# N5 Chemical Plant Operation


Gateways to Engineering Studies - Chris Brink

HYBRID LEARNING SOLUTIONS

# Gateways to Engineering Studies

## Chemical Plant Operation

## N5

Chris Brink

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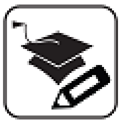
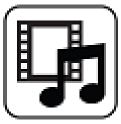
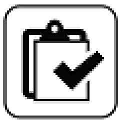
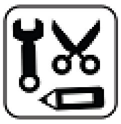
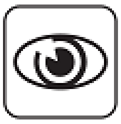
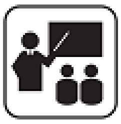
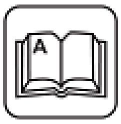
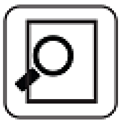
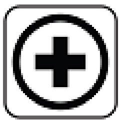
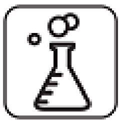
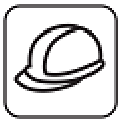
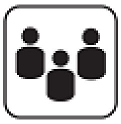
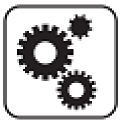
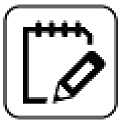
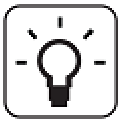
|  | Assessment / Activity |  | Multimedia |
|  | Checklist |  | Practical |
|  | Demonstration/ observation |  | Presentation/ Lecture |
|  | Did you know? |   | Read |
|  | Example |  | Safety |
|  | Experiment |  | Site visit |
|  | Group work/ discussions, role-play, etc. |  | Take note of |
|  | In the workplace |  | Theoretical – questions, reports, case studies, etc. |
|  | Keywords |  | Think about it |

# Module 1

# Thermodynamics

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

- Describe energy
- Conditions of steam
- Calculations
- Turbine equipment

## 1.1 Introduction

Thermodynamics is a branch of natural science concerned with heat and temperature and their relation to energy and work. It defines macroscopic variables, such as internal energy, entropy, and pressure, that partly describe a body of matter or radiation.

It states that the behavior of those variables is subject to general constraints, that are common to all materials, not the peculiar properties of particular materials. These general constraints are expressed in the four laws of thermodynamics.

Thermodynamics describes the bulk behavior of the body, not the microscopic behaviors of the very large numbers of its microscopic constituents, such as molecules.

## 1.2 Energy

- *Potential energy* ($P_e$): That is the energy of an object due to its position or state of tension, e.g. a shotgun bullet or a bomb has potential energy confined in them as a result of the chemical composition of the gunpowder or explosives. $P_{e.}$ = m g h. With other words it refers to an object, which is above a datum plane, possesses energy because of its position.

- *Kinetic energy* ($K_e$): That is the energy of an object due to its state of movement or velocity. Thus water flow from a pipe has kinetic energy as a result of the movement and the velocity of it. $K_{e.} = \frac{1}{2} m\, v^2$

- *Internal Energy* ($u$): A fluid contains a certain amount of energy due to the temperature level and the state it a cures and is measured in J/kg. With other words it refers to a collection of molecules (matter) contained in a given volume possesses energy due to the translation of the molecules, to their vibration and rotation and to intermolecular attraction and repulsion.

| | |
|---|---|
| ⚠ | **Note:**<br>They're for Specific internal energy referring to the internal energy per unit mass and can have units of calories per gram of kJ/kg, etc. |

- *External energy* (*w*): A certain amount of work is done on fluid as it enters a system, eg work done through pumping (See N4 Manual for more information).

- *Heat (energy)*: It is the from or manifestation of energy that flows from one object to another under the influence of temperature difference. Heat is the result of molecular movement and there for is a from of energy which is measured in Joule. When heat is applied to a body, or substance, then the internal energy of the body, or substance, will increase and an increase in temperature or a change of state will occur, which referring to the following:

    - *Sensible heat*: When heat is supplied which causes an immediate rise in temperature, and then this heat is known as sensible heat.
    - *Latent heat*: When heat is supplied which causes a change in state without a change in temperature, and then this heat is known as latent heat. However latent heat of fusion refer to when a solid change to liquid (eg ice to water), and latent heat of evaporation refer to when liquid change to a gas (eg water to steam).

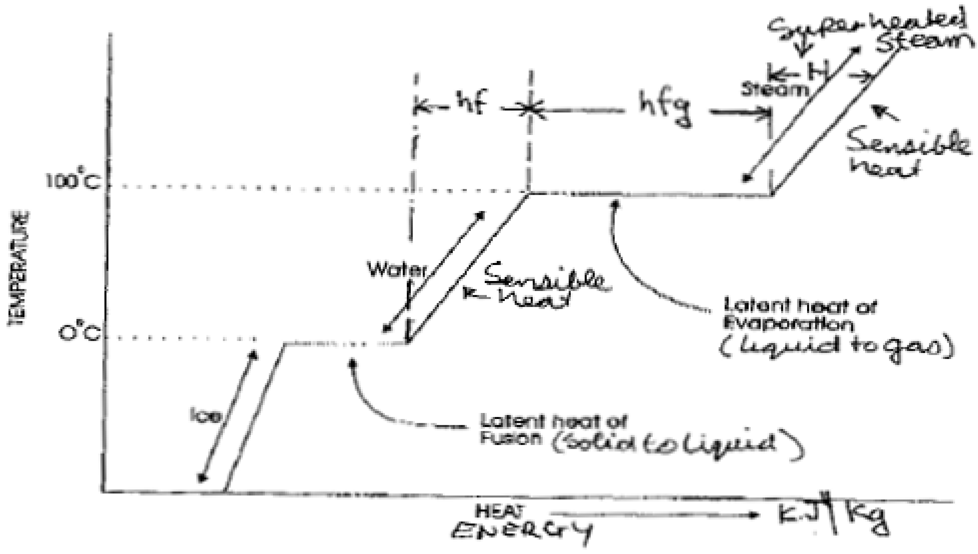
- *Calorie*: It refers to the amount of heat required to raise the temperature of one gram of water from 14,5°C to 15,5°C.

- *Kopp's rule*: The total heat capacity of a compound is approximately equal to the sum of the heat capacities of the constituent elements.

- *Heat of reaction*: this refers to the difference in energy between the products of the reaction and the reactants.

## 1.3 Conditions of Steam

Use the aid of the following graph to understand the explanations.




CHANGE OF STATE : WATER (P = 101,3 kPa)

Figure 1.1 Change of state: water (P=101,3 kPa)

- *Saturation Temperature* (*ts*): This is the temperature at which water will change to steam. The saturation temperature will depend upon the pressure on the surface of the water (refer to the steam tables).

- *Saturated Steam* (*hfq*): Saturated steam is steam at saturation temperature, corresponding to the pressure.

- *Dry Saturated Steam* (*hg = hf + hfg*): This is steam, which does not contain suspended water at all. This means that the steam is at the saturation temperature and has absorbed all of the latent heat of evaporation.

- *Wet Steam*: If the steam produced does contain particles of water suspended in it, it is called wet steam, however it is still at the saturation temperature, and it can still absorbed of the latent heat. The dryness fraction (*x*) of the steam represents the percentage of dry saturated steam in the wet mixture.

- *Superheated Steam*: ($h_{su}$) Steam that is heated to a temperature $t_{su}$) higher than the saturation temperature is called superheated steam.

**Note:**
The sensible heat that increase the temperature to produce superheated steam is called specific heat capacity ($C_s$)

- Enthalpy (*h*): The heat required to produce the steam at constant pressure is called Enthalpy. The term enthalpy is used rather than heat because when a quantity of heat has been added to water to from steam, the energy appears in the steam in two different forms.

- *Firstly*: the energy absorbed by the molecular vibration (internal energy), and
- *Secondly*: the energy in the form of "work" used to increase the volume when steam is formed.

## 1.3 Calculations

### 1.3.1 Steam calculations

**Worked Example 1.1**

Determine the heat required to change 5 kg of water at a pressure of 3 kPa. and 24,1 °C dry saturated steam at 14 MPa.

**Answer:**

Q = m ($h_g$ of steam - $h_f$ of water)
= 5 (2643 - 101) kJ -------- From the steam tables
=12 710 kJ

**Worked Example 1.2**

Superheated steam at 500°C and 4 000 kPa is concentrated at 100 kPa. Determine the heat available for the process heating. Accept that the steam $C_p$ = 1,97 kJ/kg.K

**Answer:**

Q = m [superheated steam - condensate]
= m [hg + ($C_p$ ΔT)- *hf*]
= 1 [ (2 800 + (1 ,97 x (500 - 250,3))- 418] ------------ Steam tables
= 2 873,9 kJ/kg

**Worked Example 1.3**

How much saturated steam is needed to heat oil from 20°C to 200°C?

**Given:**

| | |
|---|---|
| Flow rate of oil | = 1 000 kg.$h^{-1}$ |
| $Cp_{oil}$ | = 1197 kJ.kg.$K^{-1}$ |
| Temperature of saturated steam | = 400°C |
| Steam pressure | = 2 800 kPa |
| $Cp_{sup.steam}$ | = 1,96 kJ.kg.$K^{-1}$ |

**Answer:**

| | |
|---|---|
| Superheated Steam (Heat energy in) | = Oil (Heat energy out) |
| m [ ($C_p$ ΔT)] | = m $C_p$ ΔT |
| m [1 ,96 (400 - 230,1 )] | = 1 000 x 1,97(200 - 20) - steam tables |
| m x 333,004 | = 354 600 |
| m -------- steam require | = 354 600 ÷ 333,004 |
| | = 1 064 kg / hr. |

### 1.4 Air calculations

| Pressure MPa | | Temperature, K | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 240 | 260 | 280 | 300 | 350 | 400 | 450 | 500 | 600 | 800 | 1000 |
| 0,1 | $v$ | 0,9179 | 0,9946 | 1,071 | 1,148 | 1,340 | 1,531 | 1,723 | 1,914 | 2,297 | 3,063 | 3,829 |
| | $h$ | 240,0 | 260,1 | 280,2 | 300,3 | 350,7 | 401,3 | 452,2 | 503,4 | 607,5 | 822,5 | 1046,6 |
| 0,5 | $v$ | 0,1370 | 0,1487 | 0,1604 | 0,1720 | 0,201 | 0,3399 | 0,258 | 0,2876 | 0,3452 | 0,4602 | 0,5751 |
| | $h$ | 238,5 | 258,8 | 279,1 | 299,4 | 350,0 | 400,8 | 451,8 | 503,2 | 607,4 | 822,6 | 1046,9 |
| 1,0 | $v$ | 0,06814 | 0.07409 | 0,0800 | 0,0859 | 0,1005 | 0,1151 | 1,1296 | 0,1440 | 0,1729 | 0,2305 | 0,2881 |
| | $h$ | 236,7 | 257,6 | 277,8 | 298,3 | 349,2 | 400,2 | 451,4 | 502,9 | 607,3 | 822,7 | 1047,2 |
| 1,5 | $v$ | 0,0509 | 0,0554 | 0,0599 | 0,0644 | 0,0754 | 0,0864 | 0,0973 | 0,1081 | 0,1298 | 0,1731 | 0,2163 |
| | $h$ | 234,9 | 255,9 | 276,5 | 297,1 | 348,5 | 399,6 | 451,0 | 502,6 | 607,2 | 822,9 | 1047,4 |
| 2,0 | $v$ | 0,03371 | 0,03679 | 0,03983 | 0,04284 | 0,05030 | 0,05767 | 0,06499 | 0,07299 | 0,08681 | 0,1157 | 0,1445 |
| | $h$ | 233,2 | 254,3 | 275,2 | 296,0 | 347,7 | 399,1 | 450,7 | 502,4 | 607,2 | 923,0 | 1047,7 |

Table 1.1 Thermodynamic properties of superheated air

**Worked Example 1.4**

What is the difference in enthalpy of 10 kg air between 360 K and 800 K at 0,1 mPa?

**Answer:**

ΔH = m (h Δt)

= 10 ($h_{800\ K}$ - $h_{360\ K}$)

= 10 { 822,5 - [350,7 + (401,3 - 350,7)/5]} --- see appendix

= 10 x [822,5 - 360,8]

= 4 617 kJ

## 1.4 Turbine Equipment

### 1.4.1 Steam turbine

A steam turbine consists of two parts, the nozzle in which the internal energy of high-pressure steam is converted to kinetic energy so that the steam issues from the nozzles with high velocity, and the blades, which change the direction of the steam, so that a force acts on the blades and propels them.

The different axial-flow steam turbines classifications as follows:

- *Impulse turbine*: In an impulse turbine, the entire available pressure drop from supply to exhaust occurs across the nozzles. The steam carries out is full expansion in the nozzle and emerges with high velocity.

  The nozzle is directed so that the steam glides on to the blades, and these are so shaped that the direction of flow of steam is changed and thereby a force is exerted on the blades.

- *Reaction turbine*: In a reaction turbine, only part of the pressure drop occurs in the nozzles. The remainder occurring during the passage of the steam through the blades. The blade passages are nozzle shaped so that the acceleration of the steam occurs partly in the blades.

  Since acceleration requires a force (force = mass x acceleration), a resultant reaction occurs on the blades. Since acceleration requires a force (force = mass x acceleration), a resultant reaction occurs on the blades.

  The force of reaction is added to the force resulting from redirection of the steam to make the total propulsive force on the blades.

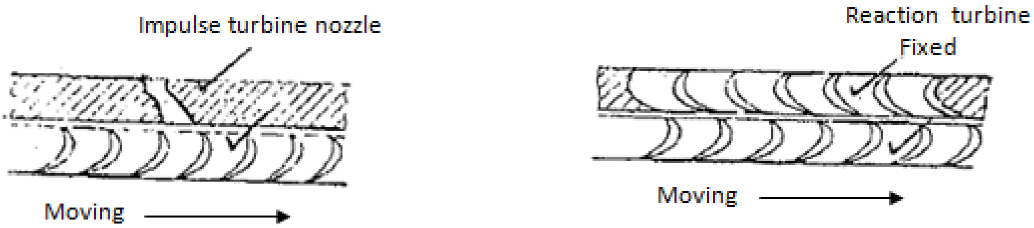



Figure 1.2 Impulse and reaction turbines

- *Impulse-reaction turbine*: It differs from the impulse turbine in that pressure drop occurs over the moving blades so that the steam expands continuously and its relative velocity at outlet is greater than its relative velocity at inlet.

  Fixed casing blades replace the nozzles of the impulse turbine and pressure drop occurs both in the fixed casing blades and the moving blades.

**Differences**

- Pressure drop occurs across the nozzles. Full expansion of steam in nozzles.
- Nozzles directed so that steam glides on to blades, the direction of the steam is changed and thereby a force exerted on blades.
- Nozzles are arranged in turbine casing.
- Part of the pressure drop occurs in nozzles, the remainder occurring during passage through blades.

- Blade passages are nozzle shaped, acceleration occurs partly in nozzles and partly in blades. A resultant reaction occurs on the blades.
- A ring of fixed blades acts as nozzles.

- *Rateua turbine: (Pressure compounding).* The pressure drop available to the turbine is used in a series of small increments, each increment being associated with one stage of the turbine. The physical arrangement is shown in the sketch. The nozzles are carried in diaphragms, which separate each stage from the next.

- *Curtis turbine: (Velocity compounding)* The velocity compounded stage called the Curtis stage after its designer is used to employ lower blade speeds and a higher utilization of the kinetic energy of the steam. In this type all the expansion takes place in a single set of nozzles and the steam then passes through a series of blades attached to a single wheel or rotor.

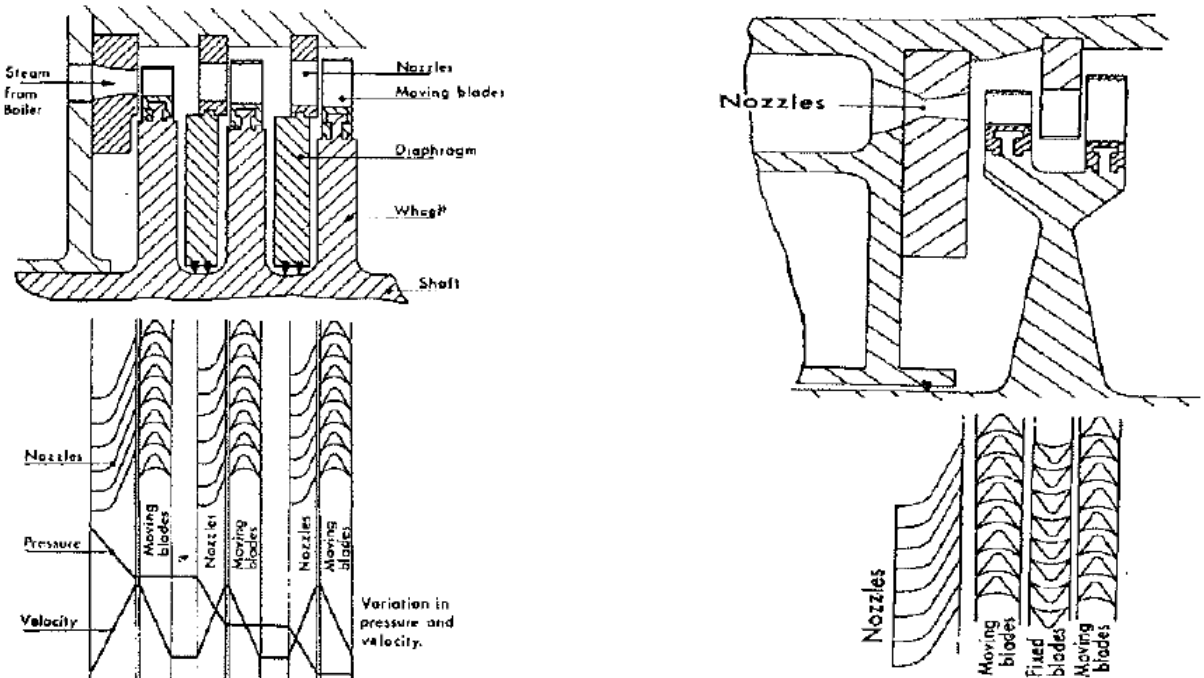



Figure 1.3

- *Steam nozzle calculation:*

| | **Worked Example 1.5** |
|---|---|
| Steam is admitted to a nozzle at 1 MN.m$^{-2}$ and expands adiabatically through the nozzle to a final pressure of 70 kN/m$^{-2}$. The specific enthalpy of the leaving steam is 2 278 kJ/kg and its dryness factor is 0,833.<br><br>Calculate the velocity of the steam issuing from the nozzles, as well as the | |

cross-sectional area required at the exit of the nozzle for a flow of 0,75 $kg.s^{-1}$

**Answer:**

$H_1$ = 2 777 kJ/kg --------- From steam tables

$H_2$ = 2 278 kJ/kg --------- Given

Enthalpy drop = $h_1 - h_2$
= 499 000 J/kg

$U_2$ (Final steam velocity) $= \sqrt{2 \times Actual\ Enthalpy\ drop}$
$= (2 \times 499 \times 10^3)^{\frac{1}{2}}$
$= 999\ m.s^{-1}$

$V_2 = 0{,}833 \times 2{,}278$
$= 1{,}897{,}6\ m^3.kg^{-1}$

$M\ (Mass\ flow) = \frac{AU_2}{V}$

$\therefore A_2 (Cross\ sectional\ exit\ area) = (mV_2)/U_2$
$= (0{,}75 \times 1{,}897{,}6)/\ 999$
$= 0{,}001426\ m^2$
$= 1426\ mm^2$

| p | $t_s$ | $v_g$ | $h_f$ | $h_{fg}$ | $h_g$ | $s_f$ | $S_g$ |
|---|---|---|---|---|---|---|---|
| kPa | °C | $m^3/kg$ | kJ/kg | kJ/kg | kJ/kg | kJ/kg.K | kJ/kg.K |
| 600 | 158,8 | 0,315 5 | 670 | 2 085 | 2 755 | 1931 | 6758 |
| 620 | 160,1 | 0,305 9 | 676 | 2 081 | 2 757 | 1944 | 6746 |
| 640 | 161,4 | 0,296 8 | 682 | 2 077 | 2 759 | 1956 | 6736 |
| 660 | 162,6 | 0,288 3 | 687 | 2 073 | 2 760 | 1968 | 6725 |
| 680 | 163,8 | 0,280 3 | 692 | 2 069 | 2 761 | 1980 | 6715 |
| 700 | 165,0 | 0,272 7 | 697 | 2 065 | 2 762 | 1992 | 6705 |
| 720 | 166,1 | 0,265 5 | 702 | 2 061 | 2 763 | 2003 | 6696 |
| 740 | 167,2 | 0,258 7 | 707 | 2 057 | 2 764 | 2014 | 6686 |
| 760 | 168,3 | 0,252 2 | 712 | 2 054 | 2 766 | 2025 | 6677 |
| 780 | 169,4 | 0,246 1 | 717 | 2 050 | 2 767 | 2035 | 6668 |
| 800 | 170,4 | 0,240 3 | 721 | 2 047 | 2 768 | 2046 | 6660 |
| 820 | 171,4 | 0,234 7 | 725 | 2 043 | 2 768 | 2056 | 6651 |
| 840 | 172,5 | 0,229 4 | 730 | 2 040 | 2 770 | 2066 | 6643 |
| 860 | 173,4 | 0,224 3 | 734 | 2 036 | 2 770 | 2075 | 6635 |
| 880 | 174,4 | 0,219 5 | 739 | 2 033 | 2 772 | 2085 | 6627 |
| 900 | 175,4 | 0,214 8 | 743 | 2 030 | 2 773 | 2094 | 6619 |
| 920 | 176,3 | 0,210 4 | 747 | 2 026 | 2 773 | 2103 | 6612 |
| 940 | 177,2 | 0,206 1 | 751 | 2 023 | 2 774 | 2112 | 6604 |
| 960 | 178,1 | 0,202 0 | 755 | 2 020 | 2 775 | 2121 | 6597 |
| 980 | 179,0 | 0,198 1 | 759 | 2 017 | 2 776 | 2130 | 6590 |
| 1 000 | 179,9 | 0,194 3 | 763 | 2 014 | 2 777 | 2138 | 6583 |
| 1 050 | 182,0 | 0,185 5 | 772 | 2 006 | 2 778 | 2159 | 6566 |
| 1 100 | 184,1 | 0,177 4 | 781 | 1 999 | 2 780 | 2179 | 6550 |
| 1 150 | 186,1 | 0,170 0 | 790 | 1 991 | 2 781 | 2198 | 6534 |
| 1 200 | 188,0 | 0,163 2 | 798 | 1 984 | 2 782 | 2216 | 6519 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 250 | 189,8 | 0,156 9 | 807 | 1 977 | 2 784 | 2234 | 6505 |
| 1 300 | 191,6 | 0,151 1 | 815 | 1 971 | 2 786 | 2251 | 6491 |
| 1 350 | 193,4 | 0,145 7 | 823 | 1 964 | 2 787 | 2268 | 6478 |
| 1 400 | 195,0 | 0,140 7 | 830 | 1 958 | 2 788 | 2284 | 6465 |
| 1 450 | 196,7 | 0,136 0 | 838 | 1 951 | 2 789 | 2299 | 6453 |
| 1 500 | 198,3 | 0,131 7 | 845 | 1 945 | 2 790 | 2315 | 6441 |
| 1 550 | 199,9 | 0,127 5 | 852 | 1 939 | 1 791 | 2330 | 6429 |
| 1 600 | 201,4 | 0,123 7 | 859 | 1 933 | 2 792 | 2344 | 6418 |
| 1 650 | 202,9 | 0,120 1 | 865 | 1 927 | 2 792 | 2358 | 6407 |
| 1 700 | 204,3 | 0,116 6 | 872 | 1 922 | 2 794 | 2371 | 6396 |
| 1 750 | 205,7 | 0,113 4 | 878 | 1 916 | 2 794 | 2385 | 6385 |
| 1 800 | 207,1 | 0,110 3 | 885 | 1 910 | 2 795 | 2398 | 6375 |
| 1 850 | 208,5 | 0,107 4 | 891 | 1 905 | 2 796 | 2410 | 6365 |
| 1 900 | 209,8 | 0,104 7 | 897 | 1 899 | 2 796 | 2423 | 6355 |
| 1 950 | 211,1 | 0,102 0 | 903 | 1 894 | 2 797 | 2435 | 6346 |
| 2 000 | 212,4 | 0,099 54 | 908 | 1 889 | 2 797 | 2447 | 6337 |
| 2 050 | 213,6 | 0,097 16 | 914 | 1 883 | 2 797 | 2459 | 6328 |
| 2 100 | 214,9 | 0,094 89 | 920 | 1 878 | 2 798 | 2470 | 6319 |
| 2 150 | 216,1 | 0,092 72 | 926 | 1 873 | 2 799 | 2481 | 6310 |
| 2 200 | 217,2 | 0 090 65 | 931 | 1 868 | 2 799 | 2492 | 6302 |

Table 1.2 Steam tables

### 1.4.2 Gas turbines

Another example of heat engines is the closed cycle and open cycle gas turbines.

- *Closed cycle gas turbine:* Heat is supplied to the air by hot gases in a heat exchanger, the turbine develops work, heat is rejected to cooling water in a cooler, and work is done on the air in a compressor.

- *Open cycle gas turbine:* The energy supplied by spraying fuel into the air stream in a combustion chamber, resulting gases expand in the turbine and are then exhausted to atmosphere.

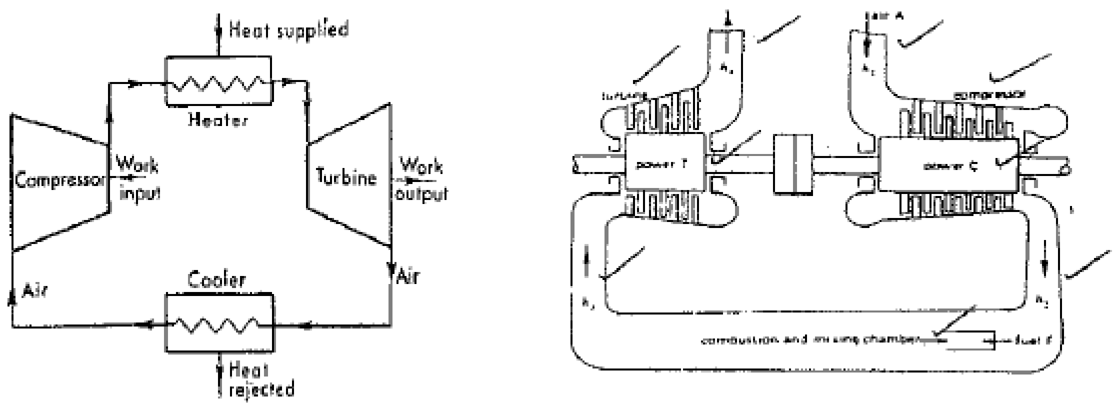



Figure 1.4 These plants/applications are internal combustion engines of the rotary type in which oxygen for combustion of fuel is supplied by the air entering from the atmosphere.

Open cycle gas turbine operates on a continuous combustion cycle and the working agent flows through the plant at a steady rate.

Air from the atmosphere is compressed in an axial-flow compressor and delivered to the combustion chamber into which fuel is injected through burners or nozzles.

Combustion is continuous. The flame tube is situated within the main casing of the combustion chamber. The secondary air flows between this tube and the outer casing of the combustion chamber and mixes with the products of combustion to reduce the resultant gas temperature.

### 1.4.3 Characteristic properties of Axial- and Radial- flow turbines

Important facts of these types of turbines are as follows:

- *Axial-flow turbines*
  - The steam flow is parallel to the turbine axis
  - Total pressure drop in nozzles
  - Steam is directed in moving blades
  - Steam transfers its velocity to the moving wheel.

- *Radial-flow turbines*
  - Steam flows from the centre outwards or from the outside to the centre
  - Pressure drop in the nozzles
  - Velocity increase due to pressure drop
  - Velocity decrease as kinetic energy is given to moving the blades.

## Activity 1.1

1. Complete **Activity 4.1** at the end of Module 4.

**Self-Check**

| I am able to: | Yes | No |
|---|---|---|
| • Describe energy | | |
| • Conditions of steam | | |
| • Calculations | | |
| • Turbine equipment | | |

If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.

# Module 2

# Combustion

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

- Define the combustions theory
- Demonstrate combustion calculations
- Describe burner equipment

## 2.1 Introduction

Combustion refers to the chemical reaction of certain elements in a fuel with oxygen, which can be obtained from air. The products, which are release during combustion, depend on the quality of the combustion process.

However combustion is synonym to the characteristic of a fire, there for the three components necessary to start combustion process namely, combustible components (fuel), oxygen, and heat in the form of a spark because this is an endothermic reaction.

**Note:**
The main purpose of combustion of a fuel is to release heat energy and therefore complete combustion conditions is essential.

The following conditions must be fulfilled:

- Enough air to provide sufficient oxygen to combine with all the combustible elements of the fuel.
- Thorough mixing (turbulence) of the air and fuel by using an applicable burner. Each particle of fuel must come in contact with the necessary air.
- Furnace temperature above ignition temperature of the fuel to ensure that the combination of fuel and oxygen takes place rapidly.
- Enough time for complete combustion before the fuel strikes the relatively cool surfaces of the furnace, for example, the boiler tubes.

When burners burning with a blue flame it indicates that combustion is visualized as a two-step mechanism with hydroxylation of the fuel occurring as the first step. When burners burning with a yellow flame it indicates glowing carbon particles from fuel in oxygen-deficient parts of the flame. Thus not enough $O_2$ for combustion.

**Definition: Heat of reaction and Combustion reaction**

1. *Heat of reaction*: It refers to the difference in energy between the products of the reaction and the reactants.

2. *Combustion reaction*: It refers to in which one (1) mole of the compound in question is reacted with just enough 02 to from the appropriate products of combustion, eg:
   - Tetra chloromethane: $CCl_4 + 2H_2O \rightarrow CO_2 + 4HCl$
   - Ethane chlorine: $CH_2Cl_2 + O_2 \rightarrow CO_2 + 2\ HCl$
   - Butane: $C_4H_{10} + 6½\ O_2 \rightarrow 4CO_2 + 5H_2O$

## 2.2 Combustion calculations

**Worked Example 2.1**

The analysis of the gas from a burner fueled with natural gas (essentially pure $CH_4$) is as follows:

- $N_2$ = 75% / mol
- $O_2$ = 10% / mol
- $CO_2$ = 5% / mol
- $H_2o$ = 10 % / mol

Calculate the ratio of moles of air to moles of natural gas fed to the burner.

**Answer:**

| | |
|---|---|
| The ratio between $O_2$ and $N_2$ | = 21% : 79% |
| ∴ $O_2$ requires | = (21 x 75) ÷ 79 |
| | = 19,94 mol $O_2$ |
| ∴ Air feed to burner | = 75 + 19,94 |
| | = 94,94 mol Air |
| $CH_4 + 2O_2$ | $= CO_2 + 2H_2O$ |
| Out of the reaction the ratio $CH_4 : CO_2$ | = 1:1 |
| $CH_4$ fed to burner for combustion | = 5 mol |
| ∴ Air : $CH_4$ | = 94,94 ÷ 5 |
| | = 18,99 : 1 |
| | ≈ 19:1 |

## 2.3 Burner equipment

### 2.3.1 Gas burner

This gas burner is a premix burner in which a proportional mixer uses air velocity to draw in a measured amount of gas.

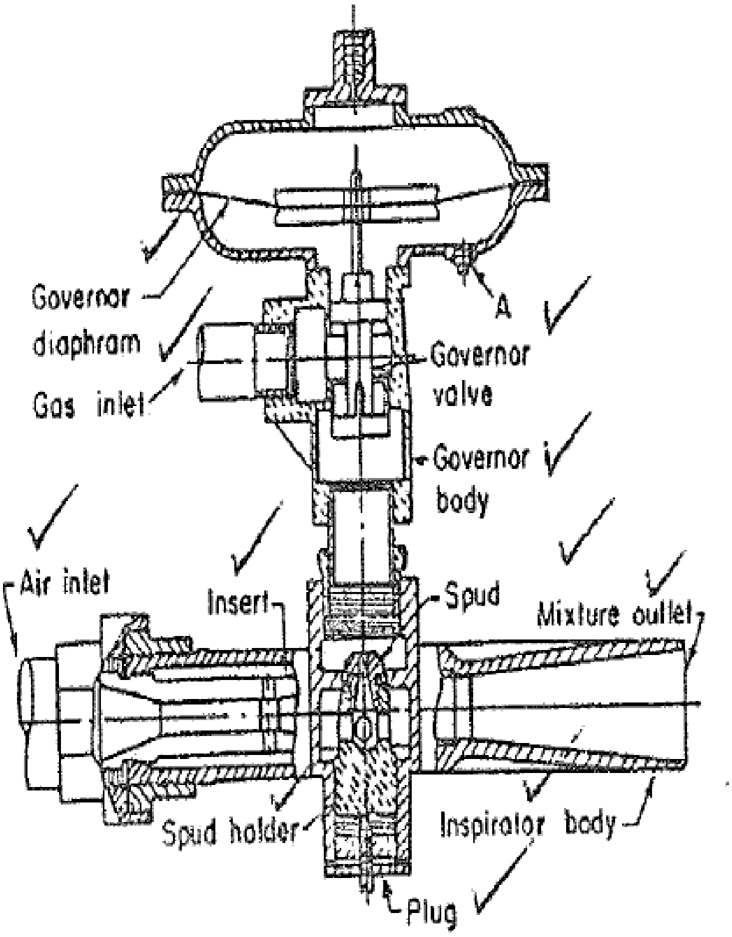



Figure 2.1 Premix burner

### 2.3.2 Nozzle-mix burners

This application mix air and gas at the burner tile. Gas can be emitted from the holes drilled in the end of the supply pipe.

Small diameter pipe can be inserted at the center of the burner or large-diameter rings can be extended to the outside of the burner tile.

These rings use very small holes and give better dispersion of gas in the air. Some burners use a "spider" through which gas is emitted.

### 2.3.3 Vaporising burners

In this application heat from the flame continually converts liquid fuel into a vapor in the combustion air, thus sustaining the flame. This principal is used in blowtorches, kerosene lamps, cigarette lighters, etc.

### 2.3.4 High-pressure steam or air-atomizing burner

Air or steam is use for atomizing. In the case of steam it heats the fuel oil and assists in combustion.

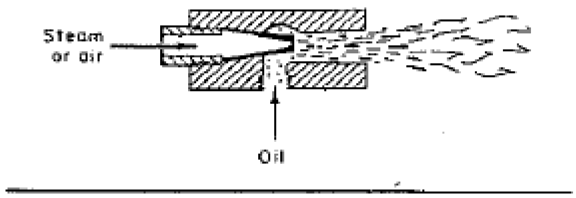



Figure 2.2

### 2.3.5 Atomizing oil burners

The fuel sprays from a nozzle under pressure or atomizes it with air or steam under pressure. Combustion air surrounds the fuel nozzle and it's blown into the furnace with the fuel spray.

Vanes and baffles are built into the air stream to assure proper air-fuel mixing. Oil spray usually enters the furnace through an ignition tile, which surrounds the burner.

### 2.3.6 Horizontal rotating-cup atomizing oil burner:

The fuel oil is preheated then mixed with the air before sprayed in under pressure. Atomizing oil burners spray the fuel from a nozzle or atomize it with air or steam.

Combustion air surrounds the fuel nozzle and is blown into the furnace with the fuel spray. Vanes and baffles are built into the air stream to assure proper air-fuel mixing.

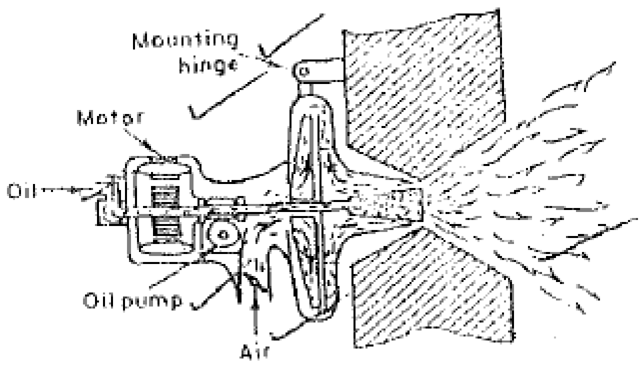



Figure 2.3

| | |
|---|---|
| | **Activity 2.1** |
| Complete **Activity 4.1** at the end of Module 4. | |

| Self-Check | | |
|---|---|---|
| **I am able to:** | **Yes** | **No** |
| • Define the combustions theory | | |
| • Demonstrate combustion calculations | | |
| • Describe burner equipment | | |
| If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development. | | |

# Module 3

# Separators, Cyclones and Mixers

**Learning Outcomes**

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

- Describe centrifuges
- Describe cyclones
- Describe mixers

## 3.1 Introduction

Cyclone Separators are designed to remove solids and liquids from a gas pipeline. Cyclone separators use multiple cyclone tubes to set the gas swirling. Liquids and solids are separated by centrifugal forces.

They are designed for a specific flow rate since reducing flows affect the cyclonic forces. The gas passing through the cyclone makes them virtually self-cleaning. They operate with a relatively high pressure loss though no allowance for cleaning is necessary. Cyclone separators are virtually maintenance free.

## 3.1 Centrifuges

### 3.1.1 Disk centrifuge

A short wide bowl turns on a vertical axis. The bowl has a flat bottom and conical top. Feed enters from above through a stationary pipe set into the neck of the bowl. Two liquid layers are formed as in a tubular centrifuge, which flow over adjustable dams into separate discharge spouts.

Inside the bowl and rotating with it are closely spaced "disks" which are actually cones of sheet metal set one above the other. Matching holes in the disks about halfway between the axis and the wall of the bowl from channels through which the liquid pass.

In operation feed liquid enters the bowl at the bottom, flows into the channels, and upward passed the disk. Heavier liquid is thrown outward, displacing lighter liquid toward the center of the bowl.

**Definition: Centrifuge**
A centrifuge is a piece of equipment, generally driven by an electric motor that puts an object in rotation around a fixed axis, applying a force perpendicular to the axis.

In its travel the heavy liquid very soon strikes the underside of a disk and flows beneath it to the periphery of the bowl without encountering any more light liquid. Light liquid similarly flows inward and upward over the upper surfaces of the disks.

### 3.1.2 Tubular centrifuge

The bowl is tall and narrow, turns in a stationary casing at about 15 000 r/min.

Feed enters from a stationary nozzle inserted through an opening in the bottom of the bowl. It separates into two concentric layers of liquid inside the bowl.

The inner or lighter layer spills over a weir at the top of the bowl, which is thrown outward into a spout. Heavy liquid flows over another weir into a separate cover and discharge spout.

### 3.1.3 Helical conveyor centrifuge

A cylindrical bowl with a conical end rotates about a horizontal axis. Feed enters through a stationary axial pipe spraying outward into a pond. Clarified liquid flows through overflow ports. Solids settle through the liquid to the inner surface of the bowl.

A helical conveyor turning slightly slower than the bowl moves the solids to the discharge opening. Drained sludge and clarified liquor are thrown out from the bowl into different parts of the casing, from which they leave through suitable openings.

**Definition: Helical**
Having the shape or form of a helix; spiral.

### 3.1.4 Nozzle-discharge centrifuge

The separator is a modified disk-type centrifuge with a double conical bowl. In the periphery of the bowl at its maximum diameter is a set of small holes or nozzles, perhaps 3 mm in diameter.

The central part of the bowl operates in the same way as the usual disk centrifuge, which overflowing either one or two streams of clarified liquid.

Solids are thrown to the periphery of the bowl and escape continuously through the nozzles, together with considerable liquid.

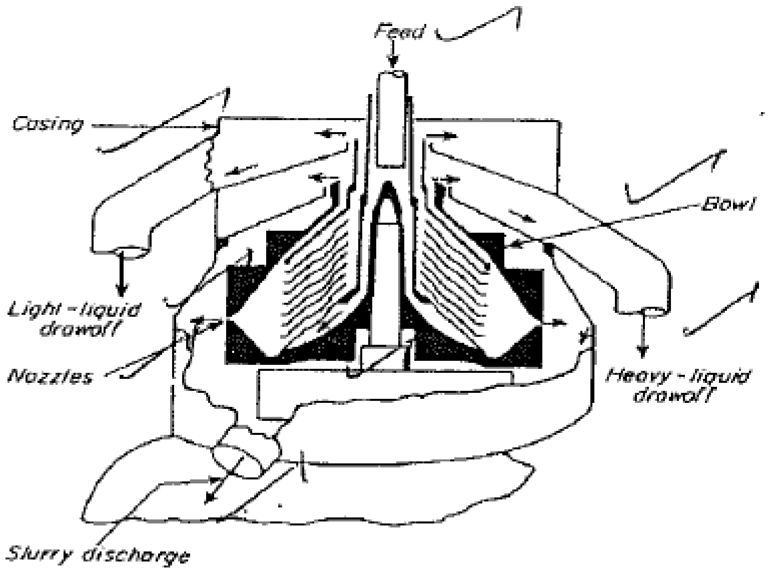



Figure 3.1

### 3.1.5 Impact wheels

Fine powders such as insecticides are blend by spreading out in thin layers under centrifugal action. A premix of several dry ingredients is fed continuously near the center of a high-speed spinning disk, which throws it outwards into a stationary casing.

The intense shearing forces acting on the powders during their travel over the disk surface thoroughly blend the various materials. The disks in some machines are in vertical and in other horizontal positions.

### 3.1.6 Continuous sludge separators:

In this helical-conveyer centrifuge a cylindrical bowl with conical end section rotates about a horizontal axis. Feed enters through a stationary axial pipe spraying outwards into a "pond" or annular layer of liquid inside the cylindrical bowl.

Solids settle through the liquid to the inner surface of the bowl. A helical conveyer turning slightly slower than the bowl moves the solids out of the pond and up on the "beach" to the discharge openings. Wash liquid may be sprayed on the solids as they travel up the beach to remove soluble impurities.

## 3.2 Cyclones

The incoming dust laden air receives a rotating motion on entrance to the cylinder. The vortex so formed develops centrifugal force, which act to throw the particles radially towards the wall. The path of the air in a cyclone follows a downward vortex or spiral adjacent to the wall and reaching to the bottom of the cone.

Particles leave the cyclone at the bottom. The air stream then moves upward in a tighter spiral, concentric with the first and leaves through the outlet pipe still whirling. Both spirals rotate in the same direction.

- The definite diameter of the particles, called the cut diameter, which can be defined as the diameter for which one- half the inlet particles by mass are separated and the other half retained by the air.
- The affectivity of a cyclone refers to the ordinate ability of a cyclone.

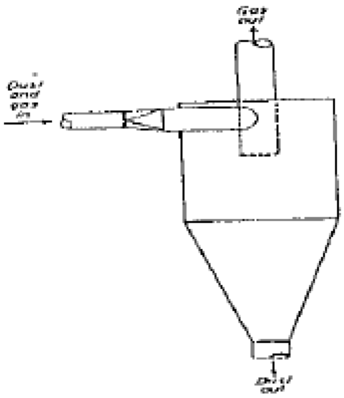



Figure 3.2

## 3.3 Mixers

### 3.3.1 Tumbling mixers

Tumbling them in a partly filled container rotating about a horizontal axis mixes many materials. Ball mills are often used as mixers. Most tumbling mills, however, do not contain grinding elements.

> **Note:**
> Tumbling mixers - use for dense solids in liquids and heavy dry powders.

Tumbling barrels, for example resemble ball mills without the balls, they effectively mix suspension of dense solids in liquids and heavy dry powders. The double-cone mixer is a popular mixer for free-flowing dry powders.

The twin-shell blender is made from two cylinders joined to from a "V" and rotated about a horizontal axis.

### 3.3.2 Pony mixer

The agitator consists of several vertical blades on a rotating head. The agitator is mounted eccentrically to the axis. The can rests on a turntable driven in a direction opposite to that of the agitator.

**Note:**
Pony mixers – use for dense solids in liquids and pastes.

When mixing is complete the agitator head is raised, lifting the blades out of the can. The can is replaced with another containing a new batch.

### 3.3.3 Ribbon mixer

Two counteracting ribbons are mounted on the same shaft. One moving slowly in one direction and the other quickly in the other direction. Mixing results from the turbulence induced by the agitators. Solids are fed in one end of the trough and discharged from the other.

**Note:**
Ribbon mixers - use for dry powders and thin pastes.

### 3.3.4 Muller mixer

In this design of Muller the pan is stationary and the central vertical shafts is driven causing the Muller wheels to roll in a circular path over a layer of solids on the pan floor.

The rubbing action results from the slip of the wheels on the solids. Plows guide the solids under the Muller wheels or to an opening in the pan floor at the end of the cycle when the mixer is being discharged .

**Note:**
Muller mixer - use for batches of heavy solids and paste, coating of Particles.

### 3.3.5 Two-arm kneader

In all these machines the mixing is done by two heavy blades on parallel horizontal shafts turning in a short trough with a saddle-shaped bottom. The blades turn towards each other drawing the mass downward over the point of the saddle then shearing it between the blades and the wall of the trough.

**Note:**
Two-arm kneader - use for suspension, pastes and light plastic Masses.

The circles of rotation of the blades are usually tangential so that the blades may turn at different speeds in any ratio. The common stigma blade is used for general purpose kneading. The double-naben or fishtail blade is particularly effective with heavy plastic materials. The dispersion blade develops the high shear forces needed to disperse powers or liquids into plastic or rubbery masses.

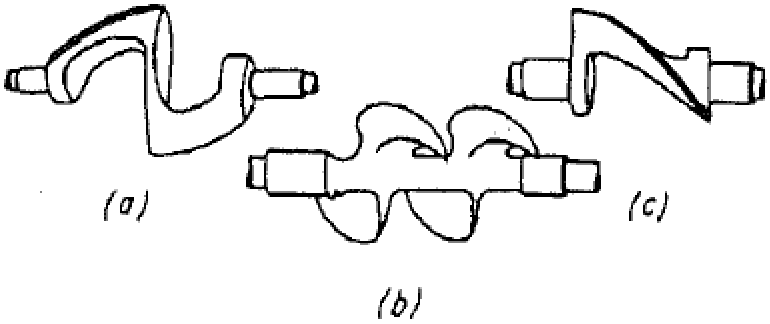



Figure 3.3 Application sketch (a) Common sigma blade (b) Dubble-naben or fishtail blade (c) Dispersion blade

**Did you know? Other different types of mixers**

- **Banbury**: Use for heavy, stiff or gummy materials.
- **Internal screw**: Use for free flowing grains and light solids.
- **Impact wheels**: Use for fine light powders such as insecticides.
- **Change-can**: Use for blend viscous liquids or light pastes as in food processing or paint manufacturing.

## Activity 3.1

Complete **Activity 4.1** at the end of Module 4.

**Self-Check**

| **I am able to:** | **Yes** | **No** |
|---|---|---|
| • Describe centrifuges | | |
| • Describe cyclones | | |
| • Describe mixers | | |

If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.

# Module 4

# Industrial Chemical Process

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

- Describe the sulphur-burning process
- Describe the production of nitric acid with 60% concentration
- Describe the production of hydrochloric acid using the salt process
- Describe the use of production reaction calculations
- Describe enthalpy difference calculation of a gas

## 4.1 Introduction

In a scientific sense, a chemical process is a method or means of somehow changing one or more chemicals or chemical compounds. Such a chemical process can occur by itself or be caused by an outside force, and involves a chemical reaction of some sort.
In an "engineering" sense, a chemical process is a method intended to be used in manufacturing or on an industrial scale to change the composition of chemicals or materials, usually using technology similar or related to that used in chemical plants or the chemical industry.

## 4.2 Sulphur-burning process

Commercially the production through sulfur burning is the most common process practice.

**Note:**
The burning of sulphur ----------------- $S + O_2 \rightarrow SO_2$

This plant type is the simplest and cheapest for the production of sulphuric acid because, no special purification of burner gases is not required.

Also no need to heat sulphur dioxide gases, only cooling is required and all the evolved heat may be recovered to produce relative high-pressure steam.

Chronological description of the process

- $SO_2$ is produced by the burning of Sulphur (S).
- As the gases from the combustion pass through the next exchanger, which heat the water for the boilers.
- The cooled gases are pumped into the absorbers through acid proof pump.
- The gas flows through the steam tower and is then cooled.
- The gas is then passed through a drying tower in which sulphuric acid is used.
- Sulphur dioxide is liquefied by compression and stored in cylinders.

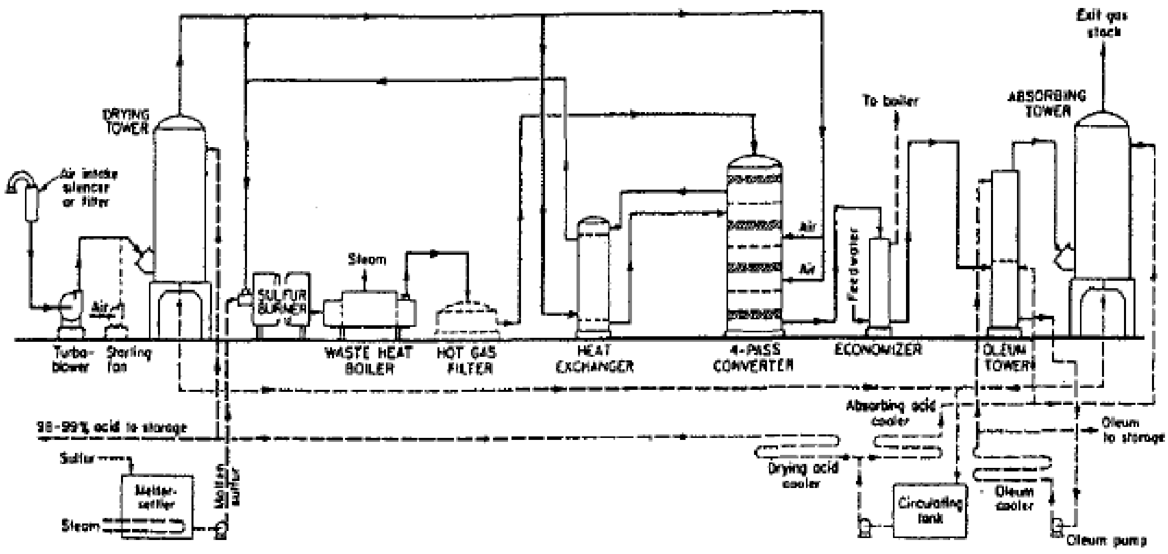



Figure 4.1 Typical Production Flowchart

Physical-Chemical Principles Influence the conversion of $SO_2$ to $SO_3$

- Reaction rate increases:
  - Temperature is raised from about 410°C to 600°C
  - Increase of $SO_2$ or $O_2$
  - Increase in pressure
  - Removal of portion of $SO_3$ formed
  - Clean $SO_2$

- Reaction rate decreases:
  - When equilibrium is approached
  - Stop when 60% to 70% of $SO_2$ has been converted
  - 410°C > temperature > 600°C.

- Maximize the chemical conversion of S02 to S03
  The following to be bear in mind:

- o Equilibrium is an inverse function of temperature and a direct function of the $O_2/SO_2$ ratio
- o Rate of reaction is a direct function of temperature
- o Composition and ratio of the amount of catalyst to the amount of $SO_3$ formed
- o Removal of $SO_3$ causes more $SO_2$ to be converted

## 4.3 Production of Nitric acid (60% concentration) from ammonia

Chronological description of the process:

- Anhydrous $NH_3$ is evaporated continuously and uniformly in an evaporator using steam to supply the necessary heat of evaporation.
- Air for reactions is compressed in a power-recovery compressor and in a steam driven compressor and passed through heat exchangers and an air filter.
- $NH_3$ gas is oxidized with air to NO at a pressure in a converter by passing it through platinum - 10% rhodium gauze at 920°C.
- Then NO with the excess air necessary for the succeeding oxidizing steps is cooled in a waste-heat boiler and a water cooler and conducted to the bottom of the absorption tower.
- Successive oxidants and hydrations of the NO are carried out with continuous water-cooling in a stainless steel absorption tower.
- The acid (61% - 65% $HNO_3$) is drawn off through an acid trap.
- The waste gas from the top of the absorption tower is heated in an exchanger counter to reaction gasses and expanded through a compressor (expander) for part of the air before being exhausted to the atmosphere.

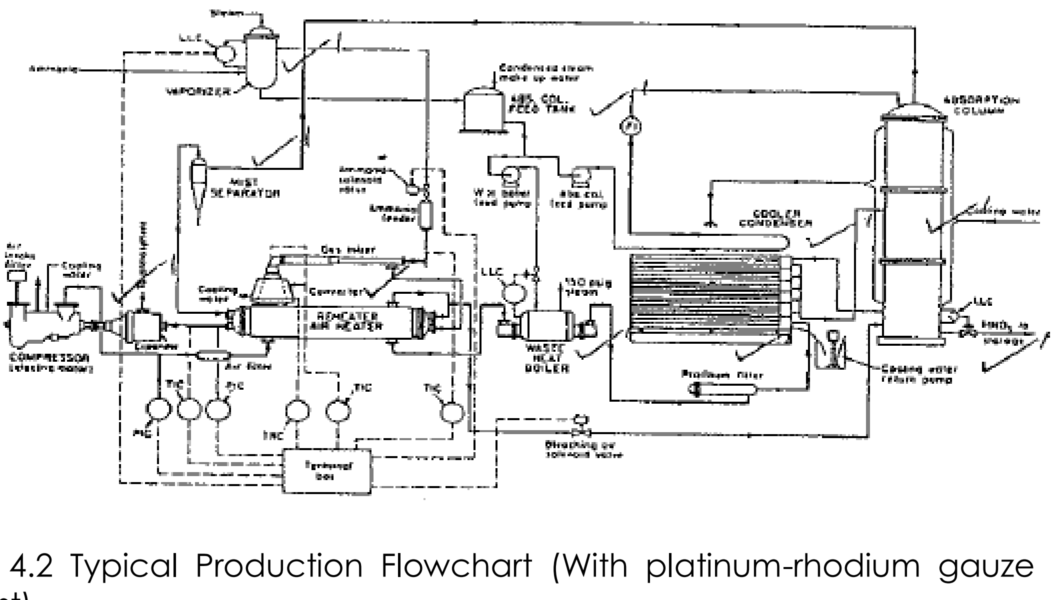



Figure 4.2 Typical Production Flowchart (With platinum-rhodium gauze as a catalyst)

## 4.4 Production of Hydrochloric acid (salt process)

- Chronological description of the process

- Sulphuric acid and salt are roasted in a furnace to from hydrogen chloride and sodium sulphate.
- Passing it through coolers cooled externally by water, the hot hydrogen chloride contaminated with droplets of sulphuric acid and particles of salt cake.
- The cooled gas is then passed through a coke tower to remove suspended foreign materials.
- Purified hydrogen chloride from the top of the coke tower is absorbed in water in a tantalum of carbide absorber.
- Finished hydrochloric acid is withdrawn from the bottom of the absorber.

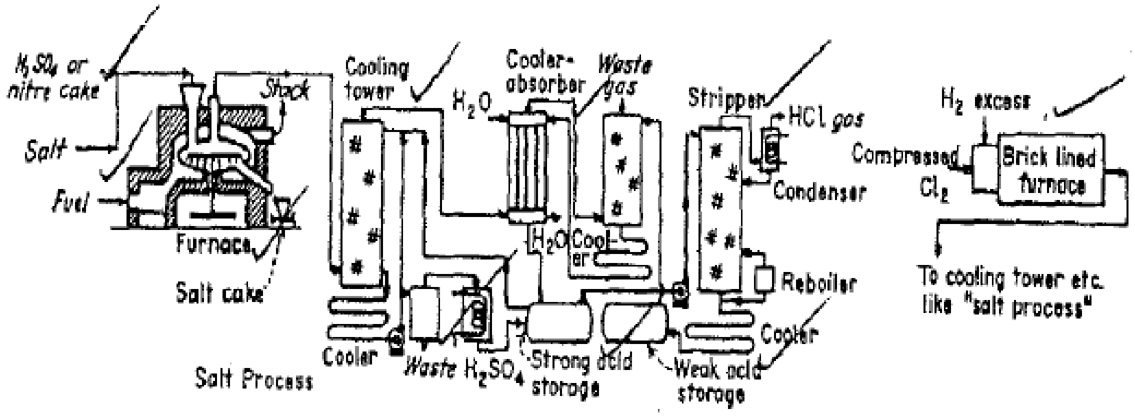



Figure 4.3 Typical Production Flowchart

## 4.5 Production reaction calculations

### 4.5.1 Hess' law

The heat of reaction equals the sum of the heats of formation of the products, minus the sum of the heats of formation of the reactants $\Delta H = \sum \Delta H_f$ (products) $- \sum \Delta H_f$ (reactants).

**Note:**

- A steady-state operation is one in which conditions within the process or system does not change with time, that is one moment to another.
- One mole of carbon is exactly 0,012 kg of this substance in the SI system.
- The relationship between SI moles and mass is as follows:
  Moles (SI) = (Mass in kg ÷ Molecular weight) x 1 000
- The gram-mol in the SI - system is the formula weight of a substance expressed in grams, and represents Avogrardo's number and therefor:
  Gram mole = mass in grams / molecular weight

### 4.5.2 Standard heat of formation ($\Delta \mathrm{H}_f$)

Refers to the heat of reaction involved in the formation of a compound from its constituent elements when all chemical species are in a stable state (physical state) at 25°C and one atmosphere. Thus 4,187 calories = 1 Joule.

### 4.5.3 Reaction heat calculation

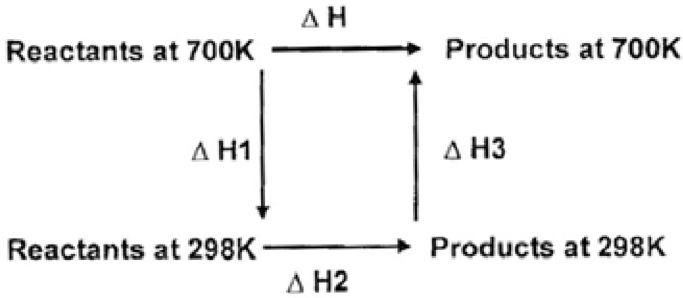
| K | $H_2$ | $N_2$ | CO | Air | $O_2$ | HCl | $Cl_2$ | $H_2O$ | $CO_2$ | $SO_2$ | $SO_3$ | $CH_4$ | $C_2H_4$ | $C_2H_4$ | $NH_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 298 | 28.84 | 29.13 | 29.18 | 29.18 | 29.39 | 29.13 | 33.99 | 33.57 | 37.57 | 40.14 | 50.69 | 35.79 | 43.74 | 52.87 | 35.50 |
| 400 | 29.01 | 29.21 | 29.32 | 29.32 | 29.75 | 29.19 | 34.57 | 33.94 | 39.23 | 41.68 | 54.77 | 38.31 | 48.85 | 59.31 | 37.21 |
| 500 | 29.15 | 29.35 | 29.45 | 29.45 | 30.18 | 29.24 | 35.16 | 34.40 | 40.07 | 43.32 | 58.42 | 41.03 | 53.71 | 65.56 | 38.76 |
| 600 | 29.19 | 29.53 | 29.67 | 29.69 | 30.65 | 29.32 | 35.58 | 34.93 | 42.72 | 44.81 | 61.63 | 43.84 | 58.29 | 71.56 | 40.19 |
| 700 | 29.24 | 29.98 | 29.98 | 30.02 | 31.14 | 29.43 | 35.86 | 35.35 | 44.16 | 46.11 | 64.40 | 46.69 | 62.46 | 77.26 | 41.55 |
| 800 | 29.31 | 30.27 | 30.27 | 30.34 | 31.60 | 29.60 | 36.10 | 35.90 | 45.43 | 47.23 | 66.80 | 49.46 | 66.26 | 83.30 | 42.89 |
| 900 | 29.36 | 30.61 | 30.61 | 30.64 | 32.00 | 29.78 | 36.30 | 36.49 | 46.54 | 48.17 | 68.85 | 52.23 | 69.73 | 87.39 | 44.23 |
| 1000 | 29.46 | 30.93 | 30.93 | 30.94 | 32.37 | 30.00 | 36.45 | 37.08 | 47.56 | 49.01 | 70.27 | 54.66 | 72.91 | 91.93 | 45.56 |
| 1100 | 29.57 | 31.24 | 31.24 | 31.27 | 32.70 | 30.25 | 36.59 | 37.68 | 48.50 | 49.75 | 72.27 | 57.06 | 75.91 | 96.20 | 48.86 |
| 1200 | 29.69 | 31.56 | 31.56 | 31.56 | 33.02 | 30.49 | 36.74 | 38.29 | 49.35 | 50.43 | 73.72 | 59.43 | 78.66 | 100.00 | 48.16 |
| 1300 | 29.89 | 31.84 | 31.84 | 31.93 | 33.32 | 30.75 | 36.85 | 39.89 | 50.10 | 51.01 | 75.11 | 61.49 | 81.15 | 103.09 | 49.44 |
| 1400 | 30.07 | 32.09 | 32.09 | 32.13 | 33.60 | 31.00 | 36.94 | 39.45 | 50.82 | 51.53 | 76.36 | 63.47 | 83.51 | 107.17 | 50.71 |
| 1500 | 30.23 | 32.34 | 32.34 | 32.38 | 33.84 | | | 40.01 | 51.43 | | | | | | |
| 1600 | 30.39 | 32.58 | 32.58 | 32.61 | 34.05 | | | 40.56 | 51.99 | | | | | | |
| 1700 | 30.56 | 32.79 | 32.79 | 32.79 | 34.23 | | | 40.03 | 52.54 | | | | | | |
| 1800 | 30.75 | 32.67 | 33.00 | 33.01 | 34.40 | | | 41.47 | 53.18 | | | | | | |
| 1900 | 30.97 | 32.86 | 33.20 | 33.24 | 34.66 | | | 41.84 | 53.43 | | | | | | |
| 2000 | 31.12 | 33.03 | 33.37 | 33.41 | 34.83 | | | 42.53 | 53.74 | | | | | | |
| 2100 | 31.32 | 33.20 | 33.52 | 33.56 | 34.98 | | | 42.98 | 54.25 | | | | | | |
| 2200 | 31.48 | 33.35 | 33.70 | 33.70 | 35.12 | | | 43.41 | 54.56 | | | | | | |

Table 4.1 Mean molar heat capacities of gases at constant pressure [kJ/(kmol.K)]

**Worked Example 4.1**

Determine the heat of reaction at 700 K and *one* atmosphere of reaction: $\frac{1}{2}H_2 + \frac{1}{2}Cl_2 = HCl$.

**Answer:**




$\Delta H = H1 + H2 + H3$

H1 $= \frac{1}{2} \times Cp_{700K}\ H_2\ \Delta t + \frac{1}{2}\ Cp_{700K}\ Cl_2\ \Delta t$
$= \frac{1}{2} \times 29{,}24(298 - 700) + \frac{1}{2} \times 35{,}86(298\text{-}700)$
$= (-5\ 877) + (-7\ 208)$ kJ/K mol
$= -13\ 085$ kJ/K mol

H2 $= -92\ 430$ kJ/K mol --- Standard heat of gas formation at one atmosphere

H3 $= 1 \times 29{,}43 \times (700 - 289)$ --- $Cp_{700K}$ HCl = 29,43 kJ/Kmol

= 11 831 kJ/K mol

$\Delta H$ = Heat of reaction at 700K
= -13 085 + -92 300 + 11 831
= -93 554 kJ/K mol

### 4.5.4 Enthalpy change of a gas

**Worked Example 4.2**

Determine the enthalpy change in kilocalories of 10 mol nitrogen between 600°C and 1 500°C.

**Answer:**

$\Delta H$ = $nCp_f\ (T_f - 25) - nCp_1\ (T_1 - 25)$
= 10 [(32,04 x (1 500- 25))- (29,19 x (600- 25))]
= 10 (47 259 - 16 784,25) Joules
= 304 747,5 ÷ 4,187 calories
= 72,784 Kcal

### 4.5.5 Reactor ratio calculation

**Worked Example 4.3**

The composition of the combined feed to a reactor at entrance and the products leaving the reactor are as follows:

| | Combined feed (mol%) : | Product from reactor (mol%) |
|---|---|---|
| $C_6H_{14}$ | 0 | 5,0 |
| $C_7H_{14}$ | 0 | 15,0 |
| $C_8H_{18}$ | 3,1 | 20,0 |
| $C_{11}H_{24}$ | 8,5 | 23,8 |
| $C_{12}H_{24}$ | 18,2 | 12,2 |
| $C_{15}H_{32}$ | 35,2 | 20,0 |
| $C_{18}H_{36}$ | 35,5 | 24,0 |

**Answer:**

| C-atom balance ratio = | Combine feed | | | ÷ Reactor product | | |
|---|---|---|---|---|---|---|
| $C_6H_{14}$ | 6 x 0 | = | 0 | 6 x 5,0 | = | 30,0 |
| $C_7H_{14}$ | 7 x 0 | = | 0 | 7 x 15,0 | = | 105,0 |
| $C_8H_{18}$ | 8 x 3,1 | = | 24,8 | 8 x 20,0 | = | 160,0 |
| $C_{11}H_{24}$ | 11 x 8,5 | = | 93,5 | 11 x 23,8 | = | 261,8 |
| $C_{12}H_{24}$ | 12 x 18,2 | = | 218,4 | 12 x 12,2 | = | 146,4 |
| $C_{15}H_{32}$ | 15 x 35,2 | = | 528,0 | 15 x 20,0 | = | 300,0 |

| | | |
|---|---|---|
| $C_{18}H_{36}$ | 18 x 35,0 = 630,0 | 18 x 24,0 = 432,0 |
| Totals | = 1494,7 : | 1435,2 |

Ratio = <u>1 : 1,042</u>

### 4.5.6 Steam consumption to produce $H_2$

**Worked Example 4.4**

One of the techniques for producing H2 is to react methane and ethane with steam in the presence of a nickel catalyst. Assume the analysis on a dry basis of the gasses leaving the reactors is as follow:

$CH_4$ 4,8mol%    CO 18,6mol%    $H_2$ 69,7mol%
$C_2H_6$ 2,3mol%    $CO_2$ 4,6mol%

Assuming that only methane and ethane are present in the hydrocarbon feed to the reactor and that 1 gram mol gas= 22,4 liters.

Determine how many kg of steam react in the reactor per 1 ton of hydrocarbon feed gas?

**Answer:**

| Input | Atoms | | | Output Comp. | H | C | D |
|---|---|---|---|---|---|---|---|
| | C | H | O | | | | |
| $CH_4$ | 1 | 4 | | 4,8% | 19,2 | 4,8 | - |
| $C_2H_6$ | 2 | 6 | | 2,3% | 13,8 | 4,6 | - |
| CO | | | | 18,6% | - | 18,6 | 18,6 |
| $CO_2$ | | | | 4,6% | - | 4,6 | 9,2 |
| $H_2$ | | | | 69,7% | 139,4 | - | - |
| $H_2O$ | | 2 | 1 | - | 0 | - | 0 |
| Total | 3 | 12 | 1 | | 172,4 | 32,6 | 27,8 |

<u>Solving the equations simultaneously</u>

- H- atom balance = 172,4 / 12 = 14,4
- C- atom balance = 32,6 / 3 = 10,9
- O- atom balance = 27,8 / 1 = 27,8

K mol in 1 000 m$^3$ feed = 1 000 / 22,4
= 44,64 k mol

Kg Steam required = [44,64 x 27,8 / (14,4 + 10,9)] x [2 + 16] ← *amu of $H_2O$*

= 49,05 x 18
= 882,9 kg steam / ton fed gas

### 4.5.7 Chloro-benzene production

**Worked Example 4.5**

The following reaction is applicable to produce $C_6H_5Cl$

$C_6H_6 + HCl + ½O_2 \rightarrow C_6H_5Cl + H_2O$

After the waste gas from such a process has been scrubbed to remove any unreacted HCl, $C_6H_6$ and all products, its composition is $N_2$ = 88,8 mol % and $O_2$ - 11,2 mol %.

Determine the number of moles of chloro-benzene.

**Answer:**

$N_2 : O_2$ -------- per 100 mol % of air
79 : 21

$O_2$ fed = (21 x 88,8) / 79
= 23,6 mol O2
$O_2$ used = 23,6 – 11,2
= 12,4 mol / ½ -------- from the reaction
= 4,8mol $C_6H_5Cl$ ------ $O_2 : C_6H_5Cl$
$C_6H_5Cl$ : Air = 24,8 / *88,8 + 23,6)
= <u>0,22 : 1</u>

### 4.5.8 Limiting reactant

**Worked Example 4.6**

Which reactant is the limiting reaction, if 5kg of methanol and 2kg of ammonia are reacted to from mono-methylamine by the reaction:

$CH_3OH + NH_3 \rightarrow CH_3NH_2 + H_2O$

**Answer:**
Molecular mass of $CH_3OH$ = 12 + 3 +16 +1 = 32 amu
Molecular mass of $NH_3$ = 14 +3 + = 17 amu

n $= \frac{m}{m}$
n $CH_3OH$ = 5 000 / 32

| | | |
|---|---|---|
| | = 156,25 mol | |
| n $NH_3$ | = 2 000 / 17 | |
| | = 117,65 mol | |
| $CH_3OH : NH_3$ | = 1:1 | ------- From the reaction |
| ∴156,25 / 117,65 | = 1,328 | |
| | > 1 | ---- Thus $NH_3$ is the limiting reactant |

### 4.5.9 Gas composition calculation

**Worked Example 4.7**

A gas has the following composition:

$$NaC\ell\ 25\%\left(\frac{m}{m}\right) NaOH\ 5\%\left(\frac{m}{m}\right) \text{ and } H_2O\left(\frac{m}{m}\right)$$

Determine the composition in mol %

**Answer:**
Accept: mol/100g

| Mass/mol | Mol | | Mol/% |
|---|---|---|---|
| NaCl : 25 / 58,45 | = 0,428 | ------- (0,428 / 4,442)100 | = 9,635 |
| NaOH : 5 / 40 | = 0,125 | -------- (0,125 / 4,442)100 | = 2,814 |
| $H_2O$ : 70 / 18 | = 3,889 | -------- (3,889 / 4,442)100 | = 87,551 |
| Total | = 4,442 | | 100% |

See **Table 4.2**

| Compound | Formula | Molecular weight | Normal melting point °C | Normal boiling point °C | Specific gravity at °C |
|---|---|---|---|---|---|
| 52. Nitric acid | $HNO_3$ | 63.02 | -42 | 86 | 1.50 (2) |
| 53. Nitrogen | $N_2$ | 28.02 | -209.86 | -195.8 | ... |
| 54. Nitrogen oxide | $N_2O$ | 44.02 | -102.3 | -90.7 | ... |
| 55. Nitrogen oxide | NO | 30.01 | -161 | -151 | ... |
| 56. Nitrogen oxide | $NO_2$ | 46.01 | -9.3 | 21.3 | ... |
| Si. Oxygen | $O_2$ | 32.00 | -218.4 | -183 | ... |
| 58. Phosphorus (yellow) | $P_4$ | 123.92 | 44.1 | 280 | 1.82 (20) |
| 59. Potassium | K | 39.10 | 62.3 | 760 | 0.86 (20) |
| 60. Potassium carbonate | $K_2CO_3$ | 138.20 | 891 | d. | 2.29 (20) |
| 61. Potassium chloride | KCl | 74.56 | 770 | 1407 | 1.99 (20) |
| 62. Potassium hydroxide | KOH | 56.1 | 380 | 1320 | 2.04 (20) |
| 63. Potassium nitrate | $KNO_3$ | 101.1 | 333 | d. 400 | 2.11 (10) |
| 64. Potassium sulfate | $K_2SO_4$ | 174.25 | 1074 | ... | 2.66 (20) |
| 65. Silicon dioxide | $SiO_3$ | 60.06 | 1425 | 2230 | 2.65 (20) |

| | | | | | |
|---|---|---|---|---|---|
| 66. Silver | Ag | 107.88 | 960.5 | 1950 | 10.5 (20) |
| 67. Sodium | Na | 23 | 97.7 | 880 | 0.97 (20) |
| 68. Sodium acetate | $NaC_2H_3O_2$ | 82.04 | 324 | … | 1.52 (20) |
| 69. Sodium bicarbonate | $NaHCO_3$ | 84.01 | $-CO_2$ 270 | … | 2.20 (20) |
| 70. Sodium bisulfate | $NaHSO_4$ | 120.06 | 315 | d. | 2.74 (20) |
| 71. Sodium carbonate | $Na_2CO_3$ | 106 | 851 | d. | 2.53 (20) |
| 71. Sodium chloride | NaCl | 58.45 | 800.4 | 1413 | 2.16 (20) |
| 13. Sodium hydroxide | NaOH | 40 | 318.4 | 1390 | 2.13 (20) |
| 74. Sodium nitrate | $NaNO_3$ | 85.01 | 308 | d. 380 | 2.26 (20) |
| 15. Sodium phosphate | $Na_3 PO_4$ | 163.97 | 1340 | … | 2.54 (18) |
| 76. Sodium sulfate | $Na_2SO^4$ | 142.05 | 884 | … | 2.70 (20) |
| 77. Sulfur (amorphous) | S | 32.06 | 120 | 444.6 | 2.05 (20) |
| 78. Sulfur (monoclinic) | $S_8$ | 256.48 | 119 | 444.6 | 1.96 (20) |
| 79. Sulfux (rhombic) | $S_8$ | 256.48 | 112.8 | 444.6 | 2.07 (20) |
| 80. Sulfur dioxide | $SO_2$ | 64.06 | -75.5 | -10 | … |
| 81. Sulfur trioxide | $SO_3$ | 80.06 | 16.8 | 44.6 | … |
| 81. Sulfuric acid | $H_2SO_4$ | 98.08 | 10.5 | d. 340 | 1.83 (18) |
| 83. Uranium | U | 238.07 | 1133 | 3500 | 18.49 (20) |
| 84. Uranium oxide | $UO_2$ | 270.07 | 2176 | … | 10.9 (20) |
| &S. Uranium oxide | $U_3O_3$ | 842.21 | d. | … | 7.31 (20) |
| 86. Vanadium oxide | $V_2O_2$ | 181.9 | 800 | d. 1750 | 3.36 (18) |
| 87. Water | $H_2O$ | 18.02 | 0 | 100 | 1.00 (4) |
| 88. Water (heavy) | $D_2O$ | 20.03 | 3.8 | 101.4 | 1.11 (20) |
| 89. Zinc | Zn | 65.38 | 419.4 | 907 | 7.14 (20) |
| 90. Zinc carbonate | $ZnCO_3$ | 125.39 | $-CO_2$ 300 | … | 4.42 (20) |
| 91. Zinc chloride | $ZnCl_2$ | 136.29 | 283 | 732 | 2.91 (25) |
| 92. Zinc sulfate | $ZnSO_4$ | 161.44 | d. 740 | … | 3.74 (15) |
| 93. Zinc sulfide | ZnS | 97.44 | 1645 | … | 4.10 (25) |

Table 4.2

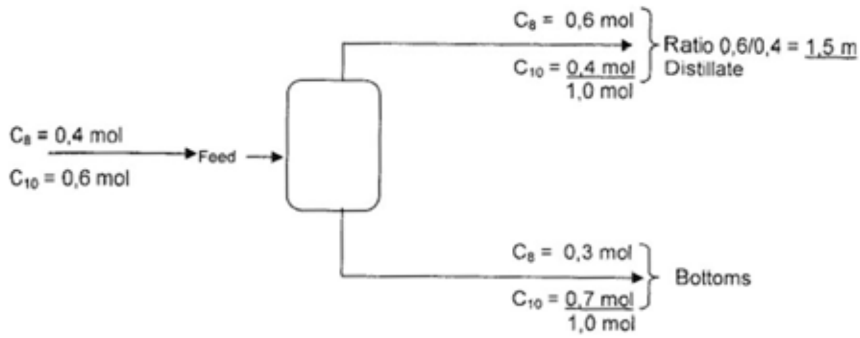
### 4.5.10 Distillation composition calculation

**Worked Example 4.8**

The feed to a distillation column contains 0,4 mol fraction $C_8$ and 0,6 mol fraction $C_{10}$ hydrocarbons. If the composition of the distillate is 0,6 mol fraction $C_8$ and 0,4 mol fraction $C_{10}$ and the composition at the bottoms is 0,3 mol fraction $C_8$ and 0,7 mol fraction $C_{10}$, on the basis of 100 mol of feed.

Calculate how many moles of distillate and bottoms are produced?

**Answer:**




Basis = 100 mole feed

| Input | | Output | |
|---|---|---|---|
| **Subs** | **Mole** | **Subs** | **Mole** |
| $C_8$ = 100 x 0,4 | | $C_8$ = 0,6 D | |
| $C_{10}$ = 100 x 0,6 | | $C_{10}$ = 0,4 D | |
| $C_8$ = 100 x 0,3 | | $C_8$ = 0,3 B | |
| $C_{10}$ = 100 x 0,7 | | $C_{10}$ = 0,7 B | |

1. $C_8$ Balance: 40 = 0,6 D + 0,3 B
2. $C_{10}$ Balance: 60 = 0,4 D + 0,7 B
3. [ 2 ] x 1,5 90 = 0,6 D + 1,05 B
4. [3-1] 60 = 0,75 B

Bottoms production: 60 ÷ 90 x 100 = 66,67 mol

∴ Distillate production: 100-66,67 = 33,33 mol

### 4.5.11 Enthalpy calculation

**Worked Example 4.9**

Compute the difference in enthalpy of chloroform at one atmosphere, between 420 and 273K.

**Answer:**

ΔH = H9Sup.heat steam @ 420K – H(sat.vap.@334,9 K + $\Delta H_{vap}$ + H(sat.Liq@273K)

$$= \int_{t1}^{t2} (a+bT+cT^2+dT^3)dt + \Delta H_{vap}\ NBP + \int_{273}^{334,9} 116,8dT$$

$$= a(T_2^2-T_1^1)+b/2(T_2^2-T_1^2)+c/3(T_2^3-T_1^3)+d/4(T^4-T^4)+[29\ 600+\{(t_1-t)mol\ H\ of\ liq\}]$$

= 31,86(420-334,9)+14,49/2 x$10^{-2}$ ($420^2$-$334,9^2$)+ -11,7/3x$10^{-5}$($420^3$-

| | |
|---|---|
| | $334,9^3)+30,74/4\times10^{-9}(420^4-334,9^4)+29\ 600+[116,8(334,9-273)]$ |
| = | 2 711,29+46 543,22+-13 600+142,46+29 600+7 229,92 |
| **=** | **42 978,00 kJ/kmol** |

See **Table 4.3** on next page AND **4.6 Calculation attachment**

Table 4.3

| Compound | Formula | Molecular weight | Normal melting point °C | Normal boiling point °C | Specific gravity of liquid at °C | Enthalpies (kcal/g mol) | | | | | | Molar heat capacities [cal/(g mol – K)] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Physical state at 25 °C | Heat of formation $\Delta H_F$ | Heat of combustion $\Delta H_C$ | Heat of fusion $\Delta H_{fus}$ | Heat of vaporisation $\Delta H_{vap}$ | | Of the liquid | Of the gas $C_p = a + bT + cT^2 + dT^3$ | | | | |
| | | | | | | | | | | At 25°C | At NBP | | $a$ | $b \times 10^2$ | $c \times 10^5$ | $d \times 10^9$ | Range °C |
| 1. Acetaldehyde | $CH_3CHO$ | 44.05 | -121 | 20.8 | 0.783 (18) | g | -39.72 | -284.98 | 0.77 | ... | 5.86 | ... | 4.19 | 3.164 | -0.515 | -3.800 | 0-1200 |
| 2. Acetic acid | $CH_3COOH$ | 60.05 | 16.7 | 118.0 | 1.049 (20) | | -116.4 | -208.34 | 2.80 | 11.48 | 5.81 | 28.1 | | | | | |
| 3. Acetone | $CH_3COCH_3$ | 58.08 | -95.4 | 56.2 | 0.790 (20) | | -19.32 | -427.79 | 1.36 | 7.53 | 7.23 | 30.6 | 1.625 | 6.661 | -3.737 | 8.307 | 0-1200 |
| 4. Acetylene | $CH{\equiv}CH$ | 26.04 | .... | -84.0 | ... | | +54.19 | -310.6 | ... | ... | 4.76 | ... | 5.21 | 2.201 | -1.559 | 4.349 | 0-1200 |
| 5. n-Amyl alcohol | $C_5H_{11}OH$ | 88.15 | -79.0 | 137.9 | 0.814 (20) | | ... | -786.7 | 2.35 | ... | 10.58 | 62.7 | | | | | |
| 6. Aniline | $C_6H_5NH_2$ | 93.12 | -6.3 | 184.2 | 1.022 (20) | | ... | -812 | 1.95 | ... | 9.65 | 47.4 | | | | | |
| 7. Anthracene | $C_{14}H_{10}$ | 178.24 | 216.3 | 340 | 1.283 (20) | | ... | -1712.0 | 6.90 | ... | 16.82 | | | | | | |
| 8. Benzene | $C_6H_6$ | 78.11 | 5.5 | 80.1 | 0.879 (20) | | +19.82 | -781.0 | 2.35 | 8.09 | 7.35 | 26.5 | -8.650 | 11.578 | -7.540 | 18.54 | 0-1200 |
| 9. Benzoic acid | $C_6H_5COOH$ | 122.12 | 122.4 | 249 | 1.266 (15) | | ... | -771.5 | 4.14 | ... | ... | 51.7 | | | -5.582 | | |
| 10. 1,3-Butadiene | $C_4H_6$ | 54.10 | -108.9 | -4.4 | ... | | +26.33 | -607.5 | ... | ... | 5.40 | ... | -1.29 | 8.350 | -4.380 | 14.24 | 0-1200 |
| 11. n-Butane | $C_4H_{10}$ | 58.12 | -138.4 | -0.5 | ... | | -30.15 | -687.7 | 1.11 | 5.04 | 5.35 | 31.9 | 0.945 | 8.873 | -5.110 | 8.36 | 0-1200 |
| 12. Butene-1 | $CH_2{=}C_2H_6$ | 56.10 | -185.4 | -6.3 | ... | | -0.03 | -649.5 | 0.92 | 4.87 | 5.24 | ... | -0.240 | 8.650 | | 12.07 | 0-1200 |
| 13. n-Butyl alcohol | $C_4H_9OH$ | 74.12 | -89.5 | 117.3 | 0.810 (20) | | -79.61 | -638.18 | 2.24 | 11.80 | 10.46 | 41.7 | | | | | |
| 14. Carbon dioxide | $CO_2$ | 44.01 | -56.6 | -78.5 | ... | | -94.05 | 0.0 | 1.90 | 6.03 | ... | ... | 5.316 | 1.429 | -0.836 | 1.784 | 0-1500 |
| 15. Carbon disulfide | $CS_2$ | 76.13 | -111.5 | 46.3 | 1.263 (20) | | +21.0 | -256.97 | 1.05 | 6.55 | 6.40 | ... | 7.390 | 1.489 | -1.096 | 2.760 | 0-1200 |
| 16. Carbon (graphite) | C | 12.01 | 3660 | 4200 | ... | | 0 | -94.05 | | | | | | | | | |
| 17. Carbon monoxide | CO | 28.01 | -205 | -191.5 | ... | | -26.42 | -67.64 | 0.20 | ... | 1.44 | ... | 6.726 | 0.040 | 0.128 | -0.531 | 0-1500 |
| 18. Carbon tetrachloride | $CCl_4$ | 153.84 | -23.0 | 76.5 | 1.594 (20) | | -33.34 | -84.17 | 6.41 | 7.84 | 7.04 | 30.9 | 12.24 | 3.400 | -2.995 | 8.828 | 0-1200 |
| 19. Chlorobenzene | $C_6H_5Cl$ | 112.56 | -45.6 | 132 | 1.106 (20) | | -12.39 | ... | ... | ... | 8.73 | 34.6 | -6.1 | 11.45 | -7.58 | 18.54 | |
| 20. Chloroform | $CHCl_3$ | 119.39 | -63.5 | 61.7 | 1.483 (20) | | ... | -114.3 | 2.2 | ... | 7.06 | 27.9 | 7.61 | 3.461 | -2.668 | 7.344 | 0-1200 |
| 21. Cyclohexane | $C_6H_{12}$ | 84.16 | 6.6 | 80.7 | 0.779 (20) | | -37.34 | -936.9 | 0.64 | 7.90 | 7.19 | ... | -15.94 | 16.454 | -9.203 | 19.27 | 0-1200 |
| 22. Cyclopentane | $C_5H_{10}$ | 70.13 | -93.9 | 49.3 | 0.746 (20) | | -25.30 | -786.3 | 0.15 | 6.82 | 6.52 | ... | -12.96 | 13.087 | -7.447 | 16.41 | 0-1200 |
| 23. Cyanamide | $H_2NCN$ | 42.04 | 42 | d. | 1.073 (20) | | +9.15 | -261.70 | 2.09 | | | | | | | | |
| 24. Cyanogen | NCCN | 52.04 | -27.9 | -21.2 | 0.954 (-21) | | +73.82 | ... | 1.94 | ... | 5.58 | ... | 9.82 | 1.486 | -0.657 | 0.0 | 0-700 |
| 25. n-Decane | $C_{10}H_{22}$ | 142.29 | -29.7 | 174.1 | 0.730 (20) | | ... | -1610.2 | 6.88 | ... | 10.91 | 75.2 | | | | | |
| 26. o-Dichlorobenzene | $C_6H_4Cl_2$ | 147.01 | -17.6 | 179 | 1.305 (20) | | ... | -671.8 | 1.09 | ... | ... | 39.7 | | | | | |
| 27. Diethanolamine | $NH(C_2H_4OH)_2$ | 105.14 | 28 | 271 | 1.097 (20) | | | ... | | | | | | | | | |
| 28. Diethylene glycol | $O(C_2H_4OH)_2$ | 106.12 | -10.5 | 245 | 1.120 (15) | | ... | ... | ... | ... | 16.15 | | | | | | |
| 29. Diethyl ether | $O(CH_2CH_3)_2$ | 74.12 | -116.2 | 34.5 | 0.714 (20) | | -65.82 | -652.59 | 1.74 | 6.77 | 6.21 | 40.5 | | | | | |
| 30. Dimethylamine | $(CH_3)_2NH$ | 45.09 | -93 | 7.4 | 0.680 (0) | | ... | -416.7 | 1.42 | ... | 6.66 | | | | | | |
| 31. n-Dodecane | $C_{12}H_{26}$ | 170.33 | -9.6 | 214.5 | 0.751 (20) | | -90.43 | ... | 8.74 | 20.93 | ... | 85.1 | | | | | |
| 32. Ethane | $C_2H_6$ | 30.07 | -183.3 | -88.6 | ... | | -20.24 | -372.8 | 0.68 | ... | 3.52 | ... | 1.648 | 4.124 | 1.530 | 1.740 | 0-1200 |
| 33. Ethanolamine | $HOCH_2CH_2NH_2$ | 61.08 | 10.5 | 172.2 | 1.018 (20) | | | | | | | | | | | | |
| 34. Ethyl acetate | $CH_3COOC_2H_5$ | 88.10 | -83.6 | 77.1 | 0.900 (20) | | -110.72 | -538.76 | 2.50 | 8.70 | ... | 40.4 | 4.75 | 5.006 | -2.479 | 4.790 | 0-1200 |
| 35. Ethyl alcohol | $C_2H_5OH$ | 46.07 | -117.3 | 78.5 | 0.789 (20) | | -66.35 | -326.7 | 1.19 | 10.12 | 9.40 | 26.5 | | | | | |
| 36. Ethylamine | $C_2H_5NH_2$ | 45.09 | -81 | 16.6 | 0.683 (20) | | ... | -409.5 | | | | | | 15.935 | -10.003 | 23.95 | 0-1200 |
| 37. Ethylbenzene | $C_6H_5C_2H_5$ | 106.20 | -95.0 | 136.2 | 0.867 (20) | | +7.12 | -1091.0 | 2.19 | 10.10 | 8.60 | 41.5 | -8.398 | | | | |
| 38. Ethyl bromide | $C_2H_5Br$ | 108.98 | -118.6 | 38.4 | 1.460 (20) | | -15.3 | -340.4 | ... | ... | 6.53 | 23.4 | | | | | |
| 39. Ethyl chloride | $C_2H_5Cl$ | 64.52 | -136.4 | 12.33 | 0.898 (20) | | ... | -339.66 | 1.06 | ... | 5.96 | 23.7 | | | | | |
| 40. Ethyl mercaptan | $C_2H_5SH$ | 62.13 | -144.4 | 34.7 | 0.840 (20) | | ... | -448.0 | 1.19 | | | | | | | | |
| 41. Ethylene | $CH_2{=}CH_2$ | 28.05 | -169.2 | -103.2 | ... | | +12.49 | -339.6 | 0.80 | ... | 3.24 | 22.8 | 0.944 | 3.735 | -1.993 | 4.220 | 0-1200 |
| 42. Ethylene chloride | $CH_2ClCH_2Cl$ | 98.97 | -35.3 | 83.5 | 1.235 (20) | | ... | -296.77 | ... | ... | 7.64 | 29.8 | 5.661 | 4.293 | -3.022 | 7.891 | 0-1200 |
| 43. Ethylene chlorohydrin | $ClCH_2CH_2OH$ | 80.52 | -67.5 | 128 | 1.200 (20) | | ... | ... | ... | ... | 10.74 | | | | | | |
| 44. Ethylene glycol | $HOCH_2CH_2OH$ | 62.07 | -12.7 | 198 | 1.109 (20) | | ... | -281.9 | 2.69 | ... | 14.03 | | | | | | |
| 45. Ethylene oxide | $CH_2CH_2O$ | 44.05 | -111 | 10.4 | 0.882 (10) | | ... | -302.1 | ... | ... | 6.82 | | | | | | |
| 46. Formaldehyde | HCHO | 30.03 | -92.0 | -21.0 | 0.815 (-20) | | -28.29 | -134.67 | ... | ... | 5.92 | | 5.447 | 0.974 | 0.170 | -2.078 | 0-1200 |
| 47. Formic acid | HCOOH | 46.03 | 8.4 | 100.7 | 1.220 (20) | | -97.8 | -64.57 | 2.73 | ... | 5.52 | 24.2 | | | | | |
| 48. Furan | $C_4H_4O$ | 68.08 | -85.7 | 31.4 | 0.951 (20) | | ... | ... | ... | ... | ... | 27.4 | | | | | |
| 49. Furfural | $C_4H_3OCHO$ | 96.08 | -38.7 | 161.7 | 1.159 (20) | | ... | -559.5 | ... | ... | 10.31 | 40.2 | | | | | |
| 50. Glycerol (glycerin) | $C_3H_8O_3$ | 92.11 | 20 | 290 | 1.261 (20) | | -159.16 | -396.27 | 4.38 | ... | ... | 53.0 | | | | | |
| 51. n-Heptane | $C_7H_{16}$ | 100.20 | -90.6 | 98.4 | 0.634 (20) | | -53.63 | -1151.3 | 3.35 | 8.74 | 7.58 | 49.0 | | | | | |
| 52. n-Hexadecane (cetane) | $C_{16}H_{34}$ | 226.43 | 18.2 | 287 | 0.773 (20) | | -89.23 | -2577.0 | 12.75 | 19.38 | 12.3 | 113.0 | | | | | |
| 53. n-Hexane | $C_6H_{14}$ | 86.17 | -95 | 68.8 | 0.660 (20) | | -47.52 | -995.0 | 3.11 | 7.54 | 6.90 | 51.5 | 1.657 | 1.319 | -6.844 | 13.78 | 0-1200 |
| 54. Hydrogen | $H_2$ | 2.016 | -259.2 | -252.7 | ... | | 0 | -68.32 | ... | ... | ... | ... | 6.952 | -0.046 | 0.096 | -0.21 | 0-1500 |

## 4.6 Calculation attachment

| | | | | |
|---|---|---|---|---|
| | a | | 31.86 | |
| D6 | $T_2$ | | 420 | |
| D7 | $T_1$ | | 334.9 | |
| D8 | t Admosphere | | 273 | |
| | b x 10 power of 2 | | 14.49 | |
| | c x 10 power of 5 | | -11.17 | |
| | d x 10 power of 9 | | 30.74 | |
| | △H vap NBP | | 29600 | |
| D13 | Mol heat cap of liq | | 116.8 | |
| | $a(T_2 - T_1)$ | | 2711.29 | 2711.29 |
| | $b/2 \times 10^{-2} (T_2^2 - T_1^2)$ | $b/2 \times 10^{-2}$ \| b/2 | 7.25 | |
| D18 | | | 0.07 | |
| D20 | | $T_2^2$ | 176400 | |
| D23 | | $T_1^2$ | 112158.01 | 4654.33 (D20-D23) x D18 |
| | | $c/3 \times 10^{-5}$ \| c/3 | -3.72 | |
| D26 | $c/3 \times 10^{-5} (T_2^3 - T_1^3)$ | | -0.000037 | |
| D28 | | $T_2^3$ | 74088000.00 | |
| D31 | | $T_1^3$ | 37561717.55 | |
| D33 | | | 36526282.45 | -1360.00 (D28-D31) x D26 |
| | | $d/4 \times 10^{-9}$ \| d/4 | 7.69 | |
| D36 | $d/4 \times 10^{-9} (T_2^4 - T_1^4)$ | | 0.0000000077 | |
| D38 | | $T_2^4$ | 31116960000 | |
| D41 | | $T_1^4$ | 12579419207 | |
| D43 | | | 18537540793 | 142.46 (D38-D41) x D36 |
| | △H vap NBP | | | 29600 |
| D47 | Mol heat cap of liq(334.9-273) | | 61.9 | 7229.92 (D7-D8) x D13 |
| | | | | **42978.00 kJ/kmol** |

## Activity 4.1

1. Define the following:
   1.1 Heat of reaction
   1.2 Standard heat of formation
   1.3 Hess' law of heat summation
   1.4 Kinetic energy
   1.5 Internal energy
   1.6 Heat
2. Determine the heat of reaction at 1 000°C and one atmosphere of the reaction : ½ $H_2$ + ½$Cl_2$ = HCl.
3. Write brief clarifying notes on:
   3.1 An impulse turbine
   3.2 Vaporizing burners
   3.3 Atomizing oil burners

4. Name the essential raw materials for the manufacture of nitric acid.
5. Draw a flow chart for the manufacture of 60% nitric acid from ammonia and give a chronological description of the process.
6. Write brief clarifying notes on:
   6.1 A two-arm kneader
   6.2 A Muller mixer
7. Describe the operation of:
   7.1 A disk centrifuge
   7.2 A tubular centrifuge
8. A gas has the following composition:

   $$NaC\ell\ 21\%\left(\frac{m}{m}\right)\ NaOH\ 9\%\left(\frac{m}{m}\right)\ \text{and}\ H_2O\left(\frac{m}{m}\right)$$

   Determine the composition in mol%
9. Draw a flow chart of the ‘salt process for the manufacture of hydrochloric acid.

| **Self-Check** | | |
|---|---|---|
| **I am able to:** | **Yes** | **No** |
| • Describe the sulphur-burning process | | |
| • Describe the production of nitric acid with 60% concentration | | |
| • Describe the production of hydrochloric acid using the salt process | | |
| • Describe the use of production reaction calculations | | |
| • Describe enthalpy difference calculation of a gas | | |
| 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

**APRIL 2013**

NATIONAL CERTIFICATE

**CHEMICAL PLANT OPERATION N5**

(**8050015**)

**28 March 2013 (X-Paper)**
**09:00 – 12:00**

Calculators may be used.

**This question paper consists of 5 pages.**

**TIME: 3 HOURS**
**MARKS: 100**

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**INSTRUCTIONS AND INFORMATION**

1. Answer ALL the questions.

2. Read ALL the questions carefully.

3. Number the answers according to the numbering system used in this question paper.

4. Write neatly and legibly

---

**QUESTION 1**

1 Give ONE word/term for each of the following descriptions. Write only the word/term next to the question number (1.1-1.5) in the ANSWER BOOK.

1.1 Used to indicate the effectivity of a cyclone (1)

1.2 The difference in energy between the product of the reaction and the reactants (1)

1.3 Defined as the total heat capacity of a compound which is approximately equal to the sum of the heat capacity of the constituent elements (1)

1.4 A type of acid which can be used for photoengraving (1)

1.5 A turbine in which only part of the pressure drop occurs in the nozzle (1)

**[5]**

**QUESTION 2**

2 Indicate whether the following statements are TRUE or FALSE. Choose the answer
and write only 'true' or 'false' next to the question number (2.1-2.5) in the ANSWER
BOOK. (12)

2.1 The common sigma blade is used for heavy plastic materials. (1)

2.2 Ribbon blenders are effective mixers for thin paste and powders that do not flow readily. (1)

2.3 In axial flow turbines steam flows from the centre outwards or from the outside to the centre. (1)

2.4 Impact wheels blend fine powders such as insecticides. (1)

2.5 Hydrochloric acid is used in the production of fertilisers. (1)

**[5]**

**QUESTION 3**

3

| COLUMN A | COLUMN B |
|---|---|
| 3.1 A vertical cylinder with a conical bottom<br><br>3.2 A turbine in which fixed casing blades replace the nozzle of the turbine | A nozzle-discharge centrifuge<br><br>B tumbling mixer<br><br>C impulse reaction-turbine<br><br>D cyclone |

| | |
|---|---|
| 3.3 Used industrially to separate immiscible liquids<br><br>3.4 A mixer in which mixing is done by two heavy blades on a parallel horizontal shaft turning in a short trough with a saddle-shaped bottom<br><br>3.5 A separator which is a modified disk-type centrifuge with a double conical bowl | E disk centrifuge<br><br>F impulse turbine<br><br>G centrifugal decanters<br><br>H two-arm kneader |

5 x 1 **[5]**

**QUESTION 4**

4 Describe the operation of the following:

4.1.1 A cyclone (10)

4.1.2 A muller mixer (5)

4.2 Name TWO types of centrifugal decanter (2)

4.3 Define *Hess's law of heat of summation*. (3)

**[20]**

**QUESTION 5**

5 Sulphuric acid is a very active chemical, one of the most widely used and most important technical products.

5.1 State FIVE uses of sulphuric acid. (5)

5.2 Give THREE properties of sulphuric acid. (3)

5.3 Draw a neat, labelled diagram of the contact process to prepare sulphuric acid by burning sulphur. (12)

**[20]**

**QUESTION 6**

6 One of the techniques for producing hydrogen is to react methane and ethane
with steam in the presence of a nickel catalyst. The analysis on a dry basis

of
the gases leaving such a reactor is:
$CH_4$ 4,6 mol %; $C_2H_6$ 2,3 mol %; CO 18,6 mol %; $CO_2$ 4,6 mol % and $H_2$ 69,7 mol % (11)

What is the molar ratio of these two gases in the feed?

6.2 Give FIVE specific procedures for solving material balance problems. (5)

6.3 What will you bear in mind to maximise the chemical conversion of $SO_2$ to $SO_3$? (4)

**[20]**

**QUESTION 7**

7.1 Sketch a closed-circuit gas turbine. (7)

7.2 State THREE disadvantages of a closed-circuit gas turbine. (3)

7.3 Sketch a premix burner. (11)

7.4 Write brief, explanatory notes on the vaporising burner. (4)

**[25]**

**TOTAL: 100**

# Marking Guidelines

higher education & training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

**APRIL 2013**

NATIONAL CERTIFICATE

**CHEMICAL PLANT OPERATIONS N5**

(8050015)

**This marking guidelines consists of 7 pages.**

**QUESTION 1**

| | | |
|---|---|---|
| 1.1 | Ordinate | (1) |
| 1.2 | Heat of reaction | (1) |
| 1.3 | Kopp's rule | (1) |
| 1.4 | Nitric acid | (1) |
| 1.5 | Reaction turbine | (1) |
| | | **[5]** |

**QUESTION 2**

| | | |
|---|---|---|
| 2.1 | False | (1) |
| 2.2 | True | (1) |
| 2.3 | False | (1) |
| 2.4 | True | (1) |
| 2.5 | True | (1) |
| | | **[5]** |

**QUESTION 3**

| | | |
|---|---|---|
| 3.1 | D | |
| 3.2 | C | |
| 3.3 | G | |
| 3.4 | H | |
| 3.5 | A | |
| | (5 x 1) | **[5]** |

**QUESTION 4**

4.1.1 It consists of a vertical cylinder with a conical bottom, a tangential inlet near the top, and an outlet for dust at the bottom of the cone. The inlet is usually rectangular. The outlet pipe is extended into a cylinder to prevent short-circuiting of air from inlet to outlet. (10)

The incoming dust-laden air is rotated on entering the cylinder. The vortex formed develops a centrifugal force, which acts to throw the particles radically towards the wall.

The air in a cyclone follows a downwards or spiral vortex adjacent to the wall and reaching to the bottom of the cone. The air stream then moves upwards in a tighter spiral, concentric with the first, and leaves through the outlet pipe, still whirling.

4.1.2 Kneading involves squashing the mass flat, folding over on itself, and squashing once more. Most kneading machines also tear the mass apart. (5)

Mixing is done by two heavy blades on parallel horizontal shafts, turning in a short trough with a saddle-shaped bottom. The blades turn over the point of the saddle, tearing materials between the blades and the wall of the trough. The blades turn at different speeds. Materials are dropped into a trough and kneaded for 20 min.

4.2 (2)
- Tubular centrifuge
- Disk centrifuge

4.3 The heat of reaction equals the sum of the heat of formation of the products minus the sum of heat of formation of the reactants. (3)

**[20]**

**QUESTION 5**

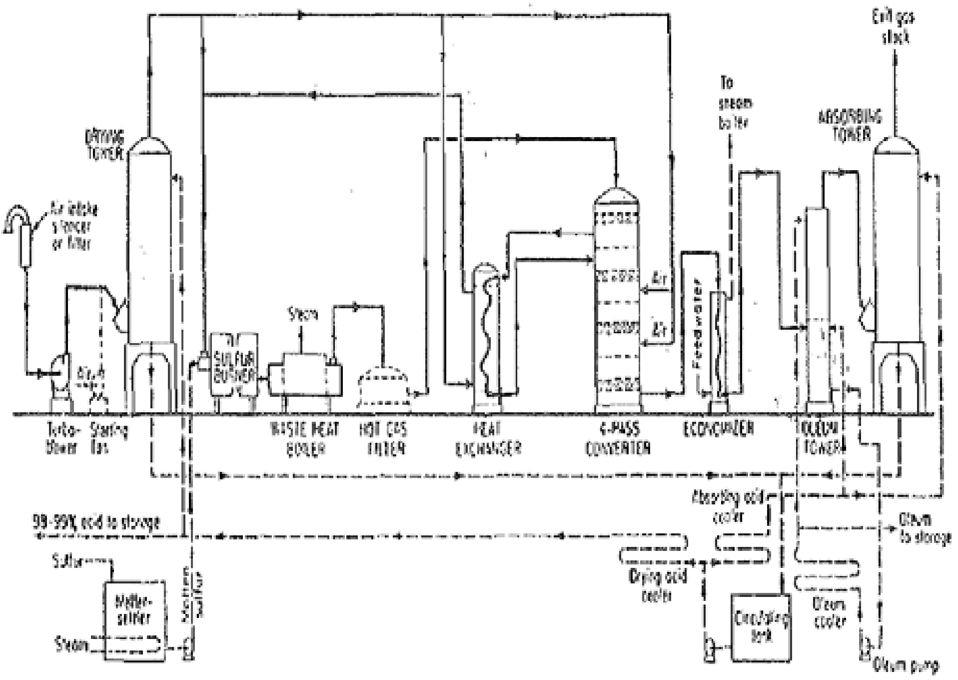
5.1 (5)
- Manufacture of sulphates
- Manufacture of fertilisers (Superphosphate)
- Manufacture of leather
- Manufacture of tin plate
- Manufacture of nitrates
- Refining of petroleum
- Manufacture of explosives
- Dyeing of fabrics
- Mineral processing

(ANY FIVE)

5.2 (3)
- Strong dibasic acid
- An oxidising agent
- Dehydrating agent
- Powerful protonating agent

(ANY THREE)

5.3 (12)




**[20]**

## QUESTION 6

6.1 H-atom: (4,6 x 4) + (2,3 x 6) + (69,7 x 2) = 171,6
C-atom: (4,6 x 1) + (2,3 x 2) + {18,6 x 1) + (4,6 x 1) = 32,4
0-atom: (18,6 x 1) + (4,6 x 2) = 27,8

H-atom balance: 4M + 6E + 28 = 171,6 (1)
C-atom balance: M + 2E = 32,4 {2) (11)
0-atom balance: S = 27,8 {3)

Substitute (3) in ( 1)

4M + 6E + 2(27,8) = 171 ,6
4M + 6E + 55,6 = 171 ,6
4M + 6E = 116

3 x (2): 3M+ 6E = 97,2
4M + 6E = 116
(4)- {5): M = 18,8

Substitute M in (2)
18,8 + 2E = 32,4
2E = 13,6
E = 6,8

M = 18,8
E = 6,8
S = 27,8

Molar ratio = M : E

$= \frac{18.8}{6,8}$

= 2,76: 1

(ACCEPT ANY OTHER METHOD)

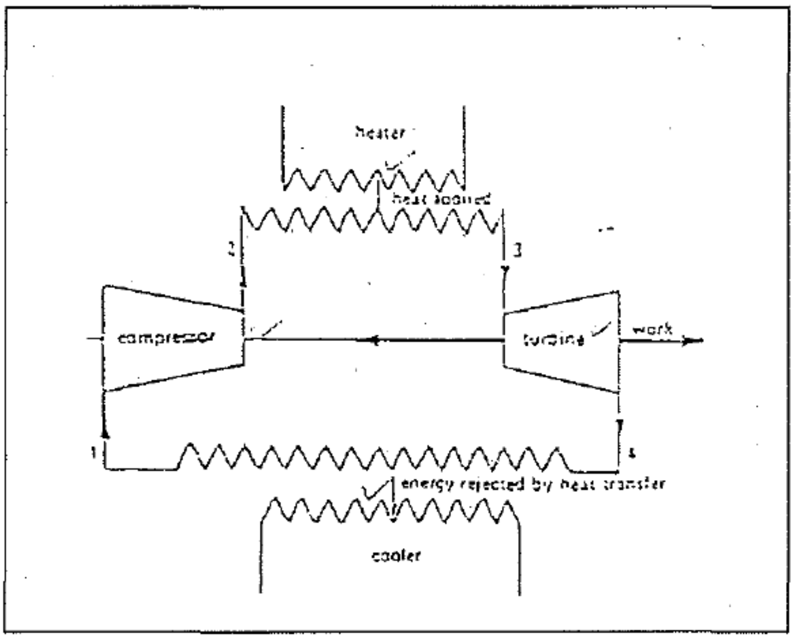
6.2
- Identify the type of question. (5)
- Draw a flow sheet.
- Select a basis for calculation.
- Construct an input-output table.
- Formulate the balances needed to solve the problem.

6.3
- Equilibrium is an inverse function of temperature and a direct function of $O_2/SO_2$. (4)
- Rate of reaction is a direct function of temperature.
- Composition and ratio of the amount of catalyst to the amount of $SO_3$ formed.
- Removal of $SO_3$ causes more $SO_2$ to be formed.

**[20]**

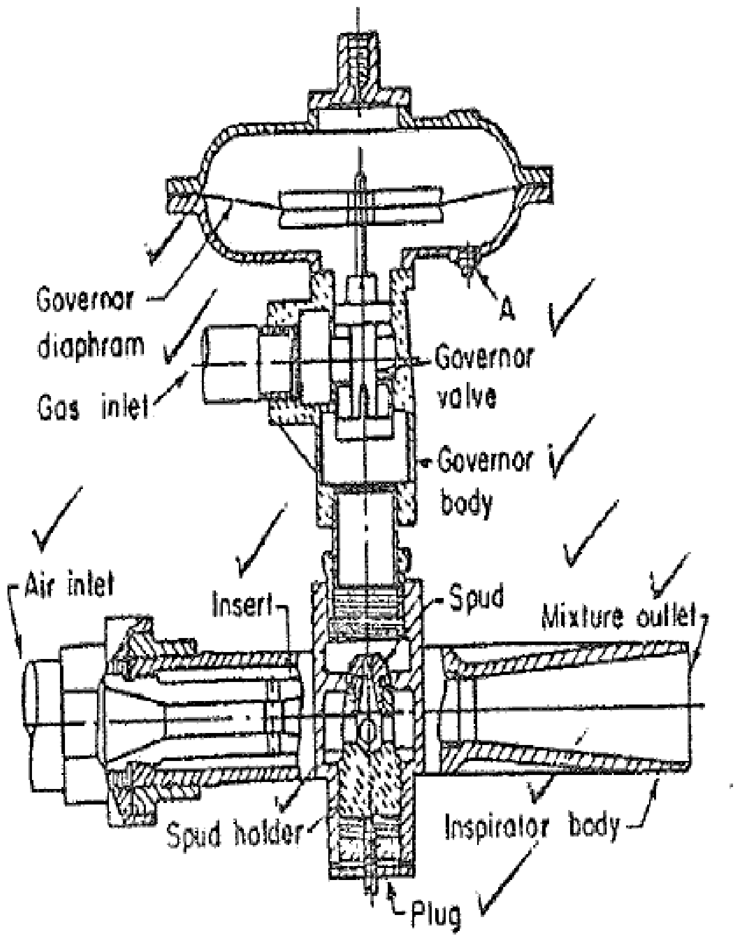
**QUESTION 7**

7.1 (7)




7.2
- It is a large construction. (3)
- Costly heating and cooling apparatus is needed.
- Air under pressure must be pumped into the system to make up for leakages.

7.3 (11)




7.4 In vaporising burners heat from the flame continually converts liquid fuel to a vapour in the combustion air, thus sustaining the flame. This principle is used in blow torches, kerosene lamps and cigarette lighters, amongst others . (4)

**[25]**

**TOTAL: 100**

# Past Examination Papers

higher education
& training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

**NOVEMBER 2012**

NATIONAL CERTIFICATE

**CHEMICAL PLANT OPERATION N5**

**(8050015)**

**23 November 2012 (X-Paper)**
**09:00 – 12:00**

Calculators may be used.

**This question paper consists of 4 pages.**

**TIME: 3 HOURS**
**MARKS: 100**

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**INSTRUCTIONS AND INFORMATION**

1. Answer ALL the questions.

2. Read ALL the questions carefully.

3. Number the answers according to the numbering system used in this question paper.

4. Write neatly and legibly

---

**QUESTION 1**

1.1 What is the difference in enthalpy of 10 kg of air between 400 K and 0,1 mpa and 1 000 K and 0,5 mpa? (6)

1.2 Write brief notes on each of the following: (3)

1.2.1 Heat of transformation (3)

1.2.2 Enthalpy (8)

1.2.3 The Van't Hoff box

**[20]**

**QUESTION 2**

2.1 The feed to a continuous still contains 20 mole per cent $C_6$ and 80 mole percent $C_{11}$ hydrocarbons. The composition of the overhead distillate is essentially pure $C_6$ hydrocarbons and the still bottom contains 5 mole per cent $C_6$ and 95 mole percent $C_{11}$ hydrocarbons. How many SI moles of distillate are produced per 100 SI mole of feed? (10)

2.2 Define each of the following:

2.2.1 The calorie (4)

2.2.2 Heat (4)

2.2.3 Potential energy (2)

**[20]**

**QUESTION 3**

3.1 Sketch the horizontal rotary-cup atomising oil burner and describe its operation. (8)

3.2 Write brief notes on the differences between an *impulse* and a *reaction turbine.* (6)

3.3 Name the THREE blades in a two-arm knead and describe the purpose for which each is used. (6)

**[20]**

**QUESTION 4**

4 Write brief, clarifying notes on each of the following:

4.1 A double-cone mixer (7)

4.2 A disk-centrifuge (8)

4.3 A tubular centrifuge (5)

**[20]**

**QUESTION 5**

5.1 Discuss the physical-chemical principles which influence the conversion of $SO_2$ to $SO_3$. (9)

5.2 *Give* a chronological description of the process for the manufacture of 60% nitric acid from ammonia. (11)

**[20]**

# Marking Guidelines

higher education & training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

**NOVEMBER 2012**

NATIONAL CERTIFICATE

**CHEMICAL PLANT OPERATIONS N5**

(8050015)

**This marking guidelines consists of 7 pages.**

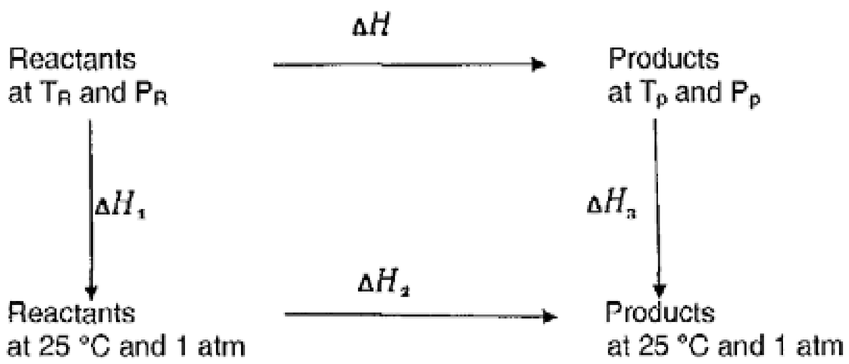
## QUESTION 1

1.1 $\Delta H$ = n[ h (air at 1 00K and 0,5 mpa) – h ( air at 400K and 0,1 mpa)] (6)
= 10 ( 1046,9 – 401,3 )
= 10 ( 645,6)
= 6456 KJ

1.2.1 Accompanying phase changes or transformation of one sort or another are energy changes. When this energy occurs under the constant pressure conditions or in steady-flow processes, the energy change is viewed as an enthalpy change, the heat of formation. (3)

1.2.2 **Enthalpy:** When dealing with flowing matters, enthalpy is the sum of internal energy and the flow energy. (3)

1.2.3 The Van't Hoff box connects the initial state (reactants) with the final state (products). (8)




**[20]**

## QUESTION 2

2.1 Basis = 1 00 mol feed (10)

| INPUT | | OUTPUT |
|---|---|---|
| **Subs** | **Mol** | **Mol** |
| $C_6$ | 20 | D mol |
| | | 0,05B |
| | | |
| $C_{11}$ | 80 | 0,95B |

$C_6$ balance: 20 = D + 0,058 ........ (1)
$C_{11}$ balance: 80 = 0,958 ......... (2)

From (2) B = $\frac{80}{0,95}$
B = 84,21
Sub B in (1) 20 = D + 0,05 (84,211)

2.2.1 **The calorie**: This is the amount of heat required to raise the temperature of 1 g of water from 14,5 to 15,5 °C. (4)

2.2.2 **Heat**: This is a form, or manifestation, of energy that flows from one object or system to another under the influence of temperature difference. (4)

2.2.3 **Potential energy**: An object which is above a datum plane possesses energy because of its position. (2)

**[20]**

**QUESTION 3**

3.1 Rotary cup (8)
- Oil is heated
- Oil and air is mixed before sprayed in under pressure
- Combustion

3.2 (6)

| **IMPULSE TURBINE** | **REACTION TURBINE** |
|---|---|
| Pressure drop occurs across the nozzles. Expansion of steam occurs in the nozzles. | Part of the pressure drop occurs in the nozzles, the remainder occurring during the passage of steam through the blades. |
| Nozzles directed so that the steam glides on the blades, the direction of steam is changed and thereby a force is exerted on the blades. | The blade passages are nozzle shaped, acceleration requires a force, a resultant reaction occurs on the blade. |
| Nozzles are arranged in turbine casing. | A ring of fixed blades acts as nozzles. |

3.3 (6)
- **The common sigma blade:** is used for general purpose kneading
- **The double naben or fishtail blade:** is particularly effective with heavy plastic materials.
- **The dispersion blade:** develops high shear force needed to disperse powders and liquids into plastic or rubbery masses.

**[20]**

**QUESTION 4**

4.1 (7)
- Is a popular mixer for free-flowing dry powders.
- A batch is charged into the body of the machine from above until it is 50 to 60 percent full.
- The ends of the container are closed and solids tumbled for 5 to 20 min.
- The machine is stopped; mixed material is dropped out the bottom of the

container into a conveyor or bin.

4.2 The bowl has a flat bottom and a conical top. Feed enters from above through a stationary pipe set into the neck of the bowl. Two liquid layers are formed; they flow over adjustable dams into separate discharge spouts. Inside the bowl are disks which are metal cones. Holes in the disks form channels through which the liquid passes. (8)

In operation the liquid enters the bowl at the bottom, flows into channels, and upward past the disks. Heavy liquid thrown outward, displacing lighter liquid toward the centre of the bowl. Heavy liquid strikes underside of the disks and the light liquid flows over upper surface of the disks. Heavy and light liquid flows in different directions causing a shearing force that can break up emulsion.

4.3 A tall and narrow bowl turns in a stationary casing. Feed enters from a stationary nozzle in the bottom of the bowl. It separates into two concentric layers of liquid inside the bowl. The inner or lighter layer spills over a weir at the top of the bowl to a spout. The heavy liquid flows over another weir into a separate cover and discharge spout. (5)

**[20]**

**QUESTION 5**

5.1 Reaction rate increase: (9)

- temperature is raised from about 410°C to 600°C
- increase of either $SO_2$ or $O_2$
- increase in pressure
- removal of portion of $SO_3$ formed clean $SO_2$ used

Reaction rate decreases:

- When equilibrium is approached
- stop when 60 - 70% of $SO_2$ has been converted
- mixture diluted with an inner gas
- - 410°C > temperature > 600°C

5.2 (11)

- Anhydrous $NH_3$ is evaporated.
- Air for reactions is compressed and passed through the heat exchangers and air filters.
- $NH_3$ is oxidised to NO by air.
- NO with excess air is cooled and conducted to the bottom of the absorption tower.
- Successive oxidations and hydration of NO are carried out to form $HNO_3$
- The acid is drawn off through an acid trap.
- Waste gas is released.

**[20]**

# Past Examination Papers

higher education & training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

**AUGUST 2012**

NATIONAL CERTIFICATE

**CHEMICAL PLANT OPERATION N5**

(**8050015**)

**30 July 2012 (X-Paper)**
**09:00 – 12:00**

Calculators may be used.

**This question paper consists of 4 pages and a 3-page annexure..**

**TIME: 3 HOURS**
**MARKS: 100**

---

**INSTRUCTIONS AND INFORMATION**

1. Answer ALL the questions.

2. Read ALL the questions carefully.

3. Number the answers according to the numbering system used in this question paper.

4. Write neatly and legibly

---

**QUESTION 1**

1.1 Determine the enthalpy change of 5 mol of water ($H_2O$) between 25°C and 900°C. (5)

1.2 Write brief notes on the following: (6)

1.2.1 The first law of thermodynamics (4)

1.2.2 Change in internal energy (5)

1.2.3 Heat of fusion

**[20]**

**QUESTION 2**

2.1 Determine the heat of reaction for the following: (8)
$CaSO_4 + Na_2CO_2 \rightarrow + CaCO_2 + Na_2SO_4$

2.2 Define the following:

2.2.1 Molar heat capacity (4)

2.2.2 Standard enthalpy of formation (5)

2.2.3 Hess' law of heat summation (3)

**[20]**

**QUESTION 3**

3.1 Name the TWO types of gas turbine. (2)

3.2 Write brief notes on the following:

3.2.1 Axial-flow turbine (4)

3.2.2 Radial-flow turbine (5)

3.2.3 The design of nozzle (9)

**[20]**

**QUESTION 4**

4.1 Give FIVE factors affecting the efficiency of a cyclone. (5)

4.2 Explain the operation of a helical-conveyor centrifuge. (7)

4.3 Sketch a premix burner and fully explain its operation. (8)

**[20]**

**QUESTION 5**

5.1 Explain the operation of the following:

5.1.1 Banbury mixer (6)

5.1.2 Impact wheels (6)

5.2 Draw a flow diagram for the manufacturing of hydrochloric acid. (8)

**[20]**

## Appendix 7C Mean molar heat capacities of gases at constant pressure [kJ/(k.mol - K)]

| K | $H_2$ | $N_2$ | CO | Air | $O_2$ | HCl | $Cl_2$ | $H_2O$ | $CO_2$ | $SO_2$ | $SO_3$ | $CH_4$ | $C_2H_4$ | $C_2H_4$ | $NH_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 298 | 28,84 | 29,13 | 29,18 | 29,18 | 29,39 | 29,13 | 33,99 | 33,57 | 37,17 | 40,14 | 50,69 | 35,79 | 43,74 | 52,87 | 35,50 |
| 400 | 29,01 | 29,21 | 29,32 | 29,32 | 29,75 | 29,19 | 34,57 | 33,94 | 39,23 | 41,68 | 54,77 | 38,31 | 48,85 | 59,31 | 37,21 |
| 500 | 29,15 | 29,35 | 29,45 | 29,45 | 30,18 | 29,24 | 35,16 | 34,40 | 40,07 | 43,32 | 58,42 | 41,03 | 53,71 | 65,56 | 38,76 |
| 600 | 29,19 | 29,53 | 29,69 | 29,69 | 30,65 | 29,32 | 35,58 | 34,93 | 42,72 | 44,81 | 61,63 | 43,84 | 58,29 | 71,56 | 40,19 |
| 700 | 29,24 | 29,76 | 30,02 | 30,02 | 31,14 | 29,43 | 35,86 | 35,35 | 44,15 | 46,11 | 64,40 | 46,69 | 62.46 | 77,26 | 41,55 |
| 800 | 29,31 | 30,31 | 30,34 | 30,34 | 31,59 | 29,60 | 36,10 | 35,90 | 45,43 | 47,23 | 66,80 | 49,46 | 66,26 | 83,30 | 42,89 |
| 900 | 29,36 | 30,34 | 30,64 | 30,64 | 32,00 | 29,78 | 36,30 | 36,59 | 46,54 | 48,17 | 68,85 | 52,23 | 69,73 | 87,39 | 44,23 |
| 1000 | 29,46 | 30,64 | 30,94 | 30,94 | 32,37 | 30,00 | 36,45 | 37,08 | 47,36 | 49,01 | 70,27 | 54,66 | 72,91 | 91,93 | 45,56 |
| 1100 | 29,57 | 30,93 | 31,27 | 31,27 | 32,70 | 30,25 | 36,59 | 37,68 | 48,50 | 49,75 | 72,27 | 57,06 | 75,91 | 96,20 | 46,86 |
| 1200 | 29,69 | 31,22 | 31,56 | 31,56 | 33,02 | 30,49 | 36,74 | 38,29 | 49,35 | 50,43 | 73,72 | 59,34 | 78,66 | 100,15 | 48,16 |
| 1300 | 29,89 | 31,50 | 31,93 | 31,93 | 33,32 | 30,75 | 36,85 | 38,89 | 50,10 | 51,01 | 75,11 | 61,49 | 81,35 | 103,09 | 49,44 |
| 1400 | 30,07 | 31,77 | 32,13 | 32,13 | 33,60 | 31,00 | 36,94 | 39,45 | 50,82 | 51,53 | 76,36 | 63,47 | 83,51 | 107,17 | 50,71 |
| 1500 | 30,23 | 32,04 | 32,38 | 32,38 | 33,84 | - | - | 40,01 | 51,43 | | | | | | |
| 1600 | 30,39 | 32,25 | 32,60 | 32,61 | 34,05 | - | - | 40,56 | 51,99 | | | | | | |
| 1700 | 30,56 | 32,46 | 32,79 | 32,79 | 34,23 | - | - | 41,03 | 52,54 | | | | | | |
| 1800 | 30,75 | 32,67 | 33,01 | 33,01 | 34,40 | - | - | 41,47 | 53,18 | | | | | | |
| 1900 | 30,97 | 32,86 | 33,20 | 33,24 | 34,66 | - | - | 41,84 | 53,43 | | | | | | |
| 2000 | 31,12 | 33,03 | 33,37 | 33,41 | 34,83 | - | - | 42,53 | 53,74 | | | | | | |
| 2100 | 31,32 | 33,20 | 33,52 | 33,56 | 34,98 | - | - | 42,98 | 54,25 | | | | | | |
| 2200 | 31,48 | 33,35 | 33,66 | 33,70 | 35,12 | - | - | 43,41 | 54,56 | | | | | | |

# Appendix 6A Properties of elements and inorganic compounds

| Compound | Formula | Molecular weight | Normal melting point K | Normal boiling point K | Specific gravity (at K) | Physical state at 298 K |
|---|---|---|---|---|---|---|
| 1. Aluminium | Al | 26,97 | 933 | 2328 | 2,70(293) | c |
| 2. Ammonia | $NH_3$ | 17,03 | 195,5 | 239,8 | - | g |
| 3. Calcium carbonate | $CaCO_3$ | 100,09 | $-CO_2$ 1098 | - | 2,71(288) | c |
| 4. Calcium chloride | $CaCl_2$ | 110,99 | 1055 | - | 2,15(288) | c |
| 5. Calcium hydroxide | $Ca(OH)_2$ | 74,10 | $-H_2O$ 853 | - | 2,2(273) | c |
| 6. Calcium oxide | CaO | 56,08 | 2843 | 3123 | 3,32(293) | c |
| 7. Calcium sulfate | $CaSO_4$ | 136,14 | - | - | 2,96(293) | c |
| 8. Carbon (amorphous) | C | 12,01 | - | 4473 | 1,8-2,1 | - |
| 9. Carbon (diamond) | C | 12,01 | 3773 | 4473 | 3,51(293) | c |
| 10. Carbon (graphite) | C | 12,01 | 3933 | 4473 | 2,26(293) | c |
| 11. Carbon dioxide | $CO_2$ | 44,01 | 216,6 | 194,7 | - | g |
| 12. Carbon monoxide | CO | 28,01 | 68 | 81,7 | - | g |
| 13. Chlorine | $Cl_2$ | 70,91 | 172,2 | 238,6 | - | g |
| 14. Copper | Cu | 63,57 | 1356 | 2868 | 8,92(293) | c |
| 15. Helium | He | 4,00 | 1,0 | 4,2 | - | g |
| 16. Hydrogen | $H_2$ | 2,016 | 14,0 | 20,5 | - | g |
| 17. Hydrogen chloride | HCl | 36,47 | 162 | 188 | - | g |
| 18. Hydrogen sulfide | $H_2S$ | 34,08 | 190,3 | 213,6 | - | g |
| 19. Iron | Fe | 55,85 | 1808 | 3008 | 7,86(293) | c |
| 20. Iron chloride | $FeCl_3$ | 162,22 | 555 | 588 | 2,80(284) | c |
| 21. Iron oxide | FeO | 71,85 | 1693 | - | 5,7(293) | c |
| 22. Iron oxide | $Fe_2O_3$ | 159,70 | d. 1833 | - | 5,12(293) | c |
| 23. Magnesium chloride | $MgCl_2$ | 95,23 | 985 | 1685 | 2,33(293) | c |
| 24. Magnesium sulfate | $MgSO_4$ | 120,38 | 1458 | - | 2,66(293) | c |
| 25. | | 58,69 | 1726 | 3173 | 8,90(293) | c |
| 26. Nitric acid | $HNO_3$ | 63,02 | 231 | 359 | | c |
| 27. Nitrogen | $N_2$ | 28,02 | 63,3 | 77,4 | - | g |
| 28. Oxygen | $O_2$ | 32,00 | 54,8 | 90 | - | g |
| 29. Potassium carbonate | $K_2CO_3$ | 138,20 | 1164 | d. | 2,29(291) | c |
| 30. Potassium chloride | KCl | 74,56 | 1043 | 1680 | 1,99(293) | c |
| 31. Potassium hydroxide | KOH | 56,10 | 653 | 1593 | 2,04(293) | c |
| 32. Potassium nitrate | $KNO_3$ | 101,10 | 606 | d. 673 | 2,11(293) | c |
| 33. Potassium sulfate | $K_2SO_4$ | 174,25 | 1347 | - | 2,66(293) | c |
| 34. Silicon dioxide | $SiO_2$ | 60,06 | 1698 | 2503 | 2,65(293) | c |
| 35. Silver | Ag | 107,88 | 1233,7 | 2223 | 10,5(293) | c |
| 36. Sodium carbonate | $Na_2CO_3$ | 106,00 | 1124 | d. | 2,53(293) | c |
| 37. Sodium chloride | | | | 1686 | 2,16(293) | c |
| 38. Sodium hydroxide | NaOH | 40,00 | 591,6 | 1663 | 2,13(293) | c |
| 39. Sodium nitrate | $NaNO_3$ | 85,01 | 581 | d. 653 | 2,26(291) | c |
| 40. Sodium sulfate | $Na_2SO_4$ | 142,05 | 1157 | - | 2,70(297) | c |
| 41. Sulphur dioxide | $SO_2$ | 64,06 | 197,7 | 263 | - | g |
| 42. Sulphur trioxide | $SO_3$ | 80,06 | 290,0 | 317,8 | - | g |
| 43. Sulphuric acid | $H_2SO_4$ | 98,08 | 283,7 | d. 613 | 1,83(291) | l |
| 44. Uranium | U | 238,07 | 1406 | 3773 | 18,49(293) | c |
| 45. Water | $H_2O$ | 18,02 | 273,2 | 373,2 | 1,00(277) | l |
| Water vapour | | | | | | g |
| 46. Zinc | Zn | 65,38 | 692,6 | 1180 | 7,14(293) | c |

| Enthalpies kJ/kmol | | | | Molar heat capacities kJ/(kmol · K) | | | |
|---|---|---|---|---|---|---|---|
| Heat of formation $\Delta H_f$ | Heat of fusion $\Delta H_m$ | Heat of vaporization $\Delta H_v$ | Heat of solution $\Delta H_s$ | Of the liquid | Of the solid $A + BT + CT^2$: A | $B \cdot 10^3$ | $C \cdot 10^5$ |
| 1 0 | 10,700 | 293,400 | - | 29,3 | 20,09 | 13,48 | 0 |
| 2 -45,900 | 5,600 | 23,400 | -34,700 | | | | |
| 3 -1,207,700 | - | - | - | - | 82,46 | 49,81 | -12,87 |
| 4 -797,900 | 25,500 | - | -77,900 | 303,4 | 70,74 | 16,16 | 0 |
| 5 -986,700 | - | - | -35,100 | - | 89,58 | 0 | 0 |
| 6 -635,500 | 51,200 | - | -81,600 | - | 41,86 | 20,26 | -4,52 |
| 7 -1,419,900 | 28,000 | - | +18,000 | - | 77,44 | 92,99 | -6,57 |
| 8 | | | | | | | |
| 9 +1,900 | - | - | - | - | 9,04 | 12,51 | -5,44 |
| 10 0 | 46,000 | - | - | - | 11,18 | 10,97 | -4,90 |
| 11 -393,700 | 8,000 | 25,200 | -17,300 | | | | |
| 12 -110,600 | 840 | 6,030 | | | | | |
| 13 0 | 6,400 | 20,400 | | | | | |
| 14 0 | 13,000 | 304,800 | - | 31,4 | 22,77 | 6,11 | 0 |
| 15 0 | 41 | 84 | | | | | |
| 16 0 | | | | | | | |
| 17 -92,300 | 2,000 | 16,200 | -74,500 | | | | |
| 18 -20,100 | 2,400 | 18,800 | -19,300 | | | | |
| 19 0 | 14,900 | 354,100 | - | 34,1 | 17,29 | 26,71 | 0 |
| 20 -403,300 | 86,200 | 50,400 | -134,400 | | | | |
| 21 -270,400 | 32,200 | - | - | - | 52,83 | 6,24 | -3,18 |
| 22 -772,100 | - | - | - | - | 103,5 | 67,90 | -17,71 |
| 23 -634,600 | 35,900 | 136,800 | +150,400 | - | 72,42 | 15,76 | 0 |
| 24 -1,276,500 | 14,700 | - | +57,700 | - | 111,8 | 0 | 0 |
| 25 0 | 17,600 | 365,400 | - | 37,1 | 17,83 | 26,79 | 0 |
| 26 | | | | | | | |
| 27 0 | 720 | 5,600 | | | | | |
| 28 0 | 460 | 6,800 | | | | | |
| 29 -1,147,000 | 32,700 | - | -28,900 | - | 125,2 | 0 | 0 |
| 30 -436,600 | 26,800 | 162,600 | +17,600 | - | 45,75 | 15,74 | 0 |
| 31 -423,000 | 8,400 | 129,100 | -54,000 | | | | |
| 32 -494,400 | 11,900 | - | +34,300 | 121,5 | 26,87 | 22,19 | 0 |
| 33 -1,434,500 | 33,500 | - | +26,000 | - | 130,2 | 0 | 0 |
| 34 -851,400 | 14,200 | - | - | - | 45,84 | 23,02 | 0 |
| 35 0 | 11,300 | 254,200 | - | 34,3 | 23,44 | 6,28 | 0 |
| 36 -1,128,100 | 29,300 | - | -23,900 | - | 121,0 | 0 | 0 |
| 37 -411,200 | 30,200 | 170,800 | +4,190 | 66,6 | 45,17 | 17,58 | 0 |
| 38 -426,600 | 6,400 | - | | | | | |
| 39 -467,600 | 15,700 | - | +20,100 | 155,7 | 19,09 | 242,8 | 0 |
| 40 -1,383,500 | 24,400 | - | -1,300 | - | 137,3 | 0 | 0 |
| 41 -297,000 | 7,400 | 24,900 | -41,400 | | | | |
| 42 -395,100 | 8,600 | 42,700 | -226,500 | | | | |
| 43 -810,500 | 10,000 | - | -76,800 | | | | |
| 44 0 | 13,600 | - | - | - | 27,80 | 0 | 0 |
| 45 -286,000 / -242,000 | 6,000 | 40,600 | - | 75,4 | 32,09 | 0 | 0 |
| 46 0 | 6,700 | 114,800 | - | 31,8 | 22,00 | 11,30 | 0 |

| $p$ kPa | $t_s$ °C | $v_g$ m³/kg | $h_f$ kJ/kg | $h_{fg}$ kJ/kg | $h_g$ kJ/kg | $s_f$ kJ/kg.K | $s_g$ kJ/kg.K |
|---|---|---|---|---|---|---|---|
| 2 500 | 223,9 | 0,079 91 | 962 | 1 839 | 2 801 | 2,554 | 6,245 |
| 2 550 | 225,0 | 0,078 35 | 967 | 1 834 | 2 801 | 2,564 | 6,246 |
| 2 600 | 226,0 | 0,076 86 | 972 | 1 830 | 2 802 | 2,574 | 6,239 |
| 2 650 | 227,1 | 0,075 41 | 977 | 1 825 | 2 802 | 2,583 | 6,232 |
| 2 700 | 228,1 | 0,074 02 | 981 | 1 821 | 2 802 | 2,592 | 6,224 |
| 2 750 | 229,1 | 0,072 68 | 986 | 1 816 | 2 802 | 2,602 | 6,217 |
| 2 800 | 230,1 | 0,071 39 | 991 | 1 811 | 2 802 | 2,611 | 6,210 |
| 2 850 | 231,0 | 0,070 14 | 995 | 1 807 | 2 802 | 2,620 | 6,204 |
| 2 900 | 232,0 | 0,068 93 | 1 000 | 1 802 | 2 802 | 2,628 | 6,197 |
| 2 950 | 232,9 | 0,067 76 | 1 004 | 1 798 | 2 802 | 2,637 | 6,190 |
| 3 000 | 233,8 | 0,066 63 | 1 008 | 1 794 | 2 802 | 2,646 | 6,184 |
| 3 100 | 235,7 | 0,064 47 | 1 017 | 1 785 | 2 802 | 2,662 | 6,171 |
| 3 200 | 237,5 | 0,062 44 | 1 025 | 1 777 | 2 802 | 2,679 | 6,159 |
| 3 300 | 239,2 | 0,060 53 | 1 034 | 1 768 | 2 802 | 2,695 | 6,146 |
| 3 400 | 240,9 | 0,058 73 | 1 042 | 1 760 | 2 802 | 2,710 | 6,134 |
| 3 500 | 242,5 | 0,057 03 | 1 050 | 1 752 | 2 802 | 2,725 | 6,123 |
| 3 600 | 244,2 | 0,055 41 | 1 058 | 1 744 | 2 802 | 2,740 | 6,112 |
| 3 700 | 245,8 | 0,052 89 | 1 065 | 1 736 | 2 801 | 2,755 | 6,100 |
| 3 800 | 247,3 | 0,052 44 | 1073 | 1 728 | 2 801 | 2,769 | 6,090 |
| 3 900 | 248,8 | 0,051 06 | 1 080 | 1 721 | 2 801 | 2,783 | 6,079 |
| 4 000 | 250,3 | 0,049 75 | 1 087 | 1 713 | 2 800 | 2,797 | 6,069 |
| 4 100 | 251,8 | 0,048 50 | 1 095 | 1 705 | 2 800 | 2,810 | 6,058 |
| 4 200 | 253,2 | 0,047 31 | 1 102 | 1 698 | 2 800 | 2,823 | 6,048 |
| 4 300 | 254,7 | 0,046 17 | 1 109 | 1 690 | 2 799 | 2,836 | 6,038 |
| 4 400 | 256,1 | 0,045 08 | 1 115 | 1 683 | 2 798 | 2,849 | 6,029 |
| 4 500 | 257,4 | 0,044 04 | 1 122 | 1 676 | 2 798 | 2,861 | 6,019 |
| 4 600 | 258,8 | 0,043 04 | 1 129 | 1 668 | 2 797 | 2,874 | 6,010 |
| 4 700 | 260,1 | 0,042 08 | 1 135 | 1 661 | 2 796 | 2,886 | 6,000 |
| 4 800 | 261,4 | 0,041 16 | 1 142 | 1 654 | 2 796 | 2,897 | 5,991 |
| 4 900 | 263,7 | 0,040 28 | 1 148 | 1 647 | 2 795 | 2,909 | 5,982 |
| 5 000 | 263,9 | 0,039 43 | 1 155 | 1 640 | 2 795 | 2,921 | 5,974 |
| 5 100 | 265,2 | 0,038 61 | 1 161 | 1 633 | 2 794 | 2,932 | 5,965 |
| 5 200 | 266,4 | 0,037 82 | 1 167 | 1 626 | 2 793 | 2,943 | 5,956 |
| 5 300 | 267,6 | 0,037 07 | 1 173 | 1 619 | 2 792 | 2,954 | 5,948 |
| 5 400 | 268,8 | 0,036 33 | 1 179 | 1 612 | 2 791 | 2,965 | 5,939 |
| 5 500 | 269,9 | 0,035 63 | 1 185 | 1 605 | 2 790 | 2,976 | 5 931 |
| 5 600 | 271,1 | 0,034 95 | 1 191 | 1 598 | 2 789 | 2,986 | 5,923 |
| 5 700 | 272,2 | 0,034 29 | 1 197 | 1 591 | 2 788 | 2,997 | 5 915 |
| 5 800 | 273,4 | 0,033 65 | 1 202 | 1 585 | 2 787 | 3,007 | 5,907 |
| 5 900 | 274,5 | 0,033 03 | 1 208 | 1 578 | 2 786 | 3,017 | 5,899 |
| 6 000 | 275,6 | 0,032 44 | 1 214 | 1 571 | 2 785 | 3,027 | 5,891 |
| 6 200 | 277,7 | 0,031 30 | 1 225 | 1 558 | 2 783 | 3,047 | 5,875 |
| 6 400 | 279,8 | 0,030 23 | 1 236 | 1 545 | 2 781 | 3,066 | 5,860 |
| 6 600 | 281,8 | 0,029 22 | 1 247 | 1 532 | 2 779 | 3,085 | 5,845 |
| 6 800 | 283,8 | 0,028 27 | 1 257 | 1 519 | 2 776 | 3,104 | 5,831 |
| 7 000 | 285,8 | 0,027 37 | 1 267 | 1 506 | 2 773 | 3,122 | 5,816 |
| 7 200 | 287,7 | 0,026 52 | 1 278 | 1 493 | 2 771 | 3,140 | 5,802 |
| 7 400 | 289,6 | 0,025 72 | 1 288 | 1 481 | 2 769 | 3,157 | 5,788 |
| 7 600 | 291,4 | 0,024 95 | 1 298 | 1 468 | 2 766 | 3,174 | 5,774 |
| 7 800 | 293,2 | 0,024 22 | 1 307 | 1 455 | 2 762 | 3,191 | 5,761 |

# Marking Guidelines

higher education & training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

**AUGUST 2012**

NATIONAL CERTIFICATE

**CHEMICAL PLANT OPERATIONS N5**

(8050015)

**This marking guidelines consists of 4 pages.**

**QUESTION 1**

1.1 $\Delta H$ = [ $nc_p(T_f$ - 25°C)] (5)
= [5 x 9.11 (900°C - 25°C)]
= 45,55 (875)
= 39856,25 Cal

1.2.1 The first law of thermodynamics: Energy cannot be created or destroyed but can be converted from one form to another. (4)

1.2.2 Change in internal energy: This is the sum of the heat supplied to the system and the work done on it. (5)

1.2.3 Heat of fusion $\Delta H$: This is a quantity of energy required to change 1 g.mol of substance from the solid to the liquid phase.

**[20]**

**QUESTION 2**

2.1 $\Delta H = \Sigma \Delta H_f$ (product) - $\Sigma \Delta H_f$ (reactants) (8)
= $\Sigma \Delta H_f$ ($CaCO_3 + Na_2SO_4$) - $\Sigma \Delta H_f$ ($CaSO_4 + Na_2CO_3$)
= [(-288,5 + (- 330,5 )] – [( - 338,74 + (- 270,3)]
= - 619 – (- 609,04)
=-9.96 →

2.2.1 Molar heat capacity: This is the amount of energy required to raise the temperature of 1 g.mol substance with 1 K. (4)

2.2.2 Standard enthalpy of formation: This refers to the enthalpy change when the compound in its standard state is formed from the elements in their standard state. (5)

2.2.3 Hess 's law: The heat of reaction is equals the sum of the heats of formation of the products, minus the sum of the heats of formation of the reactants. (3)

**[20]**

**QUESTION 3**

3.1 (2)
- Open circuit gas turbine
- Closed circuit gas turbine

3.2.1 Axial-flow turbine (4)
- Steam flow parallel to turbine axis.
- Total pressure drop in the nozzle
- Steam enter at high velocity's directed in the moving blade and transfers

most of its velocity to the moving wheel.

3.2.2 Radial-flow turbine· (5)

- Steam flow from centre outwards or from outside toward the centre.
- Pressure drop during passage of steam through the nozzle, and then remain constant.
- Velocity increase due to pressure drop in the nozzle.
- Velocity decrease as kinetic energy is given to the moving blade.

3.2.3 The design of nozzle. (9)

- The shape of the nozzle must be such that the conversion from internal energy to kinetic energy is carried out with greatest efficiency.
- Nozzles are either converging or converging-diverging.
- The minimum section of a nozzle is called a throat.
- The corresponding pressure at the throat is called critical pressure.
- If the discharge pressure is greater than the critical pressure, converging nozzles are required.
- If discharge pressure is less than critical pressure, converging-diverging nozzles are required.

**[20]**

**QUESTION 4**

4.1 (5)

- Particles size and cyclone diameter
- Efficiency decrease with increased temperature
- Efficiency increases with particles density.
- Separation is more efficient if the particles are larger, small particles can agglomerate.
- Larger diameter cyclone tend to be less efficient because of a loss in centrifugal force, this effect is offset by the increased surface area.

4.2 (7)

- Feed enters through a stationary axial pipe, spraying outward into a 'pond' or annular layer of liquid inside the cylindrical bowl.
- Clarified liquid flows through overflow ports.
- Solid settles through the liquid to the inner surface of the bowl.
- A helical conveyor turning slightly slower than the bowl moves the solids to the discharge opening.
- Drained sludge and clarified liquor are thrown out from the bowl into different parts of the casing, from which they leave through suitable opening.

4.3 PREMIX BURNER (8)

- High-pressure air is used to aspirate the gas.
- The governor controls the amount of gas admitted to the aspirator.
- Fuel is premixed.

**[20]**

**QUESTION 5**

5.1
- Mixing chamber is closed during operation cycle.
- Heavy-duty, two-arm mixer in which the agitators are in the form of interrupted spirals.
- Solid are charged in from above and held in the trough during mixing by an air-operated piston under pressure.
- Mixed material is discharged through a sliding door in the bottom of the trough
- Heat generated is removed by cooling water spayed on the wall of the mixing chamber.

(6)

5.2
- Fine; light powders may be blended by continuously spreading them out in a thin layer under centrifugal action.
- A premix of the ingredients is fed near the centre of a high-speed spinning disk which throws them outward into a stationery casing.
- The shearing forces on the powders during their travel over the disk, blend the materials. (6)

5.2 Hydrochloric acid flowchart. (8)

**[20]**

# Past Examination Papers

higher education & training

Department: Higher Education and Training
REPUBLIC OF SOUTH AFRICA

**APRIL 2012**

NATIONAL CERTIFICATE

**CHEMICAL PLANT OPERATION N5**

(**8050015**)

**26 March 2012 (X-Paper)**
**09:00 – 12:00**

Calculators may be used.

**This question paper consists of 4 pages and a 1-page annexure.**

**TIME: 3 HOURS**
**MARKS: 100**

---

**INSTRUCTIONS AND INFORMATION**

1. Answer ALL the questions.

2. Read ALL the questions carefully.

3. Number the answers according to the numbering system used in this question paper.

4. Write neatly and legibly

---

**QUESTION 1**

1.1 Give the specific procedures for solving material balance problems. (5)

1.2 Define the following

1.2.1 Steady-state operation (4)

1.2.2 Kinetic energy (2)

1.3 The analysis of the waste gas from a burner fuelled with natural gas (essentially pure $CH_4$) is as follows:

$N_2$ 75 mol%; $O_2$10 mol%; $CO_2$ 5 mol% and $H_20$ 10 mol%

What is the ratio of moles of air to moles of natural gas fed to the burner? (9)

**[20]**

**QUESTION 2**

2.1 Draw a Van't Hoff box. (6)

2.2 Define the following:

2.2.1 Hess' law of heat summation (4)

2.2.2 Kopp's rule (4)

2.3 Determine the enthalpy change of 15 mol of nitrogen between 400°C and 1100°C. (6)

**[20]**

**QUESTION 3**

3.1 State the criteria for good combustion of fuels. (3)

3.2 Sketch a closed-circuit gas turbine and describe its principle of operation. (10)

3.3 State ONE advantage of the following:

3.3.1 Closed-circuit gas turbine (1)

3.3.2 Open-circuit gas turbine (1)

3.4 Indicate whether the following statements are TRUE or FALSE. Choose the answer and write only 'true' or 'false' next to the question number (3.4.1 - 3.4.5) in the ANSWER BOOK.

3.4.1 In an axial steam turbine, the steam flow is parallel to the turbine axis. (1)

3.4.2 A cyclone consists of a vertical cylinder with a conical top. (1)

3.4.3 In an impulse turbine all the available pressure drop from supply to the exhaust occurs across the blades. (1)

3.4.4 In impulse reaction turbine, only part of the pressure drop occurs over the moving blades. (1)

3.4.5 In a reaction turbine, the pressure drop occurs over the moving blade. (1)

**[20]**

**QUESTION 4**

4.1 Sketch an atomizing oil burner (low-pressure) and describe its operation. (8)

4.2 Define the following terms with reference to a cyclone:

4.2.1 Cut diameter (2)

4.2.2 Ordinate (2)

4.3 Write brief, clarifying notes to distinguish between a kneader; a dispenser and a masticator. (8)

**[20]**

**QUESTION 5**

5.1 What would you bear in mind to maximise the chemical conversion of $SO_2$ to $SO_3$? (4)

5.2 Draw a flowchart of the salt process for the manufacturing of hydrochloric acid and give a chronological description of the process. (16)

**[20]**

Appendix 7B Mean molar heat capacities of gases at constant pressure [Btu/(lb mol · °F) or cal/(g mol · °C)]

| °C | °F | $H_2$ | $N_2$ | CO | Air | $O_2$ | HCl | $Cl_2$ | $H_2O$ | $CO_2$ | $SO_2$ | $SO_3$ | $CH_4$ | $C_2H_6$ | $C_2H_4$ | $NH_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | 77 | 6.89 | 6.96 | 6.97 | 6.97 | 7.02 | 6.96 | 8.12 | 8.02 | 8.88 | 9.54 | 12.11 | 8.55 | 10.45 | 12.63 | 8.48 |
| 100 | 212 | 6.92 | 6.97 | 7.00 | 7.00 | 7.08 | 6.97 | 8.24 | 8.08 | 9.25 | 9.85 | 12.84 | 8.98 | 11.35 | 13.76 | 8.79 |
| 200 | 392 | 6.96 | 7.00 | 7.02 | 7.02 | 7.18 | 6.98 | 8.37 | 8.18 | 9.70 | 10.25 | 13.74 | 9.62 | 12.53 | 15.27 | 9.16 |
| 300 | 572 | 6.97 | 7.04 | 7.07 | 7.07 | 7.29 | 7.00 | 8.48 | 8.32 | 10.11 | 10.62 | 14.54 | 10.29 | 13.65 | 16.72 | 9.51 |
| 400 | 752 | 6.98 | 7.09 | 7.14 | 7.15 | 7.41 | 7.02 | 8.55 | 8.41 | 10.46 | 10.94 | 15.22 | 10.97 | 14.67 | 18.11 | 9.84 |
| 500 | 932 | 7.00 | 7.16 | 7.21 | 7.23 | 7.52 | 7.06 | 8.61 | 8.54 | 10.78 | 11.22 | 15.82 | 11.65 | 15.60 | 19.39 | 10.16 |
| 600 | 1112 | 7.01 | 7.23 | 7.29 | 7.30 | 7.62 | 7.10 | 8.66 | 8.68 | 11.05 | 11.45 | 16.33 | 12.27 | 16.45 | 20.38 | 10.48 |
| 700 | 1292 | 7.03 | 7.30 | 7.37 | 7.37 | 7.71 | 7.15 | 8.70 | 8.82 | 11.30 | 11.66 | 16.77 | 12.90 | 17.22 | 21.68 | 10.80 |
| 800 | 1472 | 7.06 | 7.37 | 7.44 | 7.45 | 7.79 | 7.21 | 8.73 | 8.96 | 11.53 | 11.84 | 17.17 | 13.48 | 17.95 | 22.72 | 11.11 |
| 900 | 1652 | 7.09 | 7.44 | 7.52 | 7.52 | 7.87 | 7.27 | 8.77 | 9.11 | 11.74 | 12.01 | 17.52 | 14.04 | 18.63 | 23.69 | 11.42 |
| 1000 | 1832 | 7.13 | 7.51 | 7.59 | 7.59 | 7.94 | 7.33 | 8.80 | 9.25 | 11.92 | 12.15 | 17.86 | 14.56 | 19.23 | 24.56 | 11.73 |
| 1100 | 2012 | 7.17 | 7.57 | 7.65 | 7.66 | 9.01 | 7.39 | 8.82 | 9.39 | 12.10 | 12.28 | 18.17 | 15.04 | 19.81 | 25.40 | 12.03 |
| 1200 | 2192 | 7.21 | 7.64 | 7.71 | 7.72 | 8.07 | 7.45 | 8.84 | 9.52 | 12.25 | 12.39 | 18.44 | 15.49 | 20.33 | 26.15 | 12.34 |
| 1300 | 2372 | 7.25 | 7.69 | 7.77 | 7.78 | 8.12 | ... | ... | 9.66 | 12.39 | | | | | | |
| 1400 | 2552 | 7.29 | 7.74 | 7.82 | 7.82 | 8.17 | ... | ... | 9.77 | 12.50 | | | | | | |
| 1500 | 2732 | 7.33 | 7.79 | 7.87 | 7.87 | 8.20 | ... | ... | 9.89 | 12.69 | | | | | | |
| 1600 | 2912 | 7.39 | 7.84 | 7.92 | 7.93 | 8.27 | ... | ... | 9.95 | 12.75 | | | | | | |
| 1700 | 3092 | 7.42 | 7.88 | 7.96 | 7.97 | 8.31 | ... | ... | 10.13 | 12.80 | | | | | | |
| 1800 | 3272 | 7.47 | 7.92 | 8.00 | 8.01 | 8.35 | ... | ... | 10.24 | 12.94 | | | | | | |
| 1900 | 3452 | 7.51 | 7.96 | 8.03 | 8.04 | 8.38 | ... | ... | 10.34 | 13.01 | | | | | | |
| 2000 | 3632 | 7.55 | 7.99 | 8.07 | 8.08 | 8.42 | ... | ... | 10.43 | 13.10 | | | | | | |

*Source:* Based on O. A. Hougan, K. M. Watson, and R. A. Ragatz, "Chemical Process Principles," Part I, p. 258, John Wiley & Sons, Inc., New York, 1954.

# Marking Guidelines

higher education & training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

**APRIL 2012**

NATIONAL CERTIFICATE

**CHEMICAL PLANT OPERATIONS N5**

(8050015)

**This marking guidelines consists of 5 pages.**

**QUESTION 1**

1.1
- Identify the type of question (5)
- Draw a flow sheet
- Select a basis for calculation
- Construct an input output table
- Formulate the balances needed to solve the problem

1.2.1 **Change in internal energy:** This is the sum of the heat supplied to the system and the work done on it (4)

1.2.2 **Kinetic energy:** If particle (object) is in motion it possesses energy because of this motion. (2)

1.3 Basis: 100 mol (9)

$O_2 : N_2 = 21:79$

$$\therefore \frac{21}{79} = \frac{x}{75}$$

$$x = \frac{21 \times 75}{79}$$

$O_2 = 19,937$

From the reaction: $CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$

$CH_4 : CO_2 = 1:1$

□ = 5 mol

The amount of air in the input = (75 + 19,937) = 94,937

$$Air : CH_4 = \frac{75 + 19,937}{5}$$

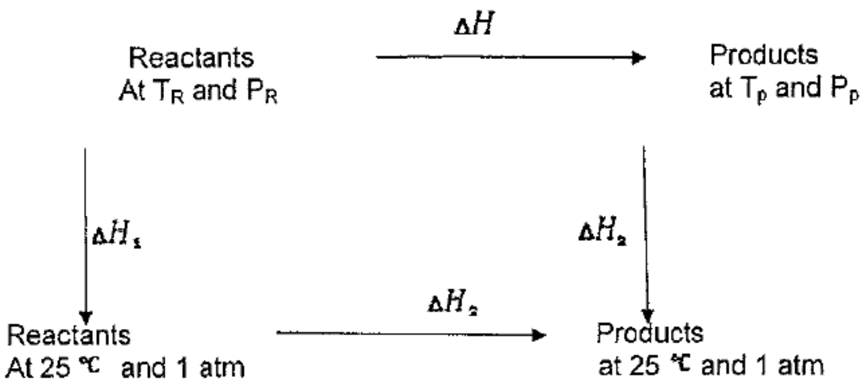
= 18,99:1

= 19:1

**[20]**

**QUESTION 2**

2.1 (6)




2.2 **Hess 's law:** The heat of reaction is equals the sum of the heats of formation of the products, minus the sum of the heats of formation of the reactants (4)

2.3 Kopp's rule: The total heat capacity of a compound is approximately equal to the sum of the heat capacities of the constituent element. (4)

2.4 (6)

$$
\begin{aligned}
\Delta H &= [n c_p(T_f - 25\ ℃)] - [n\, c_p\,(T_i - 25\ ℃)] \\
&= [15 \times 7.57\ (1\,100\ ℃ - 25\ ℃)] - [15 \times 7.09\ (400\ ℃ - 25\ ℃)] \\
&= 122066{,}25 - 39881{,}25 \\
&\underline{82\ 185\ \text{Cal}} \rightarrow
\end{aligned}
$$

**[20]**

**QUESTION 3**

3.1 Time, temperature and turbulence. (3)

3.2 Closed circuit turbine (10)

- In this plant the working agent is preheated, before it enters the heater, by energy recovered from the exhaust of the turbine.
- In practice 75% of the possible heat is transferred to the air flowing from the compressor towards the heater or combustion chamber.
- About 55% of the power developed by the turbine is required to drive the compressor and 45% is available from the plant for other purpose.

3.3.1 Working agent remains free from pollution by the product of the combustion and the interior of the plant remains clean. (1)

3.3.2 No costly heating and cooling devices are needed. (1)

3.4.1 True (1)

3.4.2 False (1)

3.4.3 False (1)

3.4.4 False (1)

3.4.5 False (1)

**[20]**

**QUESTION 4**

4.1 Atomizing oil (8)
Low

- Combustion air surrounds the fuel nozzle, and it is blown into furnace with the fuel spray.

- Vanes and baffles assure proper air-fuel mixing.

- Nozzle atomise fuel with air.

4.2.1 Cut diameter: This is the diameter for which one-half the inlet particles, by mass are separated and the other half retained by the air. (2)

4.2.2 Ordinate: Indicate the affectivity of cyclone. (2)

4.3 **A kneader:** Handles suspensions, pastes and light plastic masses (8)
**A dispenser:** It heavier in construction and draw more power than a kneader, it works additives and colour agents into stiff materials.
**A masticator:** It draws even more power. It can disintegrate scrap rubber and compound the toughest plastic masses that can be worked at all.

**[20]**

**QUESTION 5**

5.1 (4)
- Equilibrium is an inverse function of temperature and a direct function of $O_2/SO_2$ ratio.
- Rate of reaction is a direct function of temperature.
- Composition and ratio of the amount of catalyst to the amount of $SO_3$ formed.
- Removal of $SO_3$ causes more $SO_2$ to be converted.
- HCI process

5.2 (16)
- Sulfuric acid and salt are roasted in a furnace to form hydrogen chloride
- and sodium sulfate (salt cake).

- The hydrogen chloride, contaminated with droplets of sulfuric acid and particles of salt cake, is cooled by passing it through coolers, cooled externally by water.

- The cooled gas is then passed upward through a coke tower to remove suspended foreign materials.

- Purified hydrogen chloride from the top of the coke tower is absorbed in water in tantalum or Karbate absorber.

- Finished hydrochloric acid is withdrawn from the bottom of the absorber, and any undissolved gas passing out the top of the absorber is scrubbed out with the water in a packed tower.

**[20]**

# Past Examination Papers

higher education & training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

**NOVEMBER 2011**

NATIONAL CERTIFICATE

**CHEMICAL PLANT OPERATION N5**

(**8050015**)

**24 November 2012 (X-Paper)**
**09:00 – 12:00**

Calculators may be used.

**This question paper consists of 4 pages.**

**TIME: 3 HOURS**
**MARKS: 100**

**INSTRUCTIONS AND INFORMATION**

1. Answer ALL the questions.
2. Read ALL the questions carefully.
3. Number the answers according to the numbering system used in this question paper.
4. Write neatly and legibly

**QUESTION 1**

1.1 Define the following:

1.1.1 The calorie (4)

1.1.2 Hess's law of heat of summation (4)

1.1.3 The gram mole (4)

1.2 Determine the enthalpy change of 10 mol of methane ($CH_4$) between 600°C and 1 200°C. (8)

**[20]**

**QUESTION 2**

2.1 Calculate the mol percentage composition of the following mixture: (9)

$Na_2SO_4$ 2S % (m/M); NaOH 27% (m/M); NaCl 26%(m/M) and $NaCO_3$ 22% (m/M)

Given: Na = 23 g/mol; S = 32 g/mol; 0 = 16 g/mol; C = 12 g/mol;

Cl = 35,5 g/mol; H = 1 g/mol

2.2 One of the techniques for producing hydrogen is to react methane and ethane with steam in the presence of nickel catalyst. The analysis on a dry basis of the gases reacting such reactor is: (11)
$CH_4$ 4,6 mol %; $C_2H_6$ 2,3 mol %; CO 18,6 mol %, $CO_2$ 4,6 mol %;
2 69,7 mol

[1 g mol gas = 22,4L]

What is the molar ratio of the hydrocarbon gases in the feed?

**[20]**

**QUESTION 3**

3.1 Write brief, explanatory notes on the following:

3.1.1 Impulse turbines (4)

3.1.2 Reaction turbines (4)

3.2 State the criteria for combustion of liquid fuels. (3)

3.3 Make a sketch of an open-circuit gas turbine. (9)

**[20]**

**QUESTION 4**

4. Describe the operation of the following:

4.1 Centrifugal decanters (5)

4.2 Cyclones (5)

4.3 Two-arm kneader (5)

4.4 Banbury mixer (5)

**[20]**

**QUESTION 5**

5.1 Draw a flowchart of the salt process tor the manufacturing of hydrochloric acid and give a chronological description of the process. (15)

5.2 State FIVE uses of sulphuric acid. (5)

**[20]**

# Marking Guidelines

higher education & training

Department: Higher Education and Training
REPUBLIC OF SOUTH AFRICA

**NOVEMBER 2011**

NATIONAL CERTIFICATE

**CHEMICAL PLANT OPERATIONS N5**

(8050015)

**QUESTION 1**

1.1.1 The calorie is the amount of heat required to raise a temperature of 1 g of Water from 14,5 to 15,5°C (4)

1.1.2 The heat of reaction equals the sum of the heats of formation of the products minus the sum of the heats of formation of the reactants (4)

1.1.3 Is the formula weight of a substance expressed in grams and represent Avogadro's number of particles (4)

1.2 $\Delta H$ $= nc_p\,(T_f)(T_f - 25°C) – nc_p(T_1)(T_1 - 25°C)$ (8)

$= 10 \times 15,49\,(1200 – 25) – 10 \times 12,2\,(600 – 25)$

$= 182007,5 - 70150$

$= 111,858$ cal

**[20]**

**QUESTION 2**

2.1 (9)

| | MASS/MOL | MOL | MOL% |
|---|---|---|---|
| $Na_2SO_4$ | $\frac{25}{2(23) + 32 + 4(16)}$ | 0,176 | $\frac{0,176}{1,503} \times 100 = 11,7\%$ |
| NaOH | $\frac{27}{23 + 16 + 1}$ | 0,675 | $\frac{0,675}{1,503} \times 100 = 45\%$ |
| NaCl | $\frac{26}{23 + 35,5}$ | 0,444 | $\frac{0,444}{1,503} \times 100 = 29,5\%$ |
| $Na_2CO_3$ | $\frac{22}{2(23) + 12 + 3(16)}$ | 0,208 | $\frac{0,208}{1,503} \times 100 = 13,8\%$ |
| TOTAL n moles | | 1,503 | |

2.2 H -atom balance : (4, 6 x 4) + (2,3 x 6) + (69,7 x2) = 171,6 (11)
C -atom balance : (4, 6 x 1) + (2,3 x 2) + (18,6 x 1) + (4,6 x 1) = 32,4
0 -atom balance : (18,6 x 1) + (4, 6 x 2) = 27, 8

H -atom balance : 4M + 6E + 2S = 171,6 .............. (1)
C -atom balance : M + 2E = 32,4 ........................... (2)
0 -atom balance. : + S = 27, 8 ................................ (3)

Substitute (3) in (1)

4M + 6E + 2(27,8) = 171,6
4M + 6E + 55,6) = 171,6
4M + 6E = 116 ...................... (4)

3 x (2) 3M + 6E = 97,2
∴ M= 18,8

Substitute Min (2)

18,8 + 2E = 32,4

2E = 13,6
E = 6,8

M = 18,8
E = 6,8

Molar ratio **M:E**
18,8/6,8
**2,76:1**

**[20]**

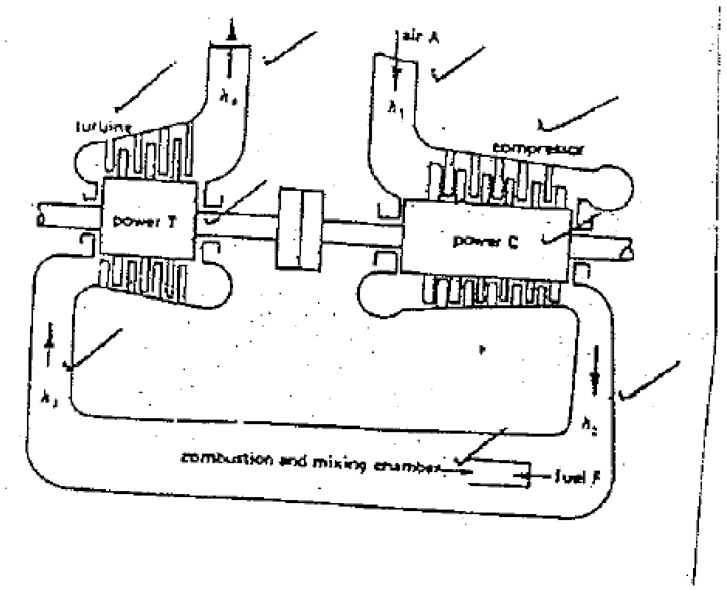
**QUESTION 3**

3.1.1 In an impulse turbine all the available pressure drop from supply to exhaust occurs across the nozzle. The steam carries out all its full expansion in the nozzles and emerges with velocity. The nozzle is directed so that the steam glides on the blade, and these are so shaped that the direction of flow of steam is changed and thereby a force is exerted on the blades. (4)

3.1.2 In a reaction turbine, only part of the pressure drop occurs in the nozzles. The remainder occurring during the passage of steam through the blades. The blade passage are nozzle shaped so that the acceleration requires a force (force = mass x acceleration); a resultant reaction occurs on the blades. The force of reaction is added to force resulting from redirection of the steam to make the total propulsive force on the blades. (4)

3.2 Time; temperature and turbulence (3)

3.3 (9)




**[20]**

**QUESTION 4**

4.1 **Centrifugal decanters** (5)

Their operation is similar to that of the gravity decanters, except that the separating force is much larger than that of gravity and it acts in the direction away from the axis of rotation instead of downward toward the earth's surface. The main types of centrifugal decanters are tubular and disk centrifuges.

4.2 **Cyclone** (5)

It consists of a vertical cylinder with a conical bottom, a tangential inlet near the top and an outlet for dust at the bottom of the cone. The inlet is usually rectangular. The outlet pipe is extended into the cylinder to prevent short circuiting of air from the inlet to the outlet. The incoming dust-laden air receives an rotating motion on entrance to the cylinder. The vortex so formed develops centrifugal force which acts to throw the particles radically towards the wall.

The part of the air in a cyclone follows a down ward vortex or spiral adjacent to the wall and reaching to the bottom of the cone. The air stream then moves upward in a tighter spiral, concentric with the first and leaves through the outlet pipe, still whirling

4.3 **Two-arm kneader** (5)

It handles suspensions, paste and light plastic masses. In all these machines the mixing is done by two heavy blades on parallel horizontal shafts turning in a short trough with a saddle-shaped bottom. The blades turn toward each other at the top, drawing the mass downward over the point of the saddle, then shearing it between the blades and the wall of the trough.

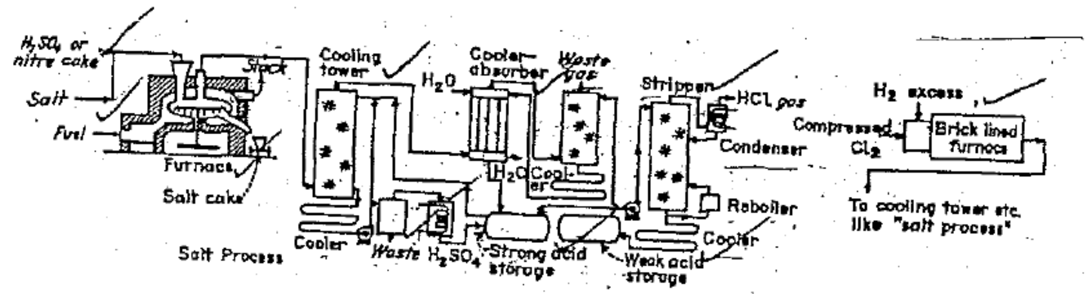
4.4 **Branbury mixer** (5)

This heavy two-arm mixer in which the agitators are in the form interrupted spirals. Solids are charged in from above and held in the trough during mixing by air-operated piston under a pressure. Mixed material is discharged through a sliding door in the bottom of the trough. Branbury mixers compound rubber and plastic solids. The heat generated in the walls of the mixing chamber

**[20]**

**QUESTION 5**

5.1 Flow chart of HCl (15)




- Sulfuric acid and salt are roasted in a furnace to form hydrogen chloride and sodium sulfate
- The hot hydrogen chloride contaminated with droplets of sulfuric acid V and particles of salt cake is cooled by passing it through coolers, cooled externally by water
- The cooled gas is then passed through a coke tower to remove suspended foreign materials
- Purified hydrogen chloride from the top of the coke tower is absorbed in a water in a tantalum of karbate absorber
- Finished hydrochloric acid is withdrawn from the bottom of the absorber

5.2
- Manufacture of sulfate (5)
- Manufacture of fertilizers
- Manufacture of tin plate
- Manufacture of leather
- Refining of petroleum
- Dying of fabrics

**[20]**

**N5 Chemical Plant Operation is one of many publications introducing the gateways to Engineering Studies. This course is designed to develop the skills for learners that are studying toward a career in plant operation in the engineering and related fields and to assist them to achieve their full potential in an industrial engineering career.**

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