapour.

3.1.2 When a vapour mixture is cooled and only a part is condensed and the condensate contains a greater quantity than the one fluid then the other is referred to as partial evaporation.

3.1.3 Bottom products refer to the heavy product that is tapped from the bottom of a distillation tower.

3.1.4 An increase in pressure in a fractionation tower has the opposite effect and therefore requires less energy to obtain the same amount of vapour.

3.1.5 A packed tower is a typical example of a fractionation tower.

3.2 Explain temperature gradient as control variable for effective operation of a distillation tower to produce high quality products. (5)

3.3 Explain the difference between fractionation and distillation. (2)

3.4 Draw a controller operating on the principle of vapour pressure. (9)

3.5 Discuss the causes and consequences of too much vapour in a fractionation tower. (4)

[25]

QUESTION 4: INSTRUMENTATION

4.1 Indicate whether the following statements are TRUE or FALSE. Write only 'true' or 'false' next to the question number (4.1.1 - 4.1.5) in the ANSWER BOOK. (5)

4.1.1 263 K equals 10℃
4.1.2 m^3/sec refers to a rate variable
4.1.3 A dead mass tester is based on the principles of Dalton's law.
4.1.4 A pressure type thermometer is based on Charles's law.
4.1.5 A nucleonic type level meter is suitable to measure the steam level of high pressure boilers.

4.2 Explain what flow rate meters are. (8)

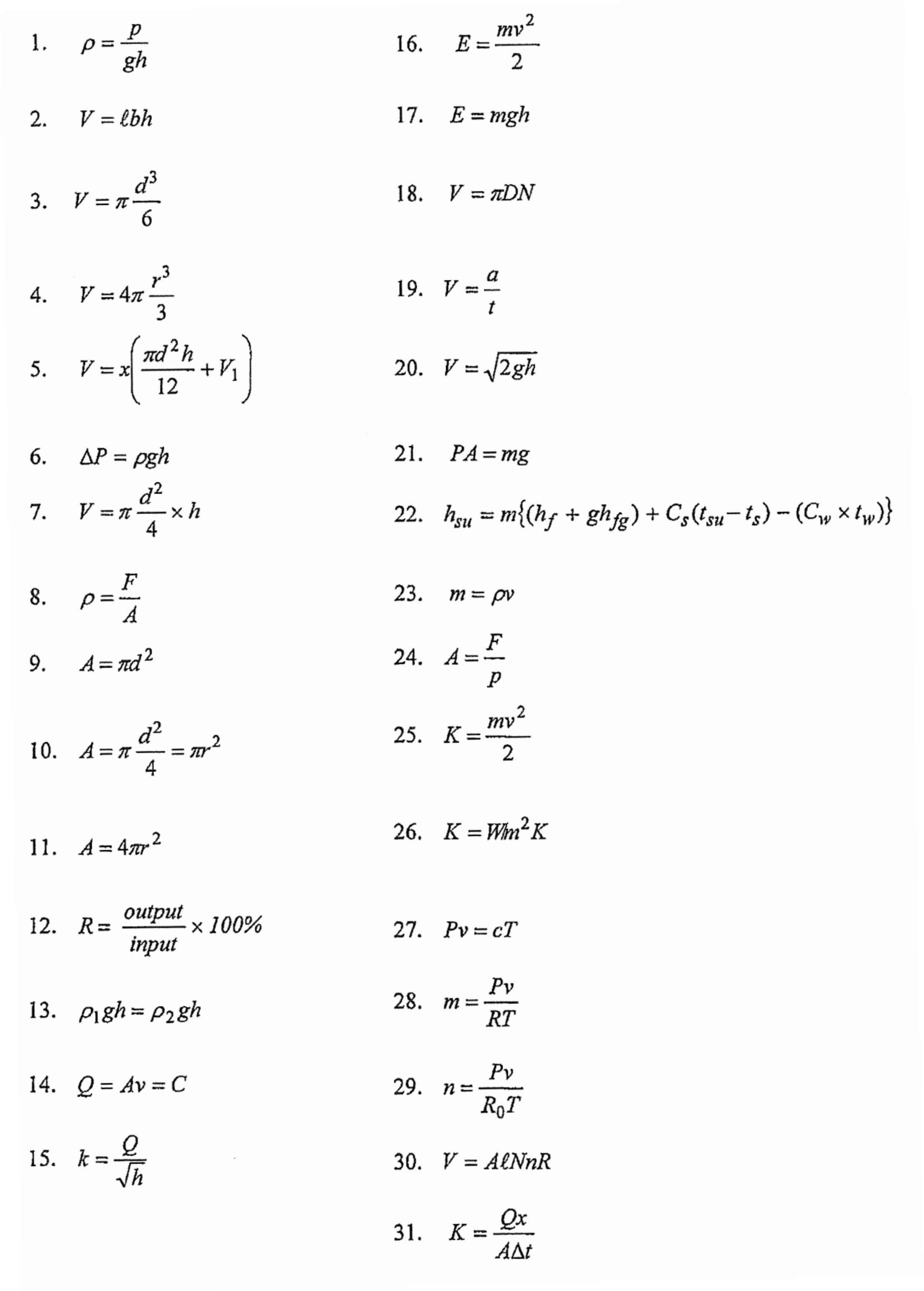
4.3 State the advantages and disadvantages of the pitot tube. (6)

4.4 Sketch a spiral type bimetal thermometer and briefly explain its operation. (6)

[25]

TOTAL: 100

FORMULA SHEET



1. $\rho = \frac{p}{gh}$
2. $V = \ell bh$
3. $V = \pi \frac{d^3}{6}$
4. $V = 4\pi \frac{r^3}{3}$
5. $V = x\left(\frac{\pi d^2 h}{12} + V_1\right)$
6. $\Delta P = \rho gh$
7. $V = \pi \frac{d^2}{4} \times h$
8. $\rho = \frac{F}{A}$
9. $A = \pi d^2$
10. $A = \pi \frac{d^2}{4} = \pi r^2$
11. $A = 4\pi r^2$
12. $R = \frac{output}{input} \times 100\%$
13. $\rho_1 gh = \rho_2 gh$
14. $Q = Av = C$
15. $k = \frac{Q}{\sqrt{h}}$
16. $E = \frac{mv^2}{2}$
17. $E = mgh$
18. $V = \pi DN$
19. $V = \frac{a}{t}$
20. $V = \sqrt{2gh}$
21. $PA = mg$
22. $h_{su} = m\{(h_f + gh_{fg}) + C_s(t_{su} - t_s) - (C_w \times t_w)\}$
23. $m = \rho v$
24. $A = \frac{F}{p}$
25. $K = \frac{mv^2}{2}$
26. $K = Wm^2K$
27. $Pv = cT$
28. $m = \frac{Pv}{RT}$
29. $n = \frac{Pv}{R_0 T}$
30. $V = A\ell NnR$
31. $K = \frac{Qx}{A\Delta t}$

Marking Guidelines

higher education
& training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

NOVEMBER 2011

NATIONAL CERTIFICATE

PLANT OPERATION THEORY N2

(11040012)

QUESTION 1: CHEMISTRY

1.1 TRUE OR FALSE (5)

1.1.1 False
1.1.2 True
1.1.3 False
1.1.4 False
1.1.5 True

1.2 **Molecular mass of CH_3OONa:** (5)

$C: 1 \times 12 = 12$
$\mathrm{H}: 3 \times 1 = 3$
$\mathrm{O}: 2 \times 16 = 32$
$\mathrm{Na}: 1 \times 23 = 23$
$\mathrm{Total} = 70\ \mathrm{amu.}$

1.3 **Hydrogen preparation with the aid of an acid:** (6)

A ***metal removed hydrogen*** from an acid when it reacts. Through for example a small portion of iron ***filings*** in a flask. Ad ***slowly drop by drop diluted acid (H2S04)*** on it and catches the gas that formed by the down words displacement of the air.

Reaction: $\boldsymbol{Fe} + \boldsymbol{H2S04} = FeS04 + \boldsymbol{H2}\ (\boldsymbol{gas})$

Anv other correct answer is acceptable

1.4 **IUPAC name:** (4)

Paraffin's = $Alkanes - C_nH_{2\,n}\ ^{+2}$
Acetylene = $Alkynes - C_nH_{2\,n}\ ^{-2}$

1.5 **$3C_2H_6$ represent the following:** (3)

3 Molecules ethane formed form a chemical bond from ***2 atoms carbon*** and ***6 atoms hydrogen.***

1.6 **Properties of hydrogen:** (2)

- It is a colorless, odorless and a tasteless gas.
- In chemistry it is the lightest matter (lighter than air).
- It burns in air but does not maintain combustion.
- It burns with air to form water.
- It is a reducing agent.
- It combines actively with halogens.

ANY 2

[25]

QUESTION 2: ENERGY AND FLUID FLOW

2.1 TRUE OR FALSE

2.1.1 True (1)
2.1.2 False (1)
2.1.3 True (1)
2.1.4 True (1)
2.1.5 False (1)

2.2 **Tidal force:** (4)

Tidal force refers to ***energy of water in motion,*** which is utilised to ***generate electricity.*** In this case, the energy of the water in motion due to ***tidal changes*** of the sea is used. An important prerequisite is that the ***tidal height between high and low tied must be significant.***

2.3 **Energy calculation:**

2.3.1 (3)

$$Ke = \frac{1}{2} m\,V^2$$
$$Ke = \frac{1}{2} \times 80 \ \times 8 \times 8$$
$$Ke = \ \mathbf{2560\ Joule\ or\ 2,56kJ}$$

2.3.2 (3)

$$Pe \quad = Ke$$
$$2560 = mgh$$
$$h \quad = \frac{2560}{80} \times 9{,}81$$
$$= \boldsymbol{3,262\ metre}$$

2.4 **Pump calculations:**

2.4.1 (4)

$$Output = \frac{Ke}{t} = \frac{Pe}{t}$$
$$Pe = mgh$$
$$= \frac{280 \ \times 1000 \times 9{,}81 \ \times 15}{90 \ \times 60}$$
$$= 7630\,Watt$$
$$= \boldsymbol{7,63\ kW}$$

2.4.2 (2)

$$R = \left(\frac{Output}{Input}\right) \times 100\%$$
$$= \frac{7{,}63}{12}$$
$$= 63{,}58\%$$

2.5 **Determined viscosity:** (4)

- A ***ball with a specific mass is dropped*** in a glass tube filled with liquid
- The ***time taken for the ball to reach the bottom*** of the tube is measured
- This is then the viscosity of the liquid, in other words the ***longer the time taken the higher the viscosity.***

- Viscosity is measured in ***poise or stokes.***

[25]

QUESTION 3: DISTILLATION AND FRACTIONATION

3.1 TRUE OR FALSE (5)

3.1.1 False
3.1.2 True
3.1.3 True
3.1.4 False
3.1.5 True

3.2 **Temperature gradient as control variable:** (5)

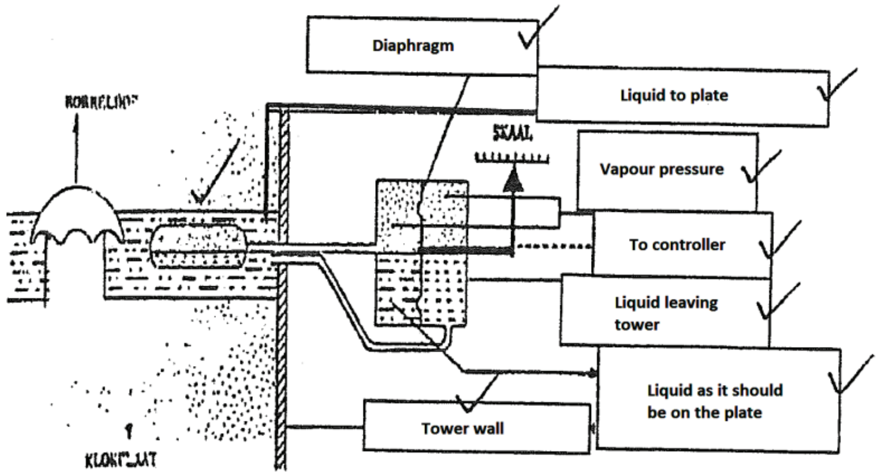
The effective temperature gradient of a distillation tower will be determent by the ***heat balance*** and the ***composition of the feed.***
The temperature gradient refers to the deference between ***the top and bottom temperature of the tower.*** To produce (refine) the purist top and bottom products it is of great importance that:

- The ***maximum heat input*** through the re-boiler apply, and
- ***Maximum reflux is maintained*** without over flowing of the tower.

3.3 **Fractionation vs. Distillation:** (2)

Fractionation is the separation of a liquid mixture into ***various compounds or side fractions***, while ***distillation*** is the separation of a liquid mixture into *an* ***overhead and bottom product only.***

3.4 **Vapour pressure controller** *(Sketch):* (9)



3.5 **Too much vapour:** (4)

Causes:

- The rate of evaporation increase due to ***too high temperature and /or too low pressure***
- Too high-pressure difference through the bubble caps inhibits the ***down flow***

and drainpipes get filled.

Consequences:

- Instead of the liquid foaming vapour, it is ***carried overhead and the tower "spits"***
- The overhead product then contains **too *much heavy components and is not pure.***

[25]

QUESTION 4: INSTRUMENTATION

4.1 TRUE OR FALSE (5)

4.1.1 False
4.1.2 True
4.1.3 False
4.1.4 True
4.1.5 False

4.2 **Flow rate meters** (8)

($\frac{1}{2}$ mark per correct answer):

- Flow rate meters indicate both the ***amount of fluid*** as well as ***the time taken*** for the fluid to ***flow through the meter.***
- The flow rate is proportional to the:
  - a) ***linear velocity*** of the fluid through the pipe
  - b) ***difference in pressure*** over a stricture in the pipe
  - c) ***square root*** of the difference in pressure.
- The principle on which the flow meter works boils down to that:
  - a) when a liquid flows in a pipe and ***the cross section changes*** than the ***velocity of the liquid changes*** and
  - b) than the ***pressure of the liquid changes accordingly***.
- The ***meter that causes the difference in pressure*** is called the ***primary flow meter*** or ***primary element*** and
- The ***meter used to measure the difference in pressure*** over the primary element is called ***the secondary flow meter or element***.
- Both these elements must ***be used together*** to measure ***flow rate*** and cannot be ***used separately*** for this purpose.

4.3 **Pitot tube:** (6)

Advantages:

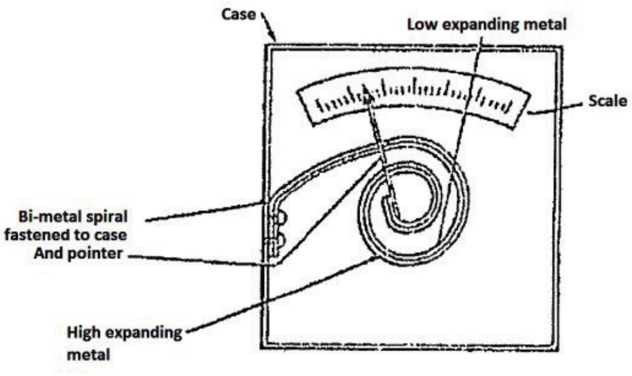
- It is ***cheaper*** than most other
- It is ***easier to replace***
- It gives a very ***small pressure loss*** and
- Depending on the type of liquid, ***any type of metal tube can be used.***

Disadvantages:

- The tube / pipe ***blocks up easily*** if the liquid contains solids
- The high-pressure tube must be ***placed exactly parallel*** in the pipe otherwise it will affect the reading.

4.4 **Type bimetal thermometer:**

(4)



(2)

Discussion:
Two metals with ***different linear expansion are used***. The one with the ***high expansion coefficient will bend the spiral.*** The movement from the free end is transfer on a scale, which reflects the temperature.

[25]

TOTAL: 100

Past Examination Papers

higher education
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Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

AUGUST 2011

NATIONAL CERTIFICATE

PLANT OPERATION THEORY N2

(**11040012**)

29 July (X-Paper)
09:00 – 12:00

REQUIREMENTS:

Candidates will require drawing instruments, pens and a ruler.

Calculators may be used.

This question paper consists of 5 pages and a 1-page formula sheet.

TIME: 3 HOURS
MARKS: 100

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1. Answer ALL the questions.

2. Read ALL the questions carefully.

3. Number the answers correctly according to the numbering system used in this question paper.

4. Sketches must be large, neat and fully labelled

5. 100 marks: 100%

6. Write neatly and legibly.

QUESTION 1: CHEMISTRY

1.1 Indicate whether the following statements are TRUE or FALSE. Choose the answer and write only 'true or false' next to the question number (1.1.1 -1.1.5) in the ANSWER BOOK. (5)

1.1.1 A molecule refers to the smallest particle of a compound.
1.1.2 In the periodic table, elements with the same number of energy levels are grouped horizontally in periods from left to right.
1.1.3 Oxygen contains 16 neutrons.
1.1.4 CH_4 is a component in natural gas.
1.1.5 NH_3 is a cleaning agent to remove fats and oils.

1.2 Determine the molecular mass of Ca $(OH)_2$ and show your calculations. (4)

1.3 Describe each of the following:

1.3.1 Atomic mass (2)
1.3.2 Isotope (2)

1.4 Describe a test to identify H_2. (5)

1.5 Sketch the complete structure of a phosphorus atom, showing the number of orbitals, their shape and number of electrons. (5)

Complete the following chemical equation: (2)

$$2K + \cdots H_2O \quad = 2KOH + \cdots \uparrow$$

[25]

QUESTION 2: ENERGY AND FLUID FLOW

2.1 Indicate whether the following statements are TRUE or FALSE. Choose the answer and write only 'true or false' next to the question number (2.1.1 - 2.1.5) in the ANSWER BOOK. (5)

2.1.1 The physical conditions do not change when heat is applied on matter.
2.1.2 Power refers to the work done per mass.
2.1.3 Change in pipe direction causes resistant of flow in pipe systems.
2.1.4 Pressure will influence the viscosity of a fluid.
2.1.5 The stripping section refers to the top section of a distillation tower.

2.2 A pump delivers fluid with a density of 900 kg/m^3 into the bottom of an open container. The maximum height is 10 meters above the pump. The depth/height of the container is 2 meters. (4)

Calculate the delivery pressure of the pump. Ignore the friction and the suction pressure.

2.3 Explain how the density of a liquid may cause a loss of pressure in a pipe. (3)

2.4 Determine the water flow in a pipe, when the differential pressure across an orifice is 12,5 kPa. When the pressure difference across the same orifice is 24,5 kPa, the flow is 15,4 m^3 per hour. (5)

2.5 Name and explain **TWO** types of energy that bodies can have. (4)

2.6 Explain **FOUR** effects of heat on a substance. (4)

[25]

QUESTION 3: DISTILLATION AND FRACTIONATION

3.1 Indicate whether the following statements are TRUE or FALSE. Choose the answer and write only 'true or false' next to the question number (3.1.1- 3.1.5) in the ANSWER BOOK. (5)

3.1.1 Evaporation is the opposite of distillation.
3.1.2 The rectification section refers to the top section above the feed inlet of a distillation tower.
3.1.3 The top product is often a thick tar type of liquid in a distillation tower.
3.1.4 Too much water condensate can cause flooding of a fractionation tower.
3.1.5 Absorbers are classified as a type of packed towers.

3.2 Explain the difference between *strippers* and *absorbers.* (4)

3.3 Explain *heat balancing.* (8)

3.4 Explain the control and effect of pressure in a fractionation column. (6)

3.5 State **FOUR** possible problems encountered when operating a fractionation tower. (2)

[25]

QUESTION 4: INSTRUMENTATION

4.1 Indicate whether the following statements are TRUE or FALSE. Choose the answer and write only 'true• or 'false'. next to the question number (4.1.1-4.1.5) in the ANSWER BOOK. (5)

4.1.1 pH measuring refers to a quality variable.
4.1.2 The electrodes of a pH meter refer to a transfer element.
4.1.3 A Bourdon tube can be used to measure pressure.
4.1.4 A manometer can be used for calibration of an orifice.
4.1.5 A Venturi tube costs relative more than a orifice.

4.2 Explain with examples, what absolute pressure and absolute temperature mean. (4)

4.3 Explain the most important requirement for effective control of any process. (3)

4.4

4.4.1 Explain how the linear expansion of metals is used for measuring temperature. (3)
4.4.2 Sketch the thermometer as it would be constructed in QUESTION 4.4.1. (2)

4.5 Sketch and explain the operation of a rotameter. (8)

[25]

TOTAL: 100

FORMULA SHEET

1. $\rho = \frac{p}{gh}$

2. $V = \ell bh$

3. $V = \pi \frac{d^3}{6}$

4. $V = 4\pi \frac{r^3}{3}$

5. $V = x\left(\frac{\pi d^2 h}{12} + V_1\right)$

6. $\Delta P = \rho gh$

7. $V = \pi \frac{d^2}{4} \times h$

8. $\rho = \frac{F}{A}$

9. $A = \pi d^2$

10. $A = \pi \frac{d^2}{4} = \pi r^2$

11. $A = 4\pi r^2$

12. $R = \frac{output}{input} \times 100\%$

13. $\rho_1 gh = \rho_2 gh$

14. $Q = Av = C$

15. $k = \frac{Q}{\sqrt{h}}$

16. $E = \frac{mv^2}{2}$

17. $E = mgh$

18. $V = \pi DN$

19. $V = \frac{a}{t}$

20. $V = \sqrt{2gh}$

21. $PA = mg$

22. $h_{su} = m\{(h_f + gh_{fg}) + C_s(t_{su} - t_s) - (C_w \times t_w)\}$

23. $m = \rho v$

24. $A = \frac{F}{p}$

25. $K = \frac{mv^2}{2}$

26. $K = W/m^2 K$

27. $Pv = cT$

28. $m = \frac{Pv}{RT}$

29. $n = \frac{Pv}{R_0 T}$

30. $V = A\ell NnR$

31. $K = \frac{Qx}{A\Delta t}$

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REPUBLIC OF SOUTH AFRICA

AUGUST 2011

NATIONAL CERTIFICATE

PLANT OPERTION THEORY N2

(11040012)

QUESTION 1: CHEMISTRY

1.1 TRUE OR FALSE (5)

1.1.1 True
1.1.2 True
1.1.3 False
1.1.4 True
1.1.5 True

1.2 **Molecular mass of $Ca(OH)_2$:** (4)

$H \quad 1 \times 2 \quad = 2$
$Ca \ \ 40 \ \times 1 = 40$
$O \quad 16 \ \times 2 = 32$
$TOTAL\text{: } \mathbf{74amu./ame}.$

1.3

1.3.1 **Atomic mass:** (2)

Is equal to the ***sum of the masses*** of all the particles forming the atom, but because the mass of an electron is so small, the atomic mass is only the sum of the ***masses of the protons and neutrons.***

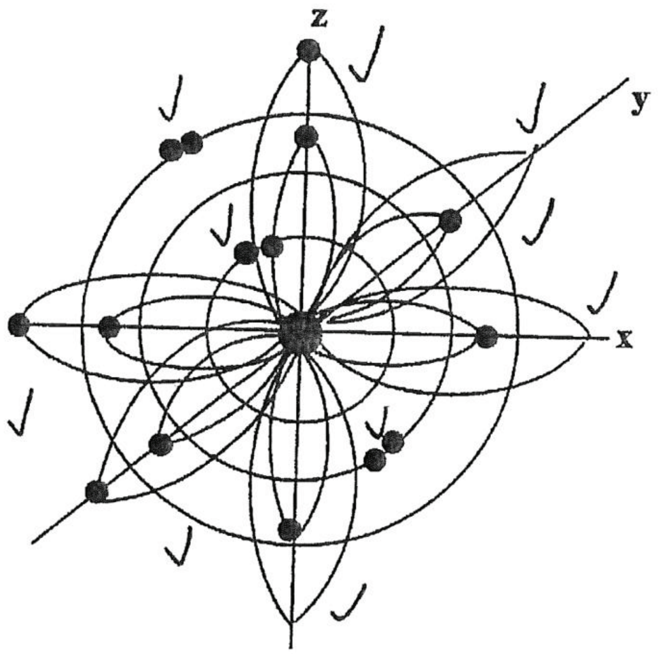
1.3.2 **Isotopes:** (2)

Are atoms of the same element, but with ***different atomic masses****,* because the ***numbers of neutrons*** appearing in the nucleus of the atoms are different.

1.4 **Hydrogen test:** (5)

Collect an amount of H2 in a flask by the downward ***displacement*** **of** ***water***
The flask must be held ***upside-down near a flame***
A loud popping sound will be heard and water will be formed
Place ***dry white copper sulphate crystals*** in the flask and the crystals will ***turn blue*** (test for water).

1.5 **Phosphorus atom.** (5)
(½ point mark)



$P(15) = 1S^2 ; 2S^2 2P^6 ; 3S^2 3P^{x1 y1 z1}$

1.6 **Chemical equation:**

$$2K + 2H_2O = 2KOH + H_2 \uparrow$$

[25]

QUESTION 2: ENERGY AND FLUID FLOW

2.1 TRUE OR FALSE (5)

2.1.1 False
2.1.2 False
2.1.3 True
2.1.4 False
2.1.5 False

2.2 **Calculate delivery pressure:** (4)

$$\begin{aligned} Delivery\ Pressure\ (P) &= qg\ (h_1 + h_2)/\ 2 \\ &= 900\ \times 9{,}81\ \times (8 + 10)/2 \\ &= 79\ 461\ Pa \\ &= \mathbf{79{,}46\ kPa} \end{aligned}$$

2.3 **Density: loss of pressure in pipes:** (3)

- Density of a fluid is the ***mass of the liquid per volume*** thereof and more energy is needed to displace a fluid with a high density,
- Than a fluid with a low density during the ***same time lapse.***
- The higher the density of the fluid, the ***greater the loss of pressure in the pipe.***

2.4 **Differential pressure calculation:** (5)

$$Q_1 = k\ (\Delta\rho_1)^{\frac{1}{2}}$$
$$k_1 = 15{,}4/24{,}5^{\frac{1}{2}}$$
$$= 3{,}111$$

$$\Delta\rho_2\ = (Q_2/k_1)^2$$
$$Q_2 =\ 12{,}5^{\frac{1}{2}}\ \times\ 3{,}111 \quad = 11m^3/hr$$

2.5 **Types of energy:** (4)

Potential energy. That is the energy of an object due to its ***position or state of tension.***
Kinetic energy. That is the energy of an object due to its state of ***movement.***

2.6 **The effect of heat:** (4)

- Applying heat cause ***molecules to move faster***, increasing the temperature.
- The physical condition ***can change***, e.g. ice to water.
- The material can ***expand or shrink*** due to the heat.
- The material can ***change colour***, e.g. a lump of iron becoming red due to the heat added.

[25]

QUESTION 3: DISTILLATION AND FRACTIONATION

3.1 TRUE OR FALSE (5)

3.1.1 False
3.1.2 True
3.1.3 False
3.1.4 True
3.1.5 False

3.2 **STRIPPERS vs. ABSORBERS:** (4)

- STRIPPERS: Here the feed ***enters the column at the top*** and the ***absorption medium enters at the bottom.***
- ABSORBERS: Here the ***gas or vapour to be purified enters at the bottom*** of the column and the absorption medium at the top.
- The difference between the two lies in the ***entrance and exit positions*** **on the column.**

3.3 **Heat balancing:** (8)

- The whole process of fractionation depends on ***evaporation and condensation*** which on their part depend on,
- ***Temperature and pressure*** which means that at every point in the tower,
- Where ***heat or flow*** is introduced into the tower, it must take place at a,
- ***Specific place*** and at a specific temperature, and there for at each of these,
- Places there must be control points so that the ***balance in the tower*** can be maintained.

- The temperature of each boiler, the flow through each, the top and bottom temperature as well as that of the ***feed and the steam are controlled*** to keep the ***temperature gradient within limits,***
- And each point where control is exercised will depend upon the type of material handled at that point in order ***to obtain the desired results.***

3.4 **Control and effect of pressure:** (6)

- Pressure control points are fitted on fractionating towers because ***variations in pressure gives fractions*** off specifications,
- And variations in pressure ***disturb the energy balance*** of the tower.
- With vacuum distillation the ***pressure inside the tower is lower than atmospheric pressure*** and condensation of the steam causes marked reductions in pressure, which must be controlled.
- A pressure controller is fitted at the bottom of the tower to control the ***flow of steam through the boiler*** and
- Thus also controls the bottom temperature, which in turn ***controls the vapour pressure of the bottom products.***
- Placing of pressure control points are determined by the ***type of fractionation to be carried out and the material to be handled.***

3.5 **Operational problems:** (2)

(½ mark for each correct answer)

- Overloading
- Poor control of column temperature
- Incorrect quantities of reflux (poor control)
- Incorrect supply (feed) inlet position
- Incorrect supply (feed) temperature / or variation of feed
- temperature
- Poor maintenance

ANY 4

[25]

QUESTION 4: INSTRUMENTATION

4.1 TRUE OR FALSE (5)

4.1.1 True
4.1.2 False
4.1.3 True
4.1.4 False
4.1.5 True

4.2 **Absolute pressure and temperature:** (4)

- ABSOLUTE PRESSURE: is ***gauge- plus atmospheric pressure*** e.g. when atmospheric pressure is measured in ***gauge pressure, it is 0 kPa. Atmospheric pressure at sea level is 101.32 kPa.***
- ABSOLUTE TEMPERATURE: is the temperature read ***on the Kelvin scale*** where the melting point of ice is ***273 Kelvin, which is equal to 0℃.***

4.3 **Most important condition for control:** (3)

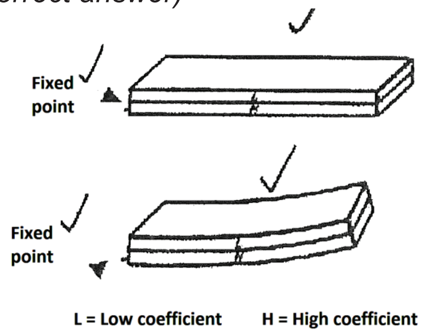
The primary or measuring element ***must be sensitive to react fast*** on process changes measured. Should the element ***by reluctant, any* change *will, after a time delay,*** be adjusted with ***accompanying* delays*.***

4.4 **Linear expansion:**

4.4.1 The degree of expansion of a metal is ***proportional*** to the temperature. (3)

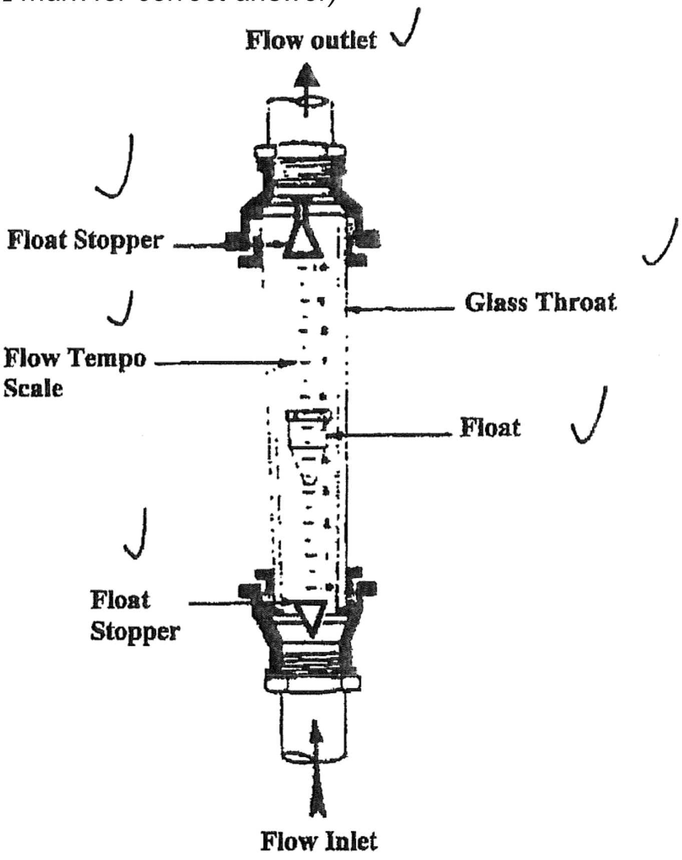
When two strips, each of a different type of metal, with ***different coefficient of expansion*** is secured to each other that will be an ***indication of the temperature*** of the strip reflect (known as a bimetal strip).

4.4.2 Sketch *(½ mark for each correct answer)* (2)



4.5 **Rotameter.** *(½ mark for correct answer)*

(3)



(5)

Operation:

The ***internal cross-sectional area*** of the tube *changes* as the tube tapers and the flow is determined as follows:

The tapered tube is mounted ***vertically in the line*** with the ***wide side up***. The tube is graded, that is ***a scale is affixed to it*** and ***a small weight or heavy float is lifted*** by the liquid stream ***to a position*** where the ***downward pressure*** of the float ***balance the upward pressure*** of the liquid. The reading is then taken on the scale, ***directly opposite to the float.***

[25]

TOTAL: 100

Past Examination Papers

higher education
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Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

NOVEMBER 2010

NATIONAL CERTIFICATE

PLANT OPERATION THEORY N2

(**11040012**)

16 November (X-Paper)
09:00 – 12:00

REQUIREMENTS:

Calculators may be used.

Candidates will require drawing instruments, pens and a ruler.

This question paper consists of 4 pages and a 1-page formula sheet.

TIME: 3 HOURS
MARKS: 100

---

1. Answer ALL the questions.
2. Read ALL the questions carefully.
3. Number the answers correctly according to the numbering system used in this question paper.
4. Sketches must be large, neat and fully labelled.
5. 100 marks: 100%
6. Write neatly and legibly.

QUESTION 1: CHEMISTRY

1.1 Draw an abridged periodic table giving the first 20 elements in their groups and periods. (10)

1.2 List the properties of *alkanes.* (7)

1.3 With the add of an applicable chemical reaction explanation give the chemical properties of ammonia (NH_3). (10)

1.4 Determine the molecular mass of NH_3 and show your calculations. (3)

[30]

QUESTION 2: ENERGY AND FLUID FLOW

2.1 Define and explain the following:

2.1.1 Heat (3)
2.1.2 One Joule (2)
2.1.3 Matter (3)

2.2 Briefly discuss tidal force and its utilisation. (4)

2.3 Water flows at 10 m^3/min in a pipe with a diameter of 180 mm. (4)

Calculate the velocity of the water in m/sec.

2.4 Determine the differential pressure across an orifice in a pipe when the flow is 25 000 litres per hour, if the same orifice creates a pressure difference of 30 kPa when the flow is 20 000 litres per hours. (4)

[20]

QUESTION 3: DISTILLATION AND FRACTIONATION

3.1 Explain temperature gradient as a control variable for effective operation of a distillation tower to produce a high quality product. (5)

3.2 Give a detailed description of what happens when pressure in a distillation column increases at a constant temperature. (4)

3.3 Explain the operation procedure that can be followed to ensure proper fractionation, while arrangements are being made to take the tower out of commission for mechanical repairs. (4)

3.4 Sketch a complete, fully labelled typical fraction tower. (12)

[25]

QUESTION 4: INSTRUMENTATION

4.1 Process energy variables refer to the internal energy of materials. Name and (4) explain this internal energy of materials as process variables. Give an applicable secondary measuring element and give a unit of measurement.

4.2 Convert 263 Kelvin to ℃. (1)

4.3

4.3.1 State the Jaw of Archimedes. (4)

4.3.2 Sketch a level gauge operating on the principle of Archimedes. Indicate its position at **TWO** levels. (7)

4.4 Calculate the scale reading on the inclined leg of a manometer if the angle of inclination is 40°C and the vertical mercury level differs with 160 mm. (3)

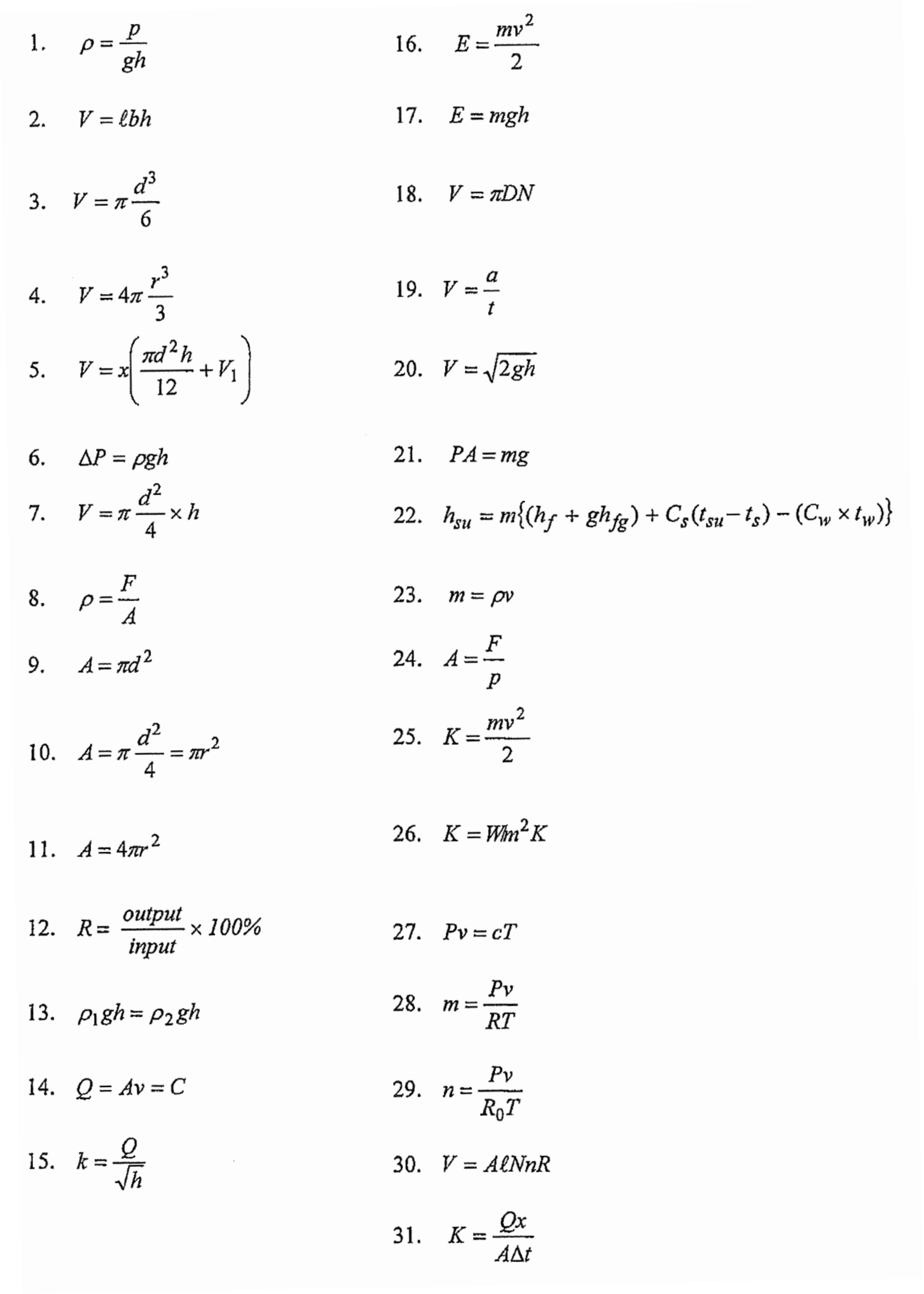
Use the following information to do the calculation: Sin 40°C = 0,643.

4.5 Sketch a spiral type bimetal thermometer and briefly explain its operation. (6)

[25]

TOTAL: 100

FORMULA SHEET



1. $\rho = \frac{p}{gh}$
2. $V = \ell bh$
3. $V = \pi \frac{d^3}{6}$
4. $V = 4\pi \frac{r^3}{3}$
5. $V = x\left(\frac{\pi d^2 h}{12} + V_1\right)$
6. $\Delta P = \rho gh$
7. $V = \pi \frac{d^2}{4} \times h$
8. $\rho = \frac{F}{A}$
9. $A = \pi d^2$
10. $A = \pi \frac{d^2}{4} = \pi r^2$
11. $A = 4\pi r^2$
12. $R = \frac{output}{input} \times 100\%$
13. $\rho_1 gh = \rho_2 gh$
14. $Q = Av = C$
15. $k = \frac{Q}{\sqrt{h}}$
16. $E = \frac{mv^2}{2}$
17. $E = mgh$
18. $V = \pi DN$
19. $V = \frac{a}{t}$
20. $V = \sqrt{2gh}$
21. $PA = mg$
22. $h_{su} = m\{(h_f + gh_{fg}) + C_s(t_{su} - t_s) - (C_w \times t_w)\}$
23. $m = \rho v$
24. $A = \frac{F}{p}$
25. $K = \frac{mv^2}{2}$
26. $K = W/m^2K$
27. $Pv = cT$
28. $m = \frac{Pv}{RT}$
29. $n = \frac{Pv}{R_0 T}$
30. $V = A\ell NnR$
31. $K = \frac{Qx}{A\Delta t}$

Marking Guidelines

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Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

NOVEMBER 2010

NATIONAL CERTIFICATE

PLANT OPERATION THEORY N2

(**11040012**)

QUESTION 1: CHEMISTRY

1.1 **Abridged periodic table:** (10)
(½ point per correct answer)

½ Point per correct answer

Groups		1	2	3	4	5	6	7	0
Periods	1	H						(H)	He
	2	Li	Be	B	C	N	O	F	Ne
	3	Na	Mg	Al	Si	P	S	Cℓ	Ar
	4	K	Ca						

1.2 **Properties of alkanes:** (7)

- The ***first four members are gases*** at normal temperature and pressure.
- As the molecules grow with an increase in carbon atoms, they ***become heavier*** and as a result some of them ***become liquids and others solids*** at normal temperature and pressure. The solids have low melting points.
- They are ***insoluble in water,*** but dissolve readily in ***other organic soluble agents and groups*** of their own kind.
- They do ***not conduct electricity****.*
- They all ***have specific shapes****.*

1.3 **Chemical properties of ammonia:** (10)

- **As a reducing agent:**
  $2NH_3 + 3Cl_2 = N_2 + 6HCl$
  or
  $2NH_3 + 3CuO = 3cU + 3H_2O + N_2$

- **It burns in pure oxygen:**
  $4NH_3 + 3O_2 = 2N_2 + 6H_2O$

- **It decomposes into nitrogen and hydrogen at high temperatures:**
  $2NH_3 \rightarrow N_2 + 3H_2$

- **It dissolves in water in large amounts:** (700 volumes dissolve in 1 litre water)
  $NH_3 + H_2O \rightarrow {NH_4}^{+} + OH$

- Due to the unshared pair of electrons on the nitrogen of the **NH_3 molecule it bonds to metallic ions** such as **Cu(NH_3)$_4$ $^{++}$**

1.4 **Molecular mass of NH$_3$:** (3)

N = 1 X 14 = 14
H = 3 X 01 = 03

Total: 17 amu. /ame.

[30]

QUESTION 2: ENERGY AND FLUID FLOW

2.1

2.1.1 **Heat:** (3)

It is the ***result of molecular movement*** and is a ***form of energy*** and is ***measured in Joules.***

2.1.2 **One joule:** (2)

It refers ***to work done*** when ***one Newton is displaced one metre***.

2.1.3 **Matter:** (3)

Consist of ***anything occupying space*** witch can be ***seen, smelt, felt or heard***. Matter is ***anything with* mass**

2.2 **Tidal force:** (4)

Tidal force refers to ***energy of water in motion***, which is utilised to ***generate electricity***. In this case, the energy of the water in motion due ***to tidal changes of the sea is used***. An important prerequisite is that ***the tidal height between high and low tied must be significant.***

2.3 **Velocity calculation:** (4)

$$\begin{aligned} Q &= (\pi \times d^2/4)\,V \\ 10/60 &= [(3{,}14 \times 0{,}18^2)/4] \times V \\ V &= 0{,}167/0{,}0254 \\ &= \mathbf{6{,}55m/sec}. \end{aligned}$$

2.4 **Differential pressure calculation:** (4)

$$Q_1 = k(h_1)^{\frac{1}{2}}$$
$$\begin{aligned} k &= 20/(30)^{\frac{1}{2}} \\ &= 3{,}65 \end{aligned}$$

$$\begin{aligned} h_2 &= (25/3{,}65)^2 \\ &= \mathbf{46{,}87kPa} \end{aligned}$$

[20]

QUESTION 3: DISTILLATION AND FRACTIONATION

3.1 **Temperature gradient as control variable:** (5)

The effective temperature gradient of a distillation tower will be (determent by the ***heat balance*** and the ***composition of the feed***. The temperature gradient refers to the deference between ***the top and bottom temperature of the tower***. To produce (refine) the purist top and bottom products it is of great importance that:

- The ***maximum heat input*** through the re-boiler apply, and

- ***Maximum reflux is maintained*** without over flowing of the tower

3.2 Pressure increases while temperature remains constant: (4)

Pressure causes vapour to ***condense****,* causing the boiling point of the fluid in the column to ***rise****.* To maintain previous rates of condensation and evaporation, either **the *pressure must be reduced*** or the ***temperature increased****.*

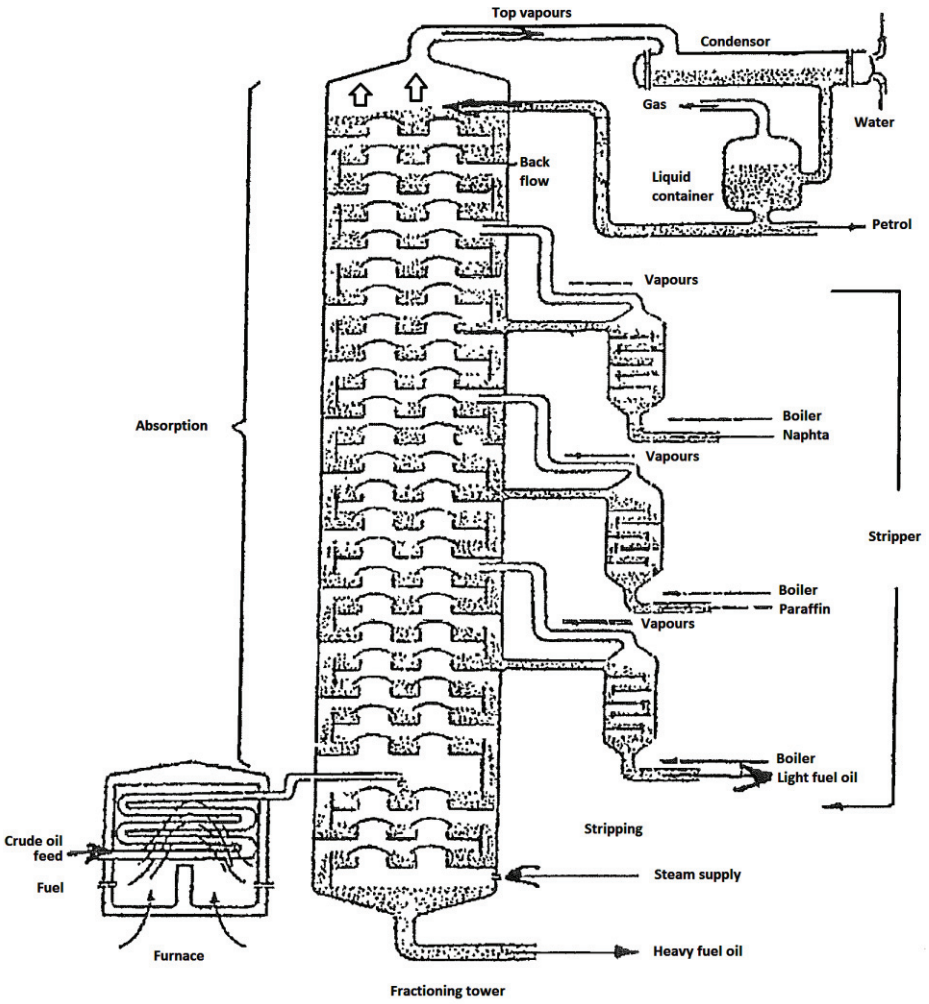
3.3 Temporary operation procedures: (4)

But the following operations procedures can in the mean time be follow:

- ***Cut the back flow (reflux),*** to reduce the liquid entering the tower at the top
- ***Drain the excess liquid*** in the bottom and at the top (overheads)
- ***Cut down the supply*** and reduce the bottom temperature if necessary
- ***Adjust back flow*** in order to regain stable operation conditions

3.4 Fraction tower: (12)

Typical Fractionation Tower



[25]

QUESTION 4: INSTRUMENTATION

4.1 **Energy variables:** (4)
(A ½ point per Correct Answer)

- Temperature: Temperature measures the ***heat energy*** of a body or substance in ***Fahrenheit (°F)*** *or* ***Celsius (°C).*** Applicable secondary elements are e.g. ***liquid -in-glass thermometers, pyrometers,*** etc.
- Pressure: Pressure refer to the ***force exerted per unit area*** which can e.g. be caused by a liquid contained in a vessel or by gases and is measure in ***Newton per m^2 (Pascal= Pa.).*** Applicable secondary elements are e.g. ***manometers, Bourdon tube meters****,* etc.

4.2 **KELVIN TO ℃:** (1)

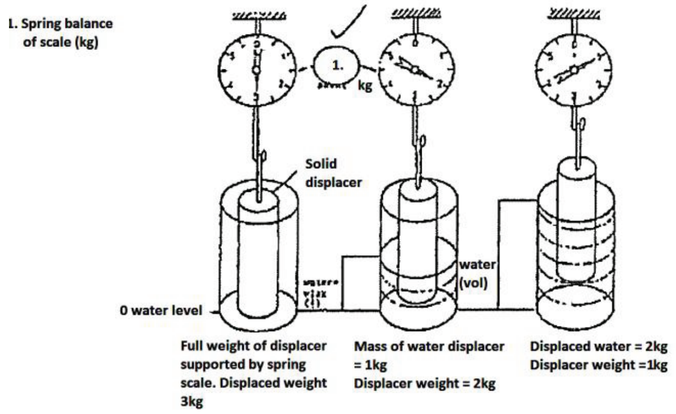
$263\,K - 273 = \mathbf{-10°C}$

4.3

4.3.1 **Law of Archimedes:** (4)

When a ***heavy object is immersed into a liquid*** it experiences ***an apparent loss of mass*** as a result of the upward pressure of the liquid against the object. The ***loss of mass is equal to the liquid being displaced****.* The ***more displacement there is, the larger the apparent loss of weight.***

4.3.2 **Principle: level gauge:** (7)

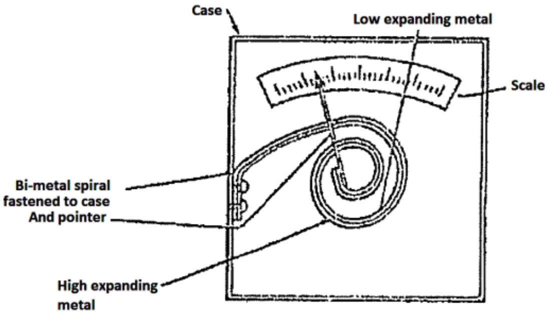


4.4 **Scale calculation:** (3)

$$Scale\ reading = \frac{h}{\text{Sin}\,40°} \qquad \text{SinA} = \text{a/c}$$
$$= 160/0{,}643$$
$$= \mathbf{248{,}83\ mm}$$

4.5 **Type bimetal thermometer:**

(4)



(2)

Discussion

Two metals with ***different linear expansion are used.*** The one with the ***high expansion coefficient will bend the spiral.*** The movement from the free end is transfer on a scale, which reflects the temperature

[25]

TOTAL: 100

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