| Course Title | ENGINEERING THERMODYNAMICS |
|---|---|
| Course Code | AMED07 |
| Class | III SEM |
| Section | A |
| Name of the Faculty | Dr G.Hima Bindu |
| Lecture hour and Date | |
| Course Outcome/s | |
| Topic covered | |
| Topic learning outcome | |

**OUTCOMES:** Determine heat, work, internal energy, enthalpy for flow & non flow process using First Law of Thermodynamics.

**Pure substance**

A substance that has a fixed chemical composition throughout the system is called a pure substance. Water, hydrogen, nitrogen, and carbon monoxide, for example, are all pure substance. A pure substance can also be a mixture of various chemical elements or compounds as long as the mixture is homogeneous. Air, a mixture of several compounds, is often considered to be a pure substance because it has a uniform chemical composition. "A mixture of two or more phases of a pure substance is still a pure substance as long as the chemical composition of all phases is the same. A mixture of ice and liquid water, for example, is a pure substance because both phases have the same chemical composition."

## PVT Surface

Pressure can be expressed as a function of temperature and specific volume: $p = p(T, v)$. The plot of $p = p(T, v)$ is a surface called $p$-$v$-$T$ surface. Figure 3.1 shows the $p$-$v$-$T$ surface of a substance such as water that expands on freezing.

(a)

(b)

(c)
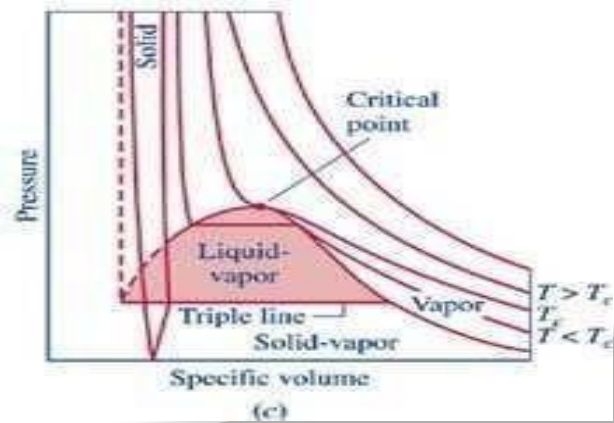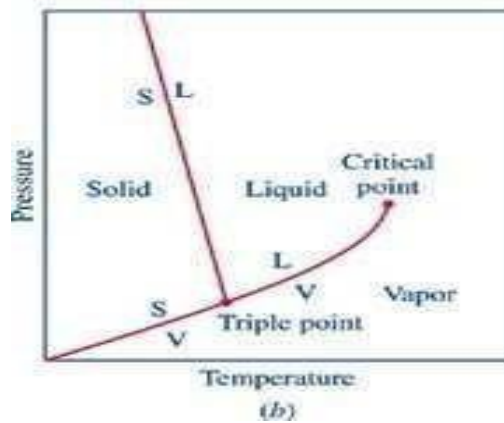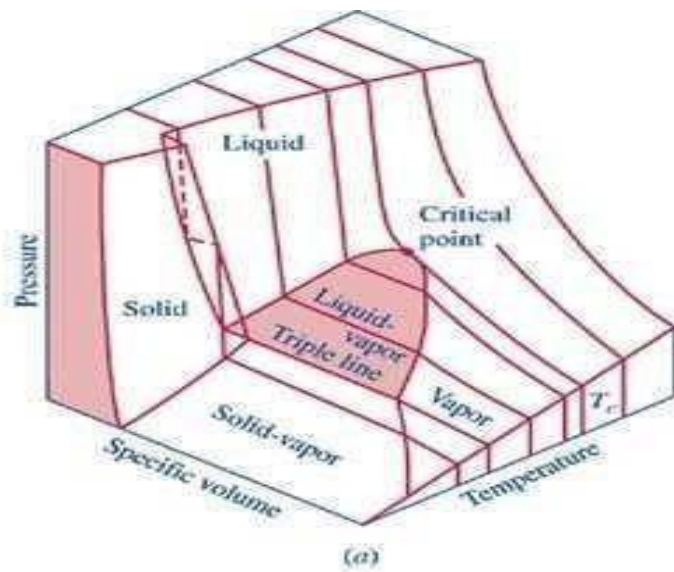
**Phase Behavior:**

    We will consider a phase change of 1 kg of liquid water contained within a piston-cycinder assembly as shown in Figure 3.2-1a. The water is at 20$^{o}$C and 1.014 bar (or 1 atm) as indicated by point (1) on Figure 3.2-2.



(a)               (b)               (c)
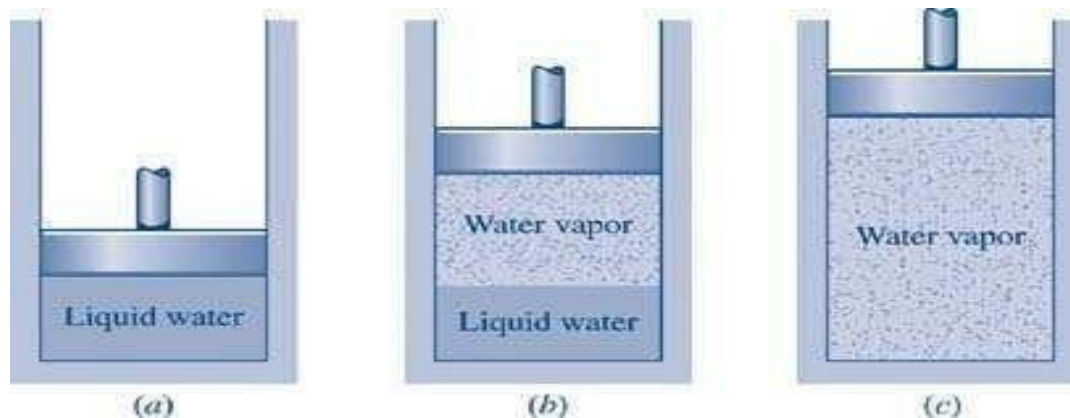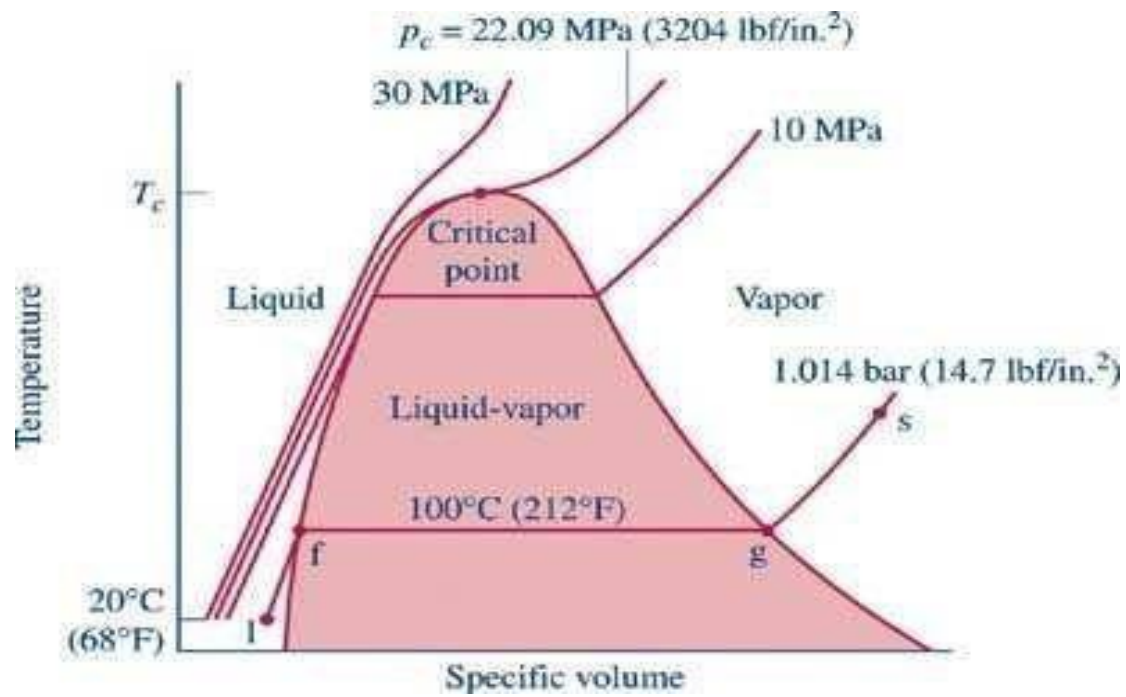
As the water is heated at constant pressure ,the temperature increases with a slight increase in specific volume until the system reaches point (f ). This is the saturated liquid state corresponding to 1.014 bar. The saturation temperature for water at 1.014 bar is 100 degree C. The liquid states along the line segment 1-f are called subcooled or compressed liquid states. When the system is at the saturated liquid state any additional heat will cause the liquid  to evaporate at constant pressure as shown in fig. When a mixture of liquid and vapor exists in equilibrium ,the liquid phase is a saturated liquid and the vapor phase is a saturated vapor.

Liquid water continues to evaporate with additional heat until it becomes all saturated vapor at point (g). Any further heating will cause an increase in both temperature and specific volume and the saturated vapor becomes superheated vapor denoted by point (s) in Figure 3.2-2. For a two-phase liquid-vapor mixture, the quality $x$ is defined as the mass fraction of vapor in the mixture

$$x = \frac{m_{vapor}}{m_{vapor} + m_{liquid}}$$

When a substance exists as part liquid and part vapor at saturation conditions, its quality (x) is defined as the ratio of the mass of the vapor to the total mass of both vapor and liquid.

| Course Title | ENGINEERING THERMODYNAMICS |
|---|---|
| Course Code | AMED07 |
| Class | III SEM |
| Section | A |
| Name of the Faculty | Dr G.Hima Bindu |
| Lecture hour and Date | |
| Course Outcome/s | |
| Topic covered | |
| Topic learning outcome | |

**OUTCOMES:** Determine heat, work, internal energy, enthalpy for flow & non flow process using First Law of Thermodynamics.

**Enthalpy–Entropy Chart**

An enthalpy–entropy chart, also known as the H–S chart or Mollier diagram, plots the total heat against entropy, describing the enthalpy of a thermodynamic system. A typical chart covers a pressure range of 0.01–1000 bar, and temperatures up to 800 degrees Celsius. It shows enthalpy H in terms of internal energy U, pressure p and volume V using the relationship H=U+pV or, in terms of specific enthalpy, specific entropy and specific volume.

On the diagram, lines of constant pressure, constant temperature and volume are plotted, so in a two-phase region, the lines of constant pressure and temperature coincide. Thus, coordinates on the diagram represent entropy and heat.

A vertical line in the h–s chart represents an isentropic process. The process 3–4 in a Rankine cycle is isentropic when the steam turbine is said to be an ideal one. So the expansion process in a turbine can be easily calculated using the h–s chart when the process is considered to be ideal (which is the case normally when calculating enthalpies, entropies, etc. Later the deviations from the ideal values and they can be calculated considering the isentropic efficiency of the steam turbine used.

engineeringtoolbox.com
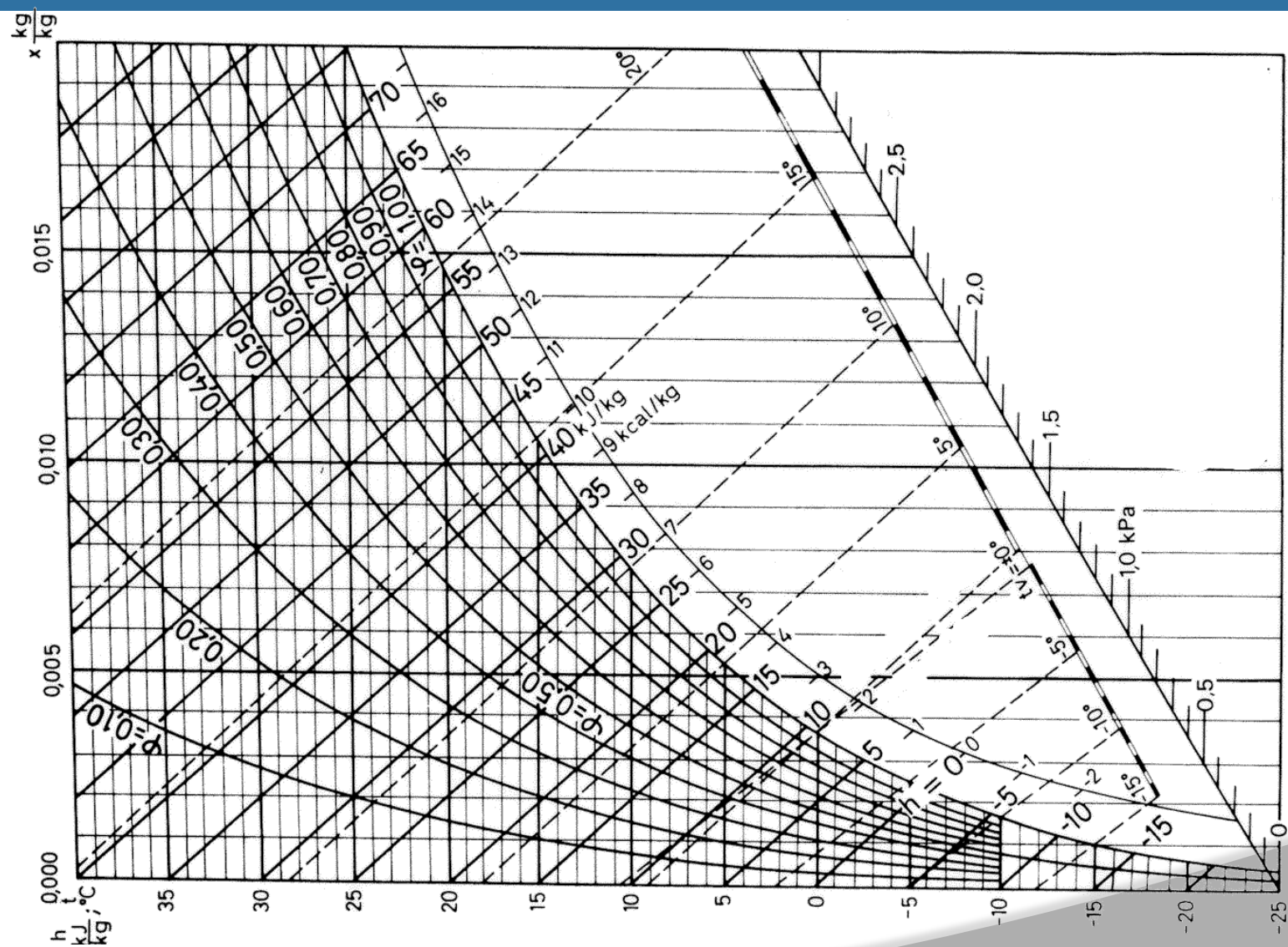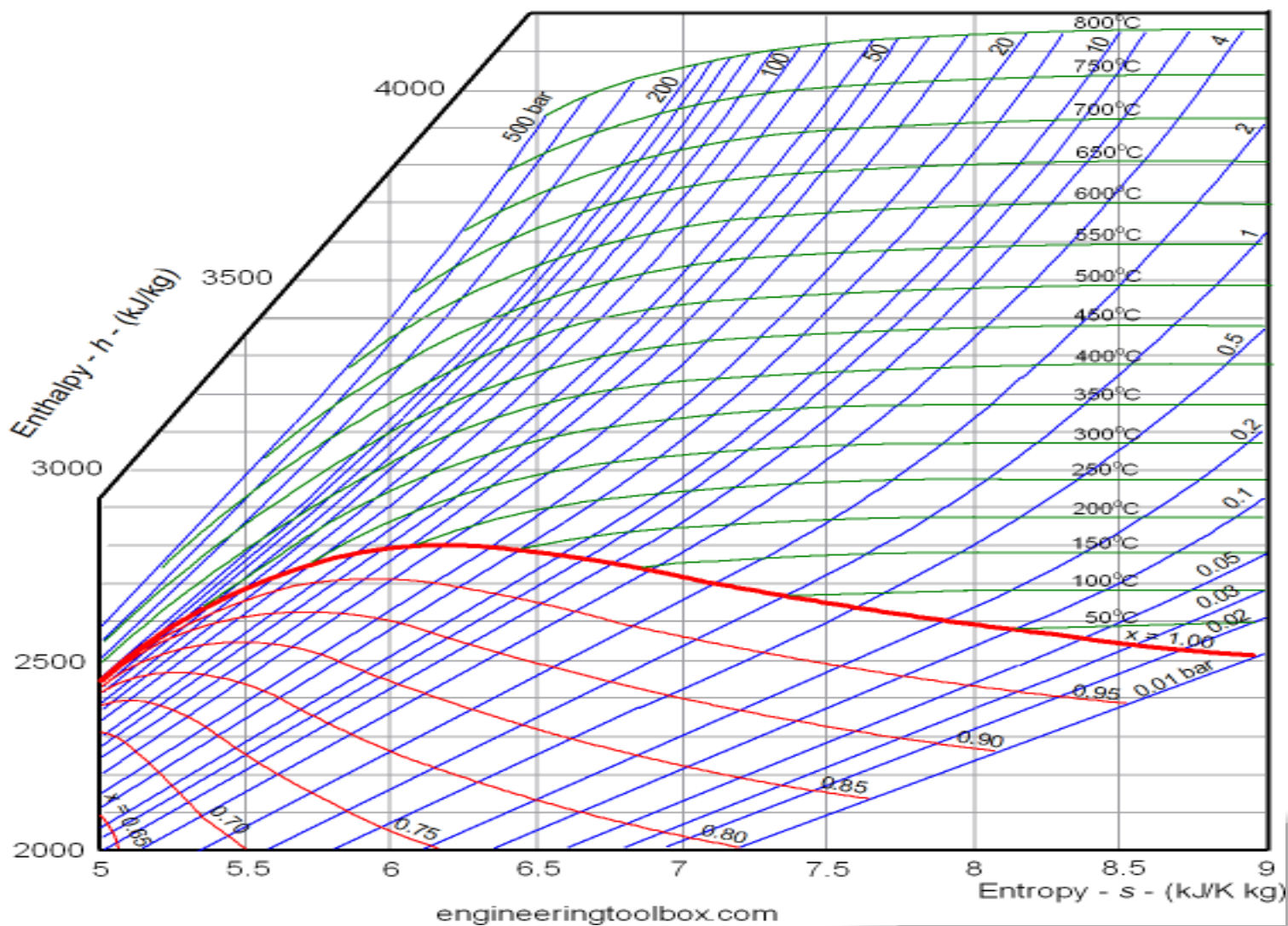
Lines of constant dryness fraction (x), sometimes called the quality, are drawn in the wet region and lines of constant temperature are drawn in the superheated region. X gives the fraction (by mass) of gaseous substance in the wet region, the remainder being colloidal liquid droplets. Above the heavy line, the temperature is above the boiling point, and the dry (superheated) substance is gas only.

**Characteristics of the critical point:**

➢ For saturated phase often its enthalpy is an important property.
➢ Enthalpy-pressure charts are used for refrigeration cycle analysis.
➢ Enthalpy-entropy charts for water are used for steam cycle analysis.
➢ Note: Unlike pressure, volume and temperature which have specified numbers associated with it, in the case of internal energy, enthalpy (and entropy) only changes are required. Consequently, a base (or datum) is defined -as you have seen in the case of water.

Let V be total volume of liquid vapour mixture of quality x, Vfthe volume of saturated liquid and Vg the volume of saturated vapour, the corresponding masses being m, mf and mg respectively.

Now, m = mf + mg

V = Vf+ Vg

m v= mfvf+ mgvg

**Saturation States**

When a liquid and its vapour are in equilibrium at certain pressure and temperature, only the pressure or the temperature i is s sufficient to identify the saturation state.
If pressure is given, the temperature of the mixture gets fixed, which is known as saturation temperature, or if the temperature is given, the saturation pressure gets fixed.
Saturation liquid or saturated vapour has only on independent variable, i.e. only one property is required to b known to fix up the state.

| Course Title | ENGINEERING THERMODYNAMICS |
|---|---|
| Course Code | AMED07 |
| Class | III SEM |
| Section | A |
| Name of the Faculty | Dr G.Hima Bindu |
| Lecture hour and Date | |
| Course Outcome/s | |
| Topic covered | |
| Topic learning outcome | |

**OUTCOMES:** Determine heat, work, internal energy, enthalpy for flow & non flow process using First Law of Thermodynamics.

**Type of Steam**

Wet steam:

Wet steam is defined as steam which is partly vapour and partly liquid suspended in it. It means that evaporation of water is not complete.

Dry saturated steam:

When the wet steam is further heated, and it does not contain any suspended particles of water, it is known as dry saturated steam.

Superheated steam: When the dry steam is further heated at constant pressure, thus raising its temperature, it is called superheated steam.

**Measurement of Steam Quality:**

The state of a pure substance gets fixed if two independent properties are given. A pure substance is thus said to have two degrees of freedom. Of all thermodynamic properties, it is easiest to measure the pressure and temperature of a substance. Therefore, whenever pressure and temperature are independent properties, it is the practice to measure them to determine that state of the substance.

Types of Calorimeters used for measurement of Steam Quality

- ➢ Barrel Calorimeter
- ➢ Separating Calorimeter
- ➢ Throttling Calorimeter
- ➢ Combined Separating and Throttling calorimeter

**Barrel Calorimeter**

Dryness fraction of steam can be found out very conveniently by barrel calorimeter as shown in figure. A vessel contains a measured quantity of water. Also water equivalent of

the vessel is determined experimentally and stamped platform of weighing machine. Sample of steam is passed through the sampling tube into fine exit holes for discharge of steam in the cold water.

The steam gets condensed and the temperature of water rises. The weighing machine gives the steam condensed.
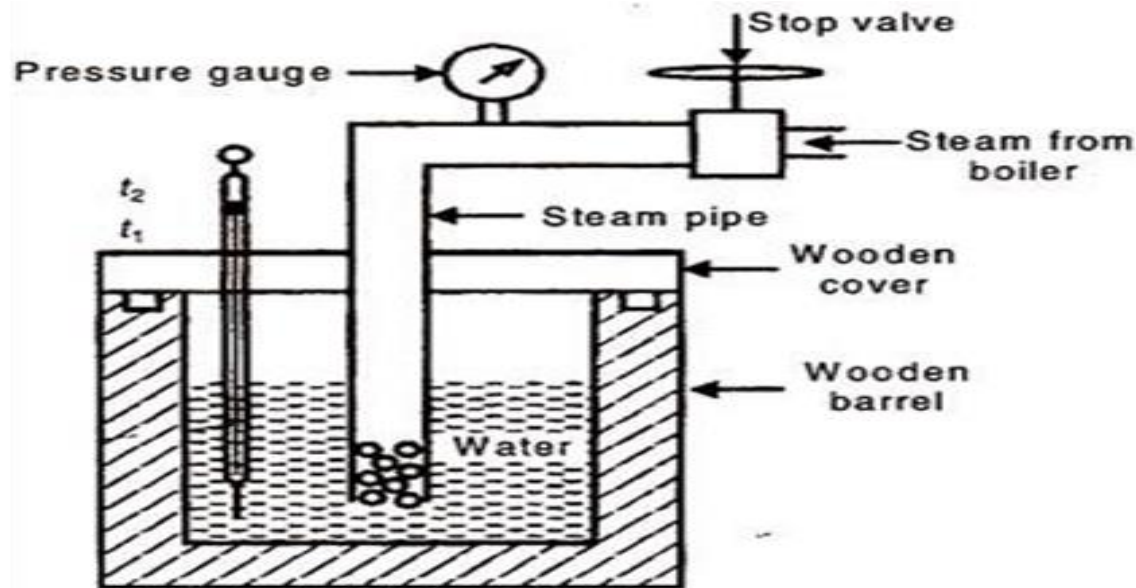
**Fig. 10.19**

Let,

$ms$ = weight of steam condensed
$m_w$ = weight of cold water in barrel
$C_{pw}$ = sp. heat of water
$x$ = dryness fraction of steam
$h_{fg}$ = latent heat of the steam at pressure of steam $P$
$t_1$ = initial temperature of water before mixing steam
$t_2$ = final temperature of steam after mixing of steam
$t$ = saturation the temperature of steam at $P$.

Then we can find the dryness fraction of steam by using the equations given below.
[Heat lost by steam] = [Heat gained by coal water]

$$Ms\left[x.h_{fg} + C_{pw}(t-t_2)\right] = M_w C_{pw}(t_2 - t_1)$$

From this equation, we can find the dryness fraction of steam $(x)$

Basically, this calorimeter is used when we want to know the approximate dryness fraction of steam, or to have a rough idea about the dryness fraction. This calorimeter gives better results if the dryness fraction of steam is greater than 0.95.
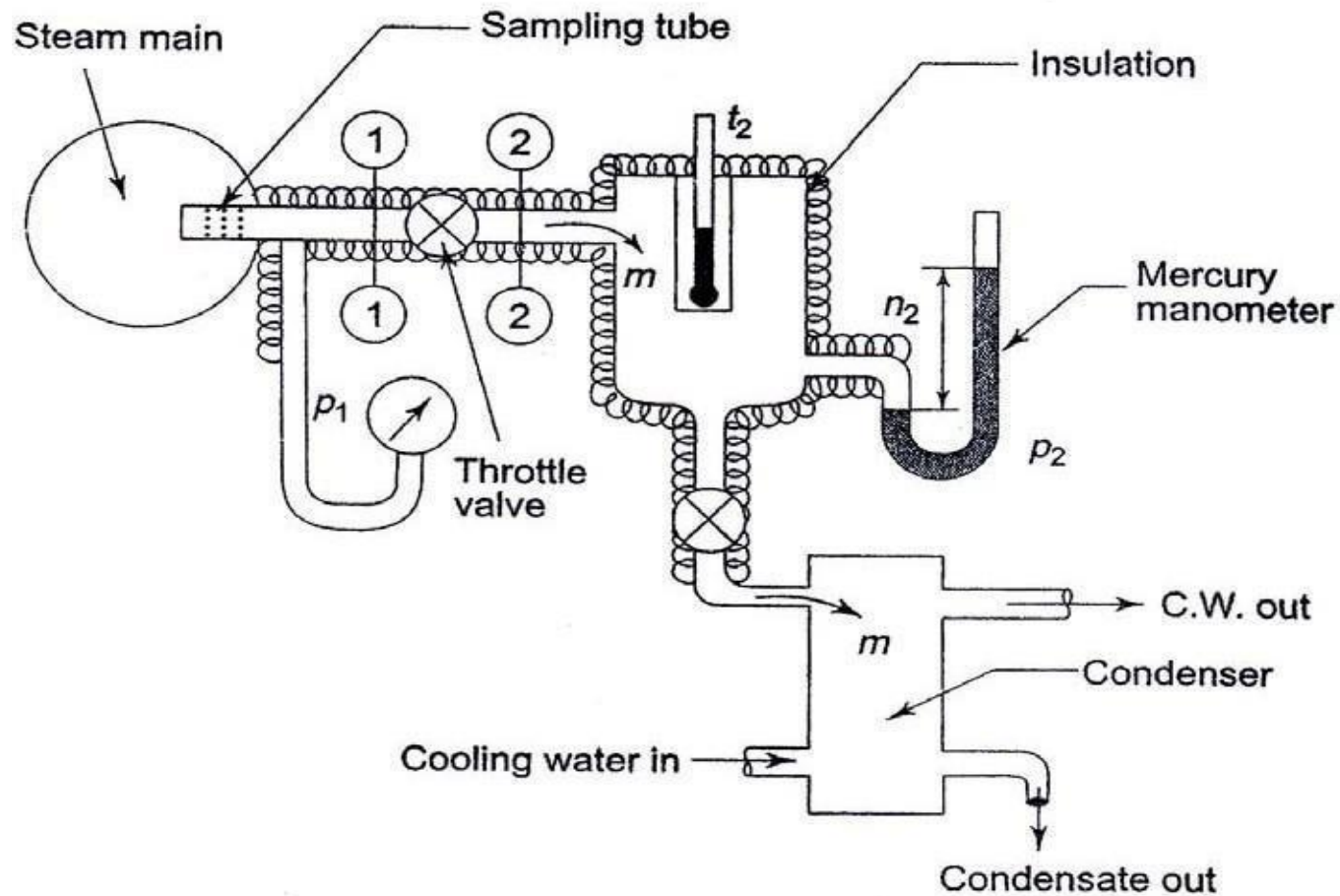
# Separating Calorimeter
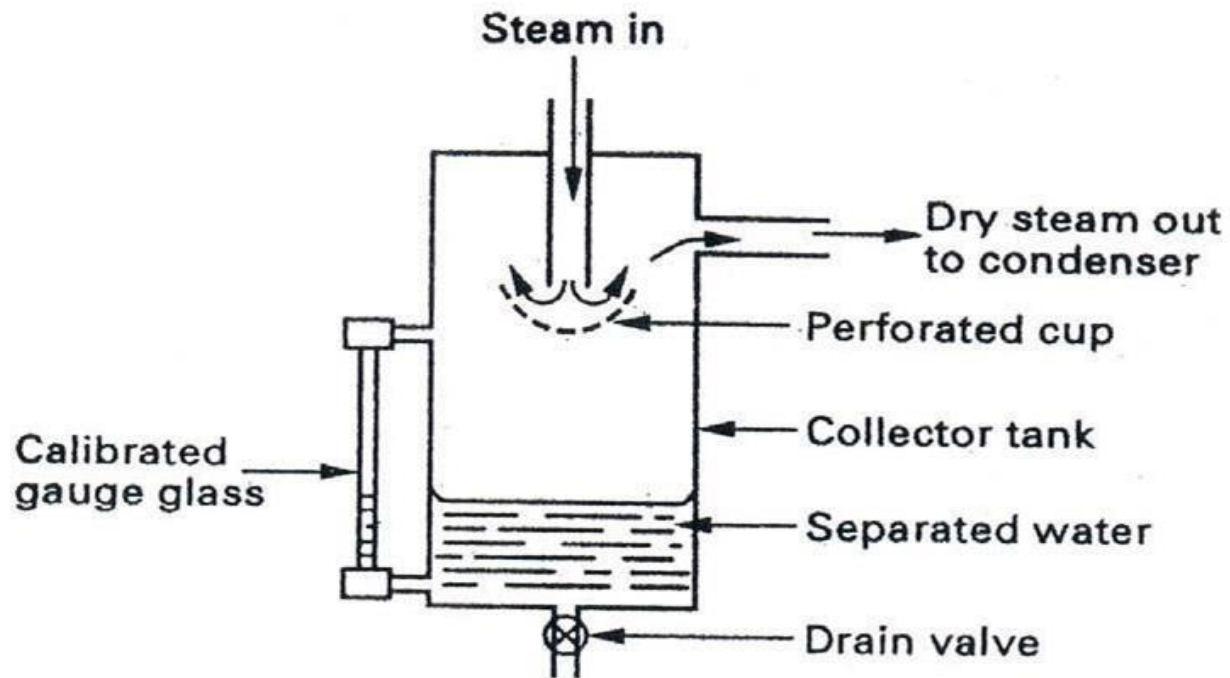
The wet steam enters at the top from the main steam pipe through holes in the sampling pipe facing up stream which should be as far as possible downstream from elbows and valves to ensure representative sample of steam when in operation the wet steam entering passes down the central passage and undergoes a sudden reversal of direction of motion when strikes perforated cup.

The weight of steam passing through the jacket may also be readily determined by passing the escaping steam into a bucket of water where it is condensed, the increase in the weight of the bucket and its contents giving the value of W. In that case gauge G is not required, but it used its reading may be taken as a check.

This calorimeter will give better results when the dryness fraction of steam to be determined is above 0.95.

# Throttling Calorimeter

In the throttling calorimeter, a sample of wet steam of mass m and at pressure P1 is taken from the steam main through a perforated sampling tube. Then it is throttled by the partially-opened valve (or orifice) to a pressure P2 measured    by    mercury manometer, and temperature t2, so that after throttling the steam is in the superheated region.

The steady flow energy equation gives the enthalpy after throttling as equal to enthalpy before throttling. The initial and final equilibrium states 1 and 2 are joined by a dotted line since throttling is irreversible (adiabatic but not isentropic) and the intermediate states are non-equilibrium states not describable by thermodynamic coordinates. The initial  state (wet) is given by P1and x1 and the final state by P2 and t2.

| | |
|---|---|
| Course Title | **ENGINEERING THERMODYNAMICS** |
| Course Code | **AMED07** |
| Class | **III SEM** |
| Section | **A** |
| Name of the Faculty | **Dr G.Hima Bindu** |
| Lecture hour and Date | |
| Course Outcome/s | |
| Topic covered | |
| Topic learning outcome | |

**OUTCOMES:** Determine heat, work, internal energy, enthalpy for flow & non flow process using First Law of Thermodynamics.

**van der Waals Equation of State:**

The ideal gas law treats the molecules of a gas as point particles with perfectly elastic collisions. This works well for dilute gases in many experimental circumstances. But gas molecules are not point masses, and there are circumstances where the properties of the molecules have an experimentally measurable effect. A modification of the ideal gas law was proposed by Johannes D. van der Waals in 1873 to take into account molecular size and molecular interaction forces. It is usually referred to as the van der Waals equation of state.

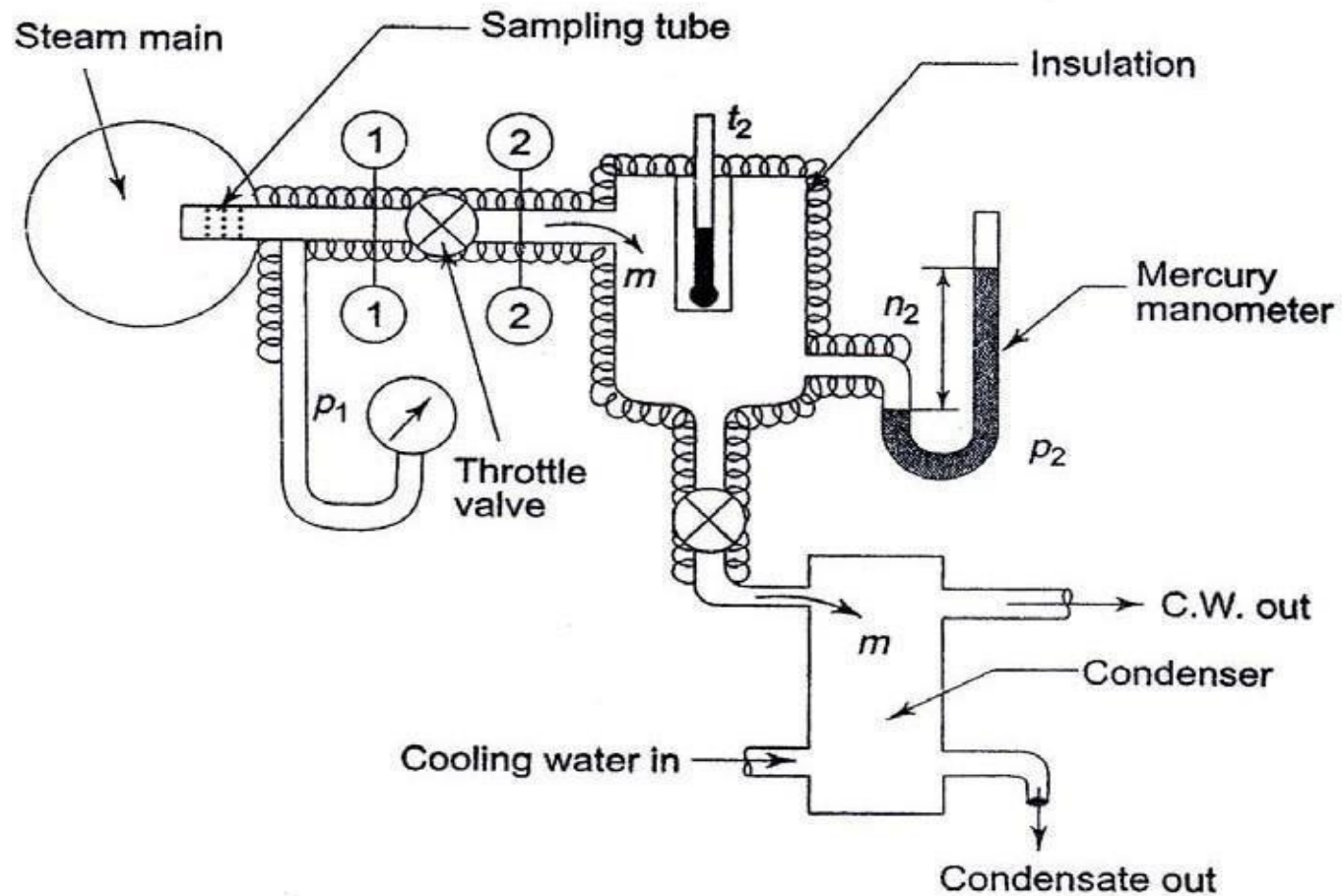$$\left[ P + a\left(\frac{n}{V}\right)^2 \right]\left(\frac{V}{n} - b\right) = RT$$

The constants a and b have positive values and are characteristic of the individual gas. The van der Waals equation of state approaches the ideal gas law PV=nRT as the values of these constants approach zero. The constant a provides a correction for the intermolecular forces. Constant b is a correction for finite molecular size and its value is the volume of one mole of the atoms or molecules.

Since the constant b is an indication of molecular volume, it could be used to estimate the radius of an atom or molecule, modeled as a sphere. Fishbane et al. give the value of b for nitrogen gas as 39.4 x 10-6 m3/mol.

| Course Title | ENGINEERING THERMODYNAMICS |
|---|---|
| Course Code | AMED07 |
| Class | III SEM |
| Section | A |
| Name of the Faculty | Dr G.Hima Bindu |
| Lecture hour and Date | |
| Course Outcome/s | |
| Topic covered | |
| Topic learning outcome | |

**OUTCOMES:** Determine heat, work, internal energy, enthalpy for flow & non flow process using First Law of Thermodynamics.

# Throttling Calorimeter

In the throttling calorimeter, a sample of wet steam of mass m and at pressure P1 is taken from the steam main through a perforated sampling tube. Then it is throttled by the partially-opened valve (or orifice) to a pressure P2 measured    by    mercury manometer, and temperature t2, so that after throttling the steam is in the superheated region.

The steady flow energy equation gives the enthalpy after throttling as equal to enthalpy before throttling. The initial and final equilibrium states 1 and 2 are joined by a dotted line since throttling is irreversible (adiabatic but not isentropic) and the intermediate states are non-equilibrium states not describable by thermodynamic coordinates. The initial  state (wet) is given by P1and x1 and the final state by P2 and t2.

**Course Title: Engineering Thermodynamics**

**Topic:  Gas Laws**

Presenter's Name – Dr. G. Hima Bindu

Presenter's ID – IARE11099

Department Name – Mechanical Engineering

Lecture Number - 01

Presentation Date – 19-08-2024

# Gas Laws

**Ideal Gas:**

Perfect gas, also called ideal gas, a gas that conforms, in physical behaviour, to a particular, idealized relation between pressure, volume, and temperature called the general gas law.

**Gas Laws:**

**<u>Boyle's Law</u>**

Boyle's Law Pressure is inversely proportional to volume: $p \propto 1/v$ Robert Boyle noticed that when the volume of a container holding an amount of gas is increased, pressure decreases, and vice versa (while the temperature is held constant). Note that this is not a linear relationship between p and V.

## Charles' Law:

Charles' Law Volume is directly proportional to temperature: $V = cT$, where $c > 0$ is constant. Scientist Jacque Charles noticed that if air in a balloon is heated, the balloon expands. For an ideal gas, this relationship between V and T should be linear (as long as pressure is constant).

## Charles' and Boyle's Laws combined

Combine the two laws above: $pV/T = K$, where k is a constant, $= pV = mRT$

## The Individual Gas Constant - R

The Individual Gas Constant depends on the particular gas and is related to the molecular weight of the gas. The value is independent of temperature. The individual gas constant, R, for a gas can be calculated from the universal gas constant, Ru (given in several units below), and the gas molecular weight, Mgas:

R = Ru/Mgas

In the SI system units are J/kg K.

## The Universal Gas Constant - Ru

The Universal Gas Constant - Ru - appears in the ideal gas law and can be expressed as the product between the Individual Gas Constant - R - for the particular gas - and the Molecular Weight - Mgas - for the gas, and is the same for all ideal or perfect gases:

Ru = Mgas R, kJ/(kmol.K) : 8.3144598 The Molecular weight of a Gas Mixture

The average molecular weight of a gas mixture is equal to the sum of the mole fractions of each gas multiplied by the molecular weight of that particular gas:

Mmixture = Σxi*Mi = (x1*M1 + . . . . . . . . + xn*Mn)

where

xi = mole fractions of each gas

Mi = the molar mass of each gas

# Throttling Process

The porous plug experiment was designed to measure temperature changes when a fluid flows steadily through a porous plug which is inserted in a thermally insulated, horizontal pipe. The apparatus used by Joule and Thomson is shown in Figure

A gas at pressure and temperature flows continuously through a porous plug in a tube and emerges into a space which is maintained at a constant pressure. The device is thermally insulated and kept horizontal. Consider the dotted portion as control volume.
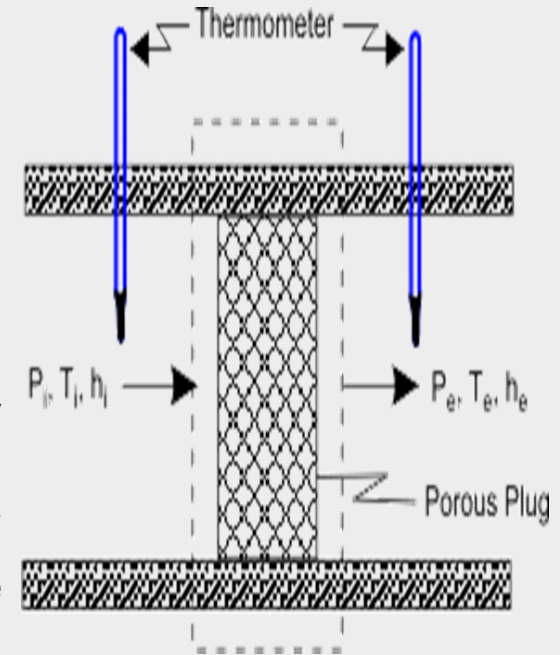
$$\dot{Q} = 0, \; W_{sh} = 0.$$

These results in $\quad h_i = h_e$

Therefore, whenever a fluid expands from a region of high pressure to a region of low pressure through a porous plug, partially opened valve or some obstruction, without exchanging any energy as heat and work with the surrounding (neglecting, the changes in PE and KE), the enthalpy of the fluid remains constant, and the fluid is said to have undergone a throttling process.

**Free expansion (or unresisted expansion) process:**

A free expansion occurs when a fluid is allowed to expand suddenly into a vacuum chamber through an orifice of large dimensions. In this process, no heat is supplied or rejected and no external work is done. Hence the total heat of the fluid remains constant. This type of expansion may also be called as constant total heat expansion. It is thus obvious, that in a free expansion process,
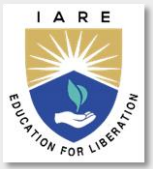
Q1-2 = 0, W1-2 = 0 and dU = 0.

# Van der Waals Equation of State:

The ideal gas law treats the molecules of a gas as point particles with perfectly elastic collisions. This works well for dilute gases in many experimental circumstances. But gas molecules are not point masses, and there are circumstances where the properties of the molecules have an experimentally measurable effect. A modification of the ideal gas law was proposed by Johannes D. van der Waals in 1873 to take into account molecular size and molecular interaction forces. It is usually referred to as the van der Waals equation of state.

$$\left[ P + a\left(\frac{n}{V}\right)^2 \right]\left(\frac{V}{n} - b\right) = RT$$

The constants a and b have positive values and are characteristic of the individual gas. The van der Waals equation of state approaches the ideal gas law PV=nRT as the values of these constants approach zero. The constant a provides a correction for the intermolecular forces. Constant b is a correction for finite molecular size and its value is the volume of one mole of the atoms or molecules.

Since the constant b is an indication of molecular volume, it could be used to estimate the radius of an atom or molecule, modeled as a sphere. Fishbane et al. give the value of b for nitrogen gas as 39.4 x 10-6 m3/mol.

**Course Title: Engineering Thermodynamics**

**Topic:  OBE**

Presenter's Name – Dr. G. Hima Bindu

Presenter's ID – IARE11099

Department Name – Mechanical Engineering

Lecture Number - 01

Presentation Date – 19-08-2024

# PROBLEMS

1. **Find specific volume and enthalpy of 1 kg of steam at 0.8 Mpa (i) when the dryness fraction is 0.9 (ii) when the steam is superheated to a temperature of $300^0$ C. The specific heat of superheated steam is 2.25 KJ/Kg K.**

**Sol:** m = 1Kg , P = 0.8 Mpa = $0.8 \times 10^6$ Pa = $8 \times 10^5$ Pa = 8 bar

(i) x = 0.9 (ii) $T_{sup}$ = $300^0$ C , $C_{ps}$ = 2.25 KJ/Kg

Find V , $V_{sup}, h, h_{sup}$

At 8 bar $V_g$ = 0.24026 $m^3$/kg

$h_f$ = 720.9 KJ/Kg ; $h_{fg}$ = 2046.5 KJ/Kg

$T_s$ = $170.4^0$ C

(i) Specific volume of wet steam = V = x * $V_g$

$$= 0.9 \times 0.24026$$

$$= 0.21623 \ m^3/\text{kg}$$

Enthalpy of wet steam h = $h_f$ + x * $h_{fg}$ = 720.9 + 0.9 x 2046.5

$$= 2562.75 \text{ KJ/Kg}$$

(ii) When steam is at superheated temperature of $300^0$ C

Specific volume of superheated steam is given by the relation $T_{sup}$ / $V_g$

Therefore  $V_{sup} = T_{sup}$ x $V_g$ / $T_s$ = 300 x 0.24026 / 170.4

$$= 0.423 \ m^3/\text{kg}$$

Enthalpy of superheated steam $h_{sup} = \ h_f$ + $h_{fg}$ + $C_{ps}$ ( $T_{sup}$ - $T_s$ )

(or) $h_g$ + $C_{ps}$ ( $T_{sup}$ - $T_s$ ) = 720.9 + 2046.5 + 2.25 ( 300 -170.4 )

$$h_{sup} = 3059 \text{ KJ/Kg}$$

**2. Calculate dryness fraction of steam of 0.6 kg of water is in suspension with 24kg of dry steam.**

**Sol:** mass of dry steam $m_g$ = 24kg

mass of water in suspension $m_f$ = 0.6 kg

Mass of wet steam = m = $m_g$ + $m_f$ = 24 + 0.6 = 24.6 kg

Dryness fraction = x = $\dfrac{m_g}{m_g + m_f}$ = $\dfrac{24}{24.6}$ = 0.97

**3. A boiler is producing steam at a pressure of 15 bars and quality as 0.98 dry. It was observed that while flowing from boiler to the place of heating through pipes, steam looses 21 kJ of heat per kg. Assuming the constant pressure, while flowing through pipe line, calculate the quality of steam at the place of heating.**

**Solution**

Given conditions of steam in boiler are

Pressure P=15 bar; x= 0.98; Heat loss= 21 kJ/ kg

From steam tables, we find that

At pressure, P=15 bar,

$h_f$ = 844.6 kJ/kg

$h_{fg}$ = 1945.3 kJ/k

So specific enthalpy of steam in boiler, $h_1$ = $h_f$ + x.$h_{fg}$

= 844.6 + 0.98  1945.3 =2751 kJ/kg

Heat loss = 21 kJ/kg

So net enthalpy of steam at the other end of pipe line or at the place of heating

= 2751−21 = 2730 kJ/kg

To find dryness fraction of this steam $x_2$ we know that enthalpy is

$h_2 = h_f + x_2.h_{fg}$

or  2730 = 844.60 + $x_2$ x 1945.3

$X_2$ = 2730 − 844.60 / 1945.3

     = 0.97

**4. Calculate the total heat of 5 kg of steam at an absolute pressure of 8 bar having dryness fraction of 0.8. Also calculate heat in kJ required to convert the steam into dry and saturated steam.**

**Solution**

From steam tables

At pressure 8 bar, $h_f$ = 720.9 kJ/kg

$$h_{fg} = 2046.5 \text{ kJ/kg}$$

$$h_g = 2767.4 \text{ kJ/Kg}$$

Sp. enthalpy of wet steam

$$h_w = h_f + x.h_{fg}$$

$$= 720.9 + 0.8 \times 2046.5$$

$$= 2358.1 \text{ kJ/kg}$$

Total heat of 5 kg steam = weight of steam x Sp. Enthalpy = 5x2358.1 = 11790.5 kJ

Now total heat of 5kg dry saturated steam = 5x $h_g$ = 5x 2767.4 = 13830 kJ

Net heat required to be supplied for conversion of wet steam into dry saturated steam = 13830 - 11790.5 = 2039.5 kJ

**5) 4 Kg of 0.5 dry steam at 6.0 bar pressure is heated, so that it becomes**

**(a)  0.95 dry at 6.0 bar pressure or**

**(b)  Dry & saturated at 6.0 bar or**

**(c)  Superheated to 300oC at 6.0 bar or**

**(d)  Superheated to 250oC at 8.0 bar**

**Using steam tables determine in each case the quantity of heat required to be supplied. Take $C_{sup}$ for superheated steam as 2.3 kJ/ kg K.**

**Sol:** Initial Condition of steam are mass,

   m = 4 kg; $x_1$= 0.5 and P = 6.0 bar

So initial enthalpy (total heat content) of 4kg steam is

   $H_1 = 4[h_f + 0.5h_{fg}]$

From steam table, at 6.0 bar pressure value of specific enthalpy of saturated water, $h_f$ and latent heat of steam, $h_{fg}$ are given as

$h_f$ = 670.4 kJ/kg, $h_{fg}$ = 2085.1 kJ/kg

Putting these values in equation (i)

$H_1$ = 4[670.4+0.5 x 2085.1] = 6851.8 kJ ≈ 6852 kJ

**Heat Supplied**

***Case I*** Final Conditions of Steam are $x_2$=0.95 and pressure, p=6.0 bar. So final enthalpy of steam is

$H_2$ = 4[$h_f$ + x.$h_{fg}$] = 4[670.4 + 0.95 x 2085.1] = 10605 kJ

Net heat supplied = Final Enthalpy - Initial Enthalpy

= $H_2$ - $H_1$ = 10605 - 6852 = 3753 kJ

**Case II** Final Conditions of Steam are pressure, p = 6.0 bar. Condition is dry saturated i.e.,

$x_2$ = 1. So final enthalpy of steam is

$H_2$ = m.hg = 4 x 2755.5 kJ/kg [From Steam Table]

   =11022 kJ

Net heat supplied = Final Enthalpy - Initial Enthalpy

= $H_2$ - $H_1$ = 11022 - 6852 = 4170 kJ

**_Case III_** Final Conditions of Steam are pressure, p=6.0 bar, Superheated to $300^0$C. Form steam tables, saturation temperature, $t_S$ at given pressure 6.0bar is $t_s$ = $158.8^0$C. So final enthalpy of superheated steam is

   $H_2$ = m [$h_g$ + $C_{Ps}$ ($t_{sup}$ - $t_s$)] = 4[2755.5 + 2.3(300-158.8)] = 12321 kJ

So Net heat supplied = Final Enthalpy - Initial Enthalpy

   = $H_2$ - $H_1$ = 12321 - 6852 = 5469 kJ

***Case IV*** Final Conditions of Steam are pressure, p=8.0 bar, Superheated to temperature, $t_{sup} = 250^0C$.

From steam tables

At 8.0 bar pressure $t_s = 170.4^0C$, $h_g = 2767.4$ kJ/kg

So $H_2 = m [h_g + C_{Ps} (t_{sup} - t_s)] = 4[2767.4 + 2.3(250-170.4)] = 11801.92 \approx 11802$ kJ

Heat Supplied = $H_2 - H_1 = 11802 - 6852 = 4950$ kJ  [Ans]

6. **Calculate the entropy and volume of 4.73 kg of superheated steam at pressure 7.8 bar and temperature $240^0$C. Take Cp for superheated steam = 2.32 kJ/kg. K**

**Solution**

At 7.8 bar  ;    Saturation temperature ts = $169.4^0$C

or Ts = 169.4+273 = 442.4 K

$V_g$ = 0.2461 m3/ kg

$S_g$ = 6.668 kJ/kg K

$t_{sup}$ = $240^0$C

so, $T_{sup}$ = 240 + 273 = 513 K

 Sp.vol. of superheated Steam = 0.2854 m3/kg

Total volume of 4.73 kg of steam = 4.73 - 0.2854 = 1.3498 $m^3$

Sp. entropy of superheated steam = $S_g$ +$C_{sup} \log_e \frac{T_{sup}}{T_s}$ = 7.0115 kJ/ kg K

Total entropy of steam = 4.73x 7.0115 = 33.16 kJ/ K

**7. A rigid vessel of volume 0.86 m3 contains 1 kg of steam at a pressure of 2 bar. Evaluate the specific volume, temperature, dryness fraction, internal energy, enthalpy, and entropy of steam.**

**Sol:** volume v = 0.86 m3 , Mass m= 1kg , Pressure p= 2 bar.

From Steam table: p= 2 bar

$T_s$ = 120.2 , $V_f$ = 0.0010601 , $V_g$ = 0.885,  $h_f$ = 504.7,  $hfg$ = 2201.6,  $hg$ = 2706.3

$S_f$ = 1.530,  $S_{fg}$ = 5.597 , $S_g$ =7.127

the Specific volume = Volume / mass = 0.86 / 1 = 0.86 m3 /kg

the dryness fraction $V = V_f + x(V_g − vf)$

∴dryness fraction x = $v − v_f$ / $v_g − v_f$ = 0.86−0.001061/ 0.885 −0.001061 = 0.97172

the Internal energy (u) = h – pv = 2644 – 200 × 0.86 = 2472 kJ/kg

the enthalpy, h = $h_f$ + x $h_{fg}$= 504.7 + 0.97172 × 2201.6 = 2644 kJ/kg

the entropy of steam. s = $S_{fg}$+x $S_f$ = 1.5301 + 0.97172 × 5.5967 = 6.9685 kJ/kg – K

**8. Steam at 10 bar pressure passes through a pipe and expands to 0.1 bar in a throttling device. The temperature of steam after expansion is $100^0\,C$. Find the state of fluid using mollier chart.**

**Sol:** $P_1 = 10\ bar\quad ,P_2 = 0.1\ bar$

$$T_2 = 100^0\,C.$$

Process 1-2 throttling process = isenthalpic process

Therefore $h_1 = h_2$

| S.No | Property | Ans |
|------|----------|-----|
| 1 | Enthalpy | 2690 KJ/Kg |
| 2 | Entropy | 6.38 KJ/Kg |
| 3 | Dryness fraction | 0.96 |

**9. A nozzle expands steam from 12 bar and $250^0 C$ to $6\ bar$. Is the nozzle convergent or convergent –divergent (C-D) . Neglecting the initial velocity find the minimum area of nozzle to flow 2kg/s of steam under given conditions. Assume the expansion of steam is isentropic. Calculate the actual throat area if the coefficient of discharge is 0.98.**

**Sol:** $P_1 = 12 bar \quad , P_2 = 6\ bar$

$\quad T_1 = 250^0 C, \quad C_1 = 0$ , m= 2kg/s

$\quad A_2 = ? \quad , \quad A_{2\ actual} = ? \quad , C_d = 0.98$

Critical pressure at throat $= \dfrac{P_2}{P_1} = (\dfrac{2}{n+1})^{\frac{n}{n-1}}$

$P_2 = P_1 \ ((\dfrac{2}{n+1})^{\frac{n}{n-1}}) \qquad ; P_2 = 12(\dfrac{2}{1.3+1})^{\frac{1.3}{1.3-1}}$ = 6.55 bar

Here 6.55 > 6 bar, therefore $P_2 = 6.55\ bar\ which\ is\ throat\ pressure\ and\ P_3 = 6\ bar$ which is back pressure

So nozzle is convergent – divergent nozzle

From mollier chart

At $P_1$ = 12 bar and $T_1$ = 250 o C,  $h_1$ = 2930 kJ/kg

At $P_2$ = 6.55 bat , $h_2$= 2810 KJ/Kg , $T_2$ = 180 0 C

$V_2$ = 0.35 m3/kg ,

Now velocity at the throat is given by

$C_2$ = 44.72 $\sqrt{h_1 - h_2}$

$C_2$ = 44.72 $\sqrt{2930 - 2810}$

$C_2$= 489.88 m/s

Now, the minimum area is given by $A_2 C_2$ = m$v_2$

$A_2$ = m$v_2$ / $C_2$ = 2 x 0.35/489.88

 = 1.49 x 10 -3 m2

 = 14.29 cm2

  ,     $A_{2\,actual}$ = A2 / Cd 14.29 / 0.98 = = 14.581 $cm^2$