

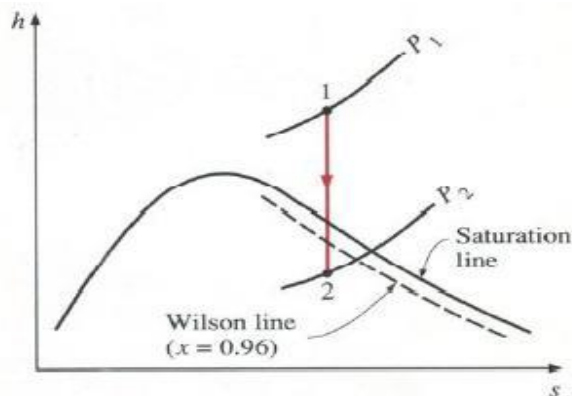
UNIT II

STEAM NOZZLES AND INJECTOR

1. Describe about supersaturated flow or metastable flow in a nozzle and state effect of supersaturation

As steam expands in the nozzle, its pressure and temperature drop, and it is expected that the steam starts condensing when it strikes the saturation line. But this is not always the case. Owing to the high velocities, the residence time of the steam in the nozzle is small, and there may not be sufficient time for the necessary heat transfer and the formation of liquid droplets. Consequently, the condensation of steam is delayed for a little while. This phenomenon is known as supersaturation, and the steam that exists in the wet region without containing any liquid is known as supersaturated steam.

The locus of points where condensation will take place regardless of the initial temperature and pressure at the nozzle entrance is called the Wilson line. The Wilson line lies between 4 and 5 percent moisture curves in the saturation region on the h - s diagram for steam, and is often approximated by the 4 percent moisture line. The supersaturation phenomenon is shown on the h - s chart below:



The h - s diagram for the isentropic expansion of steam in a nozzle.

Effects of Supersaturation:

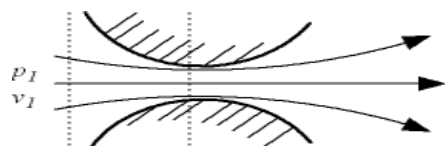
The following are the effects of supersaturation in a **nozzle**.

- The temperature at which the supersaturation occurs will be less than the saturation temperature corresponding to that pressure. Therefore, the density of supersaturated steam will be more than that of equilibrium condition which gives the increase in the mass of steam discharged.
- Supersaturation increases the specific volume and entropy of the steam.
- Supersaturation reduces the heat drop. Thus the exit velocity of steam is reduced.
- Supersaturation increases the dryness fraction of the steam.

Critical Pressure Ratio:

The critical pressure ratio is the pressure ratio which will accelerate the flow to a velocity equal to the local velocity of sound in the fluid.

Critical flow nozzles are also called **sonic chokes**. By establishing a shock wave the sonic choke establishes a fixed flow rate unaffected by the differential pressure, any fluctuations or changes in downstream pressure. A sonic choke may provide a simple way to regulate a gas flow.



The ratio between the critical pressure and the initial pressure for a nozzle can be expressed as

$$p_c / p_1 = (2 / (n + 1))^{n / (n - 1)}$$

where

p_c = critical pressure (Pa)

p_1 = inlet pressure (Pa)

n = index of isentropic expansion or compression - or polytropic constant

For a perfect gas undergoing an adiabatic process the index - n - is the ratio of specific heats - $k = c_p / c_v$. There is no unique value for - n . Values for some common gases are

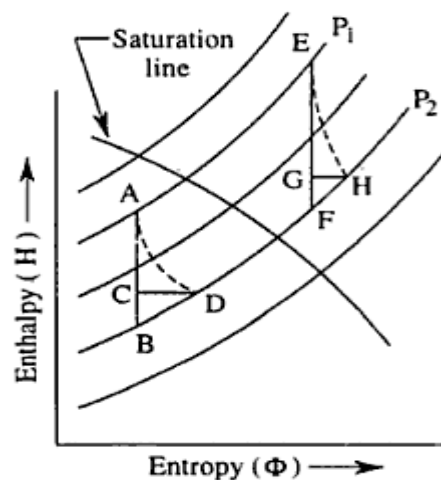
- ☐ Steam where most of the process occurs in the wet region : $n = 1.135$
- ☐ Steam superheated : $n = 1.30$
- ☐ Air : $n = 1.4$
- ☐ Methane : $n = 1.31$
- ☐ Helium : $n = 1.667$

2. Describe the Effect of Friction on Nozzles.

- 1) Entropy is increased.
- 2) Available energy is decreased.
- 3) Velocity of flow at throat is decreased.
- 4) Volume of flowing steam is decreased.
- 5) Throat area necessary to discharge a given mass of steam is increased.

Most of the **friction** occurs in the diverging part of a convergent-divergent **nozzle** as the length of the converging part is very small. The **effect** of **friction** is to reduce the available enthalpy drop by about 10 to 15 per cent. The velocity of steam will be then $V_2 = 44.72\sqrt{K(H_1 - H_2)}$ where K is the coefficient which allows for **friction** loss. It is also known as **nozzle** efficiency (η_n)

$$\therefore V_2 = 44.72\sqrt{(H_1 - H_2)\eta_n}$$



Velocity of steam at nozzle exit:

$$V_2^2 = 2000(H_1 - H_2) + V_1^2 \quad \therefore \quad V_2 = \sqrt{2000(H_1 - H_2) + V_1^2}$$

As the velocity of steam entering the **nozzle** is very small, V_1 can be neglected.

$$\therefore \quad V_2 = \sqrt{2000(H_1 - H_2)} = 44.72\sqrt{(H_1 - H_2)} \text{ m/s}$$

If frictional losses are taken into account then

$$V_2 = 44.72\sqrt{(H_1 - H_2)\eta_n} \text{ m/s}$$

3. Derive the expression for maximum discharge through a nozzle.

Mass of steam discharged through a nozzle:

$$m = A \sqrt{2000 \frac{n}{n-1} \times \frac{P_1}{v_1} \left[\left(\frac{P_2}{P_1} \right)^{\frac{2}{n}} - \left(\frac{P_2}{P_1} \right)^{\frac{n+1}{n}} \right]}$$

Condition for maximum discharge through nozzle:

The nozzle is always designed for maximum discharge

$$\frac{m}{A} = \sqrt{2000 \frac{n}{n-1} \times \frac{P_1}{v_1} \left[\left(\frac{P_2}{P_1} \right)^{\frac{2}{n}} - \left(\frac{P_2}{P_1} \right)^{\frac{n+1}{n}} \right]}$$

The mass flow per unit area will be maximum at the throat because the throat area is minimum.

It is seen from the above equation that the discharge through a **nozzle** is a function of $\frac{P_2}{P_1}$ only, as the expansion index is fixed according to the steam supplied to the **nozzle**.

Therefore, $\frac{m}{A}$ is maximum when

$$\left[\left(\frac{P_2}{P_1} \right)^{\frac{2}{n}} - \left(\frac{P_2}{P_1} \right)^{\frac{n+1}{n}} \right] \text{ is minimum}$$

Values for maximum discharge:

$$m = A \sqrt{2000 \frac{n}{n-1} \times \frac{P_1}{v_1} \left[\left(\frac{P_2}{P_1} \right)^{\frac{2}{n}} - \left(\frac{P_2}{P_1} \right)^{\frac{n+1}{n}} \right]}$$

we know $\frac{P_2}{P_1} = \left(\frac{2}{n+1} \right)^{\frac{n}{n-1}}$

Putting the value of $\frac{P_2}{P_1}$ in the above equation

$$m_{\max} = A \sqrt{2000 \frac{n}{n-1} \times \frac{P_1}{v_1} \left[\left(\frac{2}{n+1} \right)^{\frac{2}{n-1}} - \left(\frac{2}{n+1} \right)^{\frac{n+1}{n-1}} \right]}$$

$$m_{\max} = A \sqrt{2000 \frac{n}{n-1} \times \frac{P_1}{v_1} \times \left(\frac{2}{n+1} \right)^{\frac{n+1}{n-1}} \left[\left(\frac{2}{n+1} \right)^{\frac{2}{n-1} - \frac{n+1}{n-1}} - 1 \right]}$$

$$= A \sqrt{2000 \frac{n}{n-1} \times \frac{P_1}{v_1} \times \left(\frac{2}{n+1} \right)^{\frac{n+1}{n-1}} \left[\left(\frac{2}{n+1} \right)^{\frac{1-n}{n-1}} - 1 \right]}$$

$$= A \sqrt{2000 \frac{n}{n-1} \times \frac{P_1}{v_1} \times \left(\frac{2}{n+1} \right)^{\frac{n+1}{n-1}} \left[\left(\frac{2}{n+1} \right)^{-1} - 1 \right]}$$

$$= A \sqrt{2000 \frac{n}{n-1} \times \frac{P_1}{v_1} \times \left(\frac{2}{n+1} \right)^{\frac{n+1}{n-1}} \left[\frac{n+1}{2} - 1 \right]}$$

$$= A \sqrt{2000 \frac{n}{n-1} \times \frac{P_1}{v_1} \times \left(\frac{2}{n+1} \right)^{\frac{n+1}{n-1}} \left(\frac{n-1}{2} \right)}$$

$$m_{\max} = A \sqrt{1000n \times \frac{P_1}{v_1} \times \left(\frac{2}{n+1} \right)^{\frac{n+1}{n-1}}}$$

Where P_1 is the initial pressure of the steam in kpa and v_1 is the specific volume of the steam

4. *Dry saturated steam at a pressure of 15 bar enters in a nozzle and is discharged at a pressure of 1.5 bar. Find the final velocity of the steam. When the initial velocity of the steam is negligible.*

Given :

$$p_1 = 15 \text{ bar;}$$

$$p_2 = 1.5 \text{ bar}$$

Solution.

Final velocity of the steam

From steam tables, corresponding to a pressure of 15 bar, we find that enthalpy of dry saturated steam,

$$h_1 = 2789.9 \text{ kJ/Kg}$$

and corresponding to a pressure of 1.5 bar, enthalpy of dry saturated steam,

$$h_2 = 2693.4 \text{ kJ/Kg}$$

$$\therefore \text{Heat drop, } h_d = h_1 - h_2 = 2789.9 - 2693.4 = 96.5 \text{ kJ/Kg}$$

We know that final velocity of the steam,

$$V_2 = 44.72 \sqrt{h_d} = 44.72 \sqrt{96.5} = 439.3 \text{ m/s Ans.}$$

Percentage reduction in the final velocity

We know that heat drop lost in friction

$$= 10\% = 0.1$$

$\therefore$ Nozzle coefficient or nozzle efficiency

$$K = 1 - 0.1 = 0.9$$

We know that final velocity of the steam,

$$V_2 = 44.72 \sqrt{Kh_d} = 44.72 \sqrt{0.9 \times 96.5} = 416.8 \text{ m/s}$$

$\therefore$ Percentage reduction in final velocity

$$= \frac{439.3 - 416.8}{439.3} = 0.051 \text{ or } 5.1\%$$

5. Dry saturated steam at 10 bar is expanded isentropically in a nozzle to 0.1 bar. Using steam tables only, find the dryness fraction of the steam at exit. Also find the velocity of steam leaving the nozzle when 1. initial velocity is negligible, and 2. Initial velocity of the steam is 135 m/s

Given :

$$p_1 = 10 \text{ bar ;}$$

$$p_2 = 0.1 \text{ bar}$$

Solution .

Dryness fraction of the steam at exit

Let x_2 = Dryness fraction of the steam at exit.

From steam tables, corresponding to a pressure of 10 bar, we find that entropy of dry saturated steam,

$$s_1 = s_{g1} = 6.583 \text{ kJ/kgK}$$

and corresponding to a pressure of 0.1 bar,

we find that

$$s_{f2} = 0.649 \text{ kJ/kgK, And } s_{fg2} = 7.502 \text{ kJ/kgK}$$

Since the expansion of steam is isentropic,

Therefore

Entropy of steam at inlet (s_1) = Entropy of steam at exit (s_2)

$$6.583 = s_{fg2} + x_2 s_{fg2} = 0.649 + x_2 + 7.502$$

$$\mathbf{X_2 = 0.791 \quad Ans.}$$

1. Velocity of steam leaving the nozzle when initial velocity is negligible

From steam tables, corresponding to a pressure of 10 bar, we find that enthalpy or total heat of dry saturated steam,

$$h_1 = h_{g1} = 2776.2 \text{ kJ/kg}$$

and Corresponding to a pressure of 0.1 bar,

$$h_{f2} = 191.8 \text{ kJ/kg, and } h_{fg2} = 2392.9 \text{ kJ/kg}$$

∴ Enthalpy or total heat of steam of exit,

$$\begin{aligned} h_2 &= h_{f2} + x_2 h_{fg2} \\ &= 191.8 + 0.791 \times 2392.2 \\ &= 2084.6 \text{ kJ/kg} \end{aligned}$$

and heat drop,
$$h_d = h_1 - h_2 = 2776.2 - 2084.6$$

$$= 691.6 \text{ kJ/kg}$$

We know that velocity of steam leaving the nozzle,

$$V_2 = 44.72 \sqrt{h_d} = 44.72 \sqrt{691.6} = 1176 \text{ m/s} \quad \text{Ans.}$$

Velocity of steam leaving the nozzle when initial velocity,

$$V_1 = 135 \text{ m/s}$$

We know that velocity of steam leaving the nozzle,

$$V_2 = \sqrt{V_1^2 + 2000 h_d} = \sqrt{(135)^2 + 2000 \times 691.69} = 1184 \text{ m/s} \quad \text{Ans.}$$

6. Dry saturated steam enters a nozzle at a pressure of 10 bar and with an initial velocity of 90 m/s. The outlet pressure is 6 bar and the outlet velocity is 435 m/s. The heat loss from the nozzle is 9 kJ/kg of steam flow.

Calculate the dryness fraction and the area at the exit, if the area at the inlet is 1256 mm²

Given:

$$p_1 = 10 \text{ bar; } V_1 = 90 \text{ m/s;}$$

$$p_3 = 6 \text{ bar; } V_3 = 435 \text{ m/s;}$$

$$\text{Losses} = 9 \text{ kJ/Kg;}$$

$$A_1 = 1256 \text{ mm}^2 = 1256 \times 10^{-6} \text{ m}^2$$

Solution.

Dryness fraction of steam

$$\text{Let } x_3 = \text{Dryness fraction of steam at the exit.}$$

From steam tables,

corresponding to a pressure of 10 bar, we find that enthalpy of dry saturated steam,

$$h_1 = 2776.2 \text{ kJ/kg; and } v_{g1} = 0.1943 \text{ m}^3 / \text{kg} \quad \text{and}$$

corresponding to a pressure of 6 bar, we find that

$$h_g = 670.4 \text{ kJ/kg}; h_{fg} = 2085 \text{ kJ/kg}; v_g = 0.3155 \text{ m}^3/\text{kg}$$

We know that for a steady flow through the nozzle,

$$h_1 + \frac{1}{1000} \left(\frac{V_1^2}{2} \right) = h_3 + \frac{1}{1000} \left(\frac{V_3^2}{2} \right) + \text{Losses}$$

$$\begin{aligned} \therefore h_3 &= h_1 + \frac{2}{1000} (V_1^2 - V_3^2) - \text{Losses} \\ &= 2776.2 + \frac{1}{2000} [(90)^2 - (435)^2] - 9 \\ &= 2776.2 - 99.6 \\ &= 2676.6 \text{ kJ/kg} \end{aligned}$$

We also know that enthalpy of wet steam (h_3),

$$2676.6 = h_g + x_3 h_{fg} = 670.4 + x_3 \times 2085$$

$$\therefore x_3 = 0.962 \text{ Ans.}$$

Area at exit

Let A_3 Area at exit in m^2

$$\text{We know that } \frac{A_1 V_1}{x_1 v_{g1}} = \frac{A_3 V_3}{x_3 v_{g3}} \text{ or } \frac{1256 \times 10^{-6} \times 90}{1 \times 0.1943} = \frac{A_3 \times 435}{0.962 \times 0.3155}$$

...(For dry saturated steam, $x_1 = 1$)

$$A_3 = 406 \times 10^{-6} \text{ m}^2 = 406 \text{ mm}^2 \text{ Ans.}$$

7. Dry saturated steam at a pressure of 8 bar enters a convergent – divergent nozzle and leaves it at a pressure of 1.5 bar, If the flow is isentropic, and the corresponding expansion index is 1.135; find the ratio of cross – sectional area at exit and throat for maximum discharge.

Solution. Given : $p_1 = 8 \text{ bar}$; $p_3 = 1.5 \text{ bar}$; $n = 1.135$

Let A_2 = Cross-sectional area at throat,

A_3 = Cross-sectional area at exit, and

m = Mass of steam discharged per second.

We know that for dry saturated steam (or when $n= 1.135$), critical pressure ratio,

$$\frac{p_2}{p_1} = 0.577$$

$$\therefore p_2 = 0.577 p_1 = 0.577 \times 8 = 4.616 \text{ bar}$$

Now complete the Mollier diagram for the expansion of steam through the nozzle, as shown in Fig.21.8.

From Mollier diagram, we find that

$$h_1 = 2775 \text{ kJ/kg}; h_2 = 2650 \text{ kJ/kg}; h_3 = 2465 \text{ kJ/kg}; x_2 = 0.965; \text{ and } x_3 = 0.902$$

From steam tables, we also find that the specific volume of steam at throat corresponding to 4.616 bar,

$$v_{g2} = 0.405 \text{ m}^3 / \text{kg}$$

and specific volume of steam at exit corresponding to 1.5 bar,

$$v_{g3} = 1.159 \text{ m}^3 / \text{kg}$$

Heat drop between entrance and throat,

$$h_{a2} = h_1 - h_2 = 2775 - 2650 = 125 \text{ kJ/kg}$$

$\therefore$ Velocity of steam at throat,

$$V_2 = 44.72 \sqrt{h_{d2}} = 44.72 \sqrt{125} = 500 \text{ m/s}$$

and

$$m = \frac{A_2 V_2}{x_2 v_{g2}}$$

or

$$A_2 = \frac{m x_2 v_{g2}}{V_2} = \frac{m \times 0.965 \times 0.405}{500} = 0.000786 m \quad \dots(i)$$

Heat drop between entrance and exit,

$$h_{d3} = h_1 - h_3 = 2775 - 2465 = 310 \text{ kJ/kg}$$

$\therefore$ Velocity of steam at throat,

$$V_3 = 44.72 \sqrt{h_{d3}} = 44.72 \sqrt{310} = 787.4 \text{ m/s}$$

and
$$m = \frac{A_2 V_2}{x_2 v_{g2}}$$

or
$$A_3 = \frac{m x_3 v_{g3}}{V_3} = \frac{m \times 0.902 \times 1.159}{787.4} = 0.00133m \quad \dots(ii)$$

$\therefore$ Ratio of cross-sectional area at exit and throat,

$$\frac{A_3}{A_2} = \frac{0.00133m}{0.000786m} = 1.7 \text{ Ans}$$

8. Derive the expression for the critical pressure ratio in a steam nozzle.

There is only one value of the ratio (called critical pressure ratio)

$$\frac{p_2}{p_1}$$

p_1 which will produce the maximum discharge. This can be obtained by

differentiating ' m ' with respect to $\left(\frac{p_2}{p_1}\right)$ and equating it to zero. Other

quantities except the ratio $\frac{p_2}{p_1}$ are constant.

$$\frac{d}{d[p_2/p_1]} \left[\left(\frac{p_2}{p_1} \right)^{\frac{2}{n}} - \left(\frac{p_2}{p_1} \right)^{\frac{n+1}{n}} \right] = 0$$

$$\frac{2}{n} \left[\frac{p_2}{p_1} \right]^{\frac{2}{n}-1} - \frac{n+1}{n} \left[\frac{p_2}{p_1} \right]^{\frac{n+1}{n}-1} = 0$$

$$\frac{2}{n} \times \left(\frac{p_2}{p_1} \right)^{\frac{2}{n}-1} = \frac{n+1}{n} \left(\frac{p_2}{p_1} \right)^{\frac{1}{n}}$$

$$\left(\frac{p_2}{p_1} \right)^{2-n} = \left[\frac{n+1}{2} \left(\frac{p_2}{p_1} \right)^{\frac{1}{n}} \right]^n$$

$$\left[\frac{p_2}{p_1} \right]^{2-n} = \left(\frac{n+1}{2} \right)^n \left(\frac{p_2}{p_1} \right)$$

$$\frac{\left(\frac{p_2}{p_1}\right)^{2-n}}{\left(\frac{p_2}{p_1}\right)} = \left(\frac{n+1}{2}\right)^n$$

$$\left(\frac{p_2}{p_1}\right)^{2-n-1} = \left(\frac{n+1}{2}\right)^n$$

$$\left(\frac{p_2}{p_1}\right)^{1-n} = \left(\frac{n+1}{2}\right)^n \implies \frac{p_2}{p_1} = \left(\frac{n+1}{2}\right)^{n \times \frac{1}{1-n}}$$

$$\frac{P_2}{P_1} = \left(\frac{n+1}{2}\right)^{\frac{n}{1-n}}$$

Critical pressure ratio of steam nozzle,

$$\frac{P_2}{P_1} = \left(\frac{2}{n+1}\right)^{\frac{n}{n-1}}$$

9. A convergent nozzle required to discharge 2kg of steam per second. The nozzle is supplied with steam at 7 bar and 180°C and discharge takes place against a back pressure of 1 bar. The expansion up to throat is isentropic and the frictional resistance between the throat and exit is equivalent to 63 kJ/kg of steam. Take approach velocity of 75 m/s and throat pressure 4 bar, estimate

i) suitable areas for the throat and exit, and

ii) Overall efficiency of the nozzle based on enthalpy drop between the actual inlet pressure and temperature and the exit pressure.

Final velocity of the steam

From steam tables, corresponding to a pressure of 15 bar, we find that enthalpy of dry saturated steam,

$$h_1 = 2789.9 \text{ kJ/Kg}$$

and corresponding to a pressure of 1.5 bar, enthalpy of dry saturated steam,

$$h_2 = 2693.4 \text{ kJ/Kg}$$

$$\therefore \text{Heat drop, } h_d = h_1 - h_2 = 2789.9 - 2693.4 = 96.5 \text{ kJ/Kg}$$

We know that final velocity of the steam,

$$V_2 = 44.72 \sqrt{h_d} = 44.72 \sqrt{96.5} = 439.3 \text{ m/s}$$

10. Define critical pressure ratio of a nozzle and discuss why attainment of sonic velocity determines the maximum discharge through steam nozzle.

Critical Pressure Ratio:

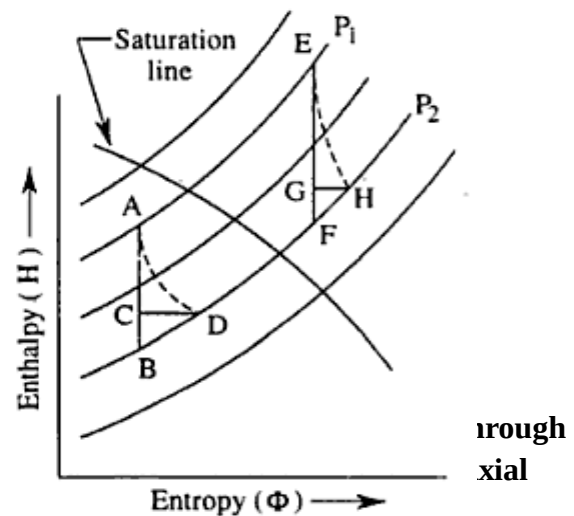
The critical pressure ratio is the pressure ratio which will accelerate the flow to a velocity equal to the local velocity of sound in the fluid.

Critical flow nozzles are also called **sonic chokes**. By establishing a shock wave the sonic choke establishes a fixed flow rate unaffected by the differential pressure, any fluctuations or changes in downstream pressure. A sonic choke may provide a simple way to regulate a gas flow.

11. Explain the metastable expansion of steam in a nozzle with help of h-s diagram.

Most of the **friction** occurs in the diverging part of a convergent-divergent **nozzle** as the length of the converging part is very small. The **effect** of **friction** is to reduce the available enthalpy drop by about 10 to 15 per cent. The velocity of steam will be then $V_2 = 44.72 \sqrt{K(H_1 - H_2)}$ where K is the coefficient which allows for **friction** loss. It is also known as **nozzle efficiency** (η_n)

$$\therefore V_2 = 44.72 \sqrt{(H_1 - H_2) \eta_n}$$



$$\theta = 29^\circ$$

(b) During force on the wheel

We know that driving force on the wheel,

$$F_x = m(V_w + V_{w1}) = 0.5 (1130 + 190) = 660 \text{ N}$$

(c) Axial thrust on the wheel

We know that axial thrust on the wheel,

$$F_y = m(V_f - V_{f1}) = 0.5(410 - 310) = 50 \text{ N}$$

(d) Power development by the turbine

We know that power development by the turbine,

$$\begin{aligned} P &= m(V_w + V_{w1}) V_b \\ &= 0.5(1130 + 190) 375 = 247\,500 \text{ W} \\ &= 247.5 \text{ kW} \end{aligned}$$

12. Dry saturated steam at a pressure of 8 bar enters a convergent divergent nozzle and leaves it at a pressure of 1.5 bar. If the flow is isentropic and if the corresponding expansion index is 1.133, find the ratio of cross sectional area at exit and throat for maximum discharge.

Heat drop between entrance and exit,

$$h_{d3} = h_1 - h_3 = 2775 - 2465 = 310 \text{ kJ/kg}$$

∴ Velocity of steam at throat,

$$V_3 = 44.72 \sqrt{h_{d3}} = 44.72 \sqrt{310} = 787.4 \text{ m/s}$$

and
$$m = \frac{A_2 V_2}{x_2 v_{g2}}$$

or
$$A_3 = \frac{m x_3 v_{g3}}{V_3} = \frac{m \times 0.902 \times 1.159}{787.4} = 0.00133 \text{ m}^2$$

∴ Ratio of cross-sectional area at exit and throat,

$$\frac{A_3}{A_2} = \frac{0.00133 \text{ m}^2}{0.000786 \text{ m}^2} = 1.7$$

13. Dry saturated steam at a pressure of 11 bar enters a convergent divergent nozzle and leaves at a pressure of 2 bar. If the flow is adiabatic and frictionless, determine

i) The exit velocity of steam and

ii) Ratio of cross section of exit and that at throat.

From steam tables, corresponding to a pressure of 10 bar, we find that enthalpy or total heat of dry saturated steam,

$$h_1 = h_{g1} = 2776.2 \text{ kJ/kg}$$

and

corresponding to a pressure of 0.1 bar,

$$h_{f2} = 191.8 \text{ kJ/kg, and } h_{fg2} = 2392.9 \text{ kJ/kg}$$

∴ Enthalpy or total heat of steam of exit,

$$\begin{aligned} h_2 &= h_{f2} + x_2 h_{fg2} \\ &= 191.8 + 0.791 \times 2392.2 \\ &= 2084.6 \text{ kJ/kg} \end{aligned}$$

and heat drop, $h_d = h_1 - h_2 = 2776.2 - 2084.6$
 $= 691.6 \text{ kJ/kg}$

1. What is the significance of critical pressure ratio?

- (i) The critical pressure gives the velocity of sound.
- (ii) The flow in the convergent portion of the nozzle is subsonic and divergent portion is supersonic
- (iii) For expanding the steam below critical pressure, the divergent portion of the nozzle is necessary.
- (iv) When p_2 approaches the critical value the rate of discharge will be maximum.

2. What is meant by super saturation in steam nozzles?

Owing to the high velocity, the residence time of steam in the steam nozzle is small, and there may not be sufficient time for necessary heat transfer and the formation of liquid droplet. Consequently the condensation of the steam may be delayed for a little while. This phenomenon is known as super saturation.

3. Define stagnation enthalpy

The stagnation enthalpy represents the enthalpy of fluid when it is brought rest adiabatically.

4. What are the different forms of steam nozzles?

- a. Convergent nozzles
- b. Divergent nozzles
- c. Convergent divergent nozzles

5. Define critical pressure ratio.

The pressure which the area is minimum and discharge per unit area is maximum is called critical pressure ratio.

Critical pressure ration = $(p_2/p_1) = (2/(n+1))^{n/(n-1)}$

6. Define coefficient of nozzle or nozzle efficiency

Nozzle efficiency = (actual enthalpy drop) / (isentropic enthalpy drop)

7. What is the effect of friction on the flow through a steam nozzle?

- a. The expansion will not be isentropic and enthalpy drop is reduced
- b. The dryness fraction of the steam is increased
- c. The specific volume of steam is increased

8. What are the differences between super saturated flow and isentropic flow in steam nozzles

Super saturated Flow	Isentropic Flow
1. Entropy is not constant	Entropy is constant

2. Reduction in enthalpy drop No reduction in enthalpy drop
3. Mollier diagram could not be used to solve the problem Mollier diagram can be used to solve the problem

9. What are the reasons for the drop in velocity of the steam for a given pressure drop in steam nozzle?

- a. Friction between the surface of the nozzle and steam
- b. Due to internal fluid friction in the steam
- c. Due to shock losses

10. What are the effects of super saturation in nozzles?

- (i) The dryness fraction of the steam is increased
- (ii) Entropy and specific volume of the steam are increased
- (iii) Exit velocity of the steam is reduced
- (iv) Mass of the steam discharged is increased.

11. What are the limits for super saturation in steam nozzles? Why?

The super saturation occurs upto above 0.94 dryness fraction and beyond that the condensation of steam occurs suddenly and irreversibly at constant enthalpy and then remain in stable condition.

12. State the relation between the velocity of steam and heat during any part of a steam nozzle.

The heat drop is converted into kinetic energy when the steam flows through nozzle.

13. What are the main functions of steam nozzles?

- Ø To supply high velocity jet of steam in steam turbine
- Ø To inject feed water in to the boiler in a steam injector.

13. Define indicated pressure ration in steam nozzles

There is only one value of the ratio (P_2/P_1), which produces maximum discharge from the nozzle. That ratio is called Critical Pressure Ratio.

14. What are the factors those change the fluid properties while a fluid flows through a nozzle with no work or heat transfer?

- Ø Change in flow area
- Ø Frictional forces

15. What are the factors reducing the final velocity of steam in nozzle flow?

- *The frictional between the nozzle surface and steam
- *The internal fluid friction in the steam
- *Shock losses

16. Explain super saturated flow (or) metastable flow in steam nozzle.

When super heated steam is expanded isentropically, it starts condensing at its meet with dry saturated line. But in nozzles, the velocity of steam is high and hence the time available is very less (about 0.001 sec). So, the condensation phenomenon does not start at point '2' for a

flow of point 1 to point 5. As a result of this, the steam continues to expand in dry condition up to point 3. The steam between state 2 and 3 is said to be supersaturated or metastable state and the flow of such super saturated steam is known as supersaturated or metastable flow. A limit to the super heated state was observed by Wilson and a line drawn on the chart through the observed points is known as Wilson line. This line becomes the saturation line for all practical purposes. Beyond this Wilson line, the steam suddenly starts to condense and restores its normal equilibrium state.

17. Define nozzle efficiency.

It is the ratio of actual enthalpy drop to isentropic enthalpy drop.

18. Differentiate super saturated flow and isentropic flow.

Super saturated

Entropy is not constant

Super saturation reduces the heat drop therefore exit velocity is reduced

Moiller diagrams cannot be used

$$C_2 = \sqrt{\left(\frac{2n}{n-1}\right) p_1 v_1 \left(1 - \left(\frac{p_1}{p_2}\right)^{\frac{(n-1)}{n}}\right)}$$

Isentropic flow

Entropy remains constant

No reduction in enthalpy drop.

Moiller diagrams can be used.

$$C_2 = \sqrt{(2000 (h_1 - h_2) + C_1^2)}$$

19. What is steam nozzle? How are they classified?

A steam nozzle is a device having variable cross-sectional passage in which the potential energy of steam is converted into kinetic energy at low pressure when a high pressure steam flows through it. They are classified as convergent type, divergent type, and convergentdivergent

20. Mention the applications of nozzle.

- Ø To inject feed water into the boiler in steam injectors.
- Ø To maintain, high vacuum in power plant condensers.
- Ø To supply, high velocity jet of steam jet in steam turbines.
- Ø To remove, air in condenser.

21. What are the advantages of convergent divergent nozzle?

- Ø The steam enters the nozzle at high pressure with negligible velocity and leaves at high velocity with low pressure.
- Ø Convergent-divergent nozzles are used in back pressure turbine.

22. What is the purpose of divergent portion after the throat section of nozzle?

- Ø It accelerates the steam leaving the nozzle.
- Ø It does not affect the discharge of steam passing through the nozzle.

23. Define degree of super saturation.

The ratio of super saturation pressures corresponding to the temperature between super saturated region is known as the degree of super saturation.

24. Define blade efficiency or utilization factor.

It is the ratio of rotor blade work to energy supplied to the rotor.

25. Define degree of reaction.

It is defined as the ratio of the actual isentropic heat drop to the total heat drop in the entire stage.

26. What is compounding and explain the purpose of compounding?

Compounding is the method in which multiple system or rotors are keyed to common shaft in series and the steam pressure or jet velocity is absorbed in stages as it flows over the rotor blades.

Purpose of compounding: Reduction of pressure (from boiler pressure to condenser pressure) in single results in the very high velocity entering the turbine blades. Therefore, the turbine rotor will run at a high speed about 30,000 rpm which is not useful for practical purpose. In order to reduce the rotor speed up to about 400 m/sec, compounding of steam turbine is necessary.

27. List the requirements of ignition system.

- Ø Ignition should takes place at the end of compression stroke.
- Ø There should be no missing cycle due to the spark failure.
- Ø Ignition must add sufficient energy for starting and sub staining the charge burning
- Ø Ignition system should supply the minimum required energy within a small volume in a very short time.

28. What are the different types of ignition system in S.I. engines?

Battery Ignition system and Magneto ignition system.

29. What is auto ignition?

A mixture of fuel and air can react spontaneously and produce heat by chemical reaction without the uses of flame to initiate the combustion, because the temperature is high than self-ignition temperature.

30. What is meant by pre-ignition?

At very high temperature carbon deposits formed inside the combustion chamber ignites the air fuel mixture much before normal ignition occurred by spark plug. This is called pre-ignition.

31. What are the factors affecting ignition lag?

Compression ratio, speed of the engine, Chemical nature of fuel and air fuel ration, and Initial pressure and temperature.

32. What is meant by knocking? How it occurs in diesel engines? Nov/Dec-2007

If the delay period of C.I. engines is long, more fuel is injected and accumulated in the chamber. When ignition begins, pulsating pressure rise can be noticed and creates heavy noise. This is known as knocking.

33. What are the effects of knocking?

- Ø The engine parts get overheated which may cause damage to the piston.
- Ø It creates heavy vibration of engine and hence louder noise and roughness.
- Ø Decrease in power output and efficiency.
- Ø More heat is lost to the coolant as the dissipation rate is rapid.
- Ø The auto-ignition may over heat the spark plug and hence pre-ignition occurs
- Ø Carbon deposits.

34. What are the effects of rich mixture in petrol engine?

An engine might run rich especially when the weather is cold, when under load or when it is accelerating

35. How are SI and CI engine fuels rated?

SI engine fuels rating is done by Octane number and CI engine fuel rating is done by Cetane number

36. What is meant by ignition delay?

The Ignition delay period is subdivided into two types. 1. physical delay 2. Chemical delay.

The physical delay period is the time between beginning of injection and attainment of chemical reaction conditions. During this period, fuel is atomised, vapourised, mixed with air and raised to its self-ignition temperature.

During chemical delay, reactions start slowly and then accelerate until the ignition takes place. Generally, the chemical delay is larger than physical delay.

37. What is the fuel injector?

Fuel injector is used in diesel engine to inject and atomize the diesel at the end of the compression stroke.

38. What is meant by SI engine? Why it is called so?

SI engine means spark ignition engine. In SI engine air fuel mixture is ignited by spark plug hence it is called spark ignition engine. It is also called as petrol engine.

39. Give four major differences between two stroke and four stroke IC engine.

No Two stroke cycle engine Four Stroke cycle engine

1 One cycle is completed in two stroke of the piston or one revolution of the crank shaft. One cycle is completed in four stroke of the piston or two revolution of the crank shaft.

2 For the same speed, twice the number of power strokes is produced than 4 stroke engine. For the same speed, half of the number of power strokes is produced than 2 stroke engine.

3 Turning moment is more uniform and hence lighter flywheel is used. Turning moment is not uniform and hence bigger flywheel is used.

4 It contains ports which are operated by the piston movement. It contains valves which are operated by valve mechanism.

40. What is meant by CI Engine? Why it is called so?

CI engine means compression ignition engine. In CI engine the fuel is injected by a fuel injector in atomized form because of high compressed air it gets ignited automatically. Hence it is called as compression ignition engine.

41. What is a two stroke engine?

A two stroke engine is an engine in which one cycle of operation is completed in two stroke of the piston or one revolution of the crank shaft.

42. What is a four stroke engine?

A four stroke engine is an engine in which one cycle of operation is completed in four stroke of the piston or two revolution of the crank shaft.

43. Name the four strokes of an IC engine?

Suction, compression, power and exhaust stroke

44. Differentiate petrol and Diesel engines.

Petrol or SI engines

Diesel or CI engine

1. Combustion of air fuel mixture takes place by spark produced by sparkplug.

1. Combustion takes place by high compressed air.

2. Carburetor is used to mix the air fuel mixture.

2. Fuel injector is used to inject the fuel in Atomized form.

3. Compression ratio varies from 6 to 8.

3. Compression ratio varies from 12 to 18.

4. It works on Otto cycle.

4. It works on Diesel or Dual cycle.

45. What is the function of push rod and rocker arm in IC engine?

The function of push rod and rocker arm in IC engine is to transmit motion of the cam to the valve.

46. What is the function of piston rings?

- * It acts as air tight sealing between piston and cylinder to prevent gas leakages
- * to wipe off the excess oil from the cylinder walls and also to return the excess oil to the sump through the slots provided on the rings.

47. What is scavenging in IC engine?

The process of pushing out of exhaust gases from the cylinder by admitting the fresh charge into the cylinder is known as scavenging.

48. What are the requirements of a fuel injection system of a diesel engine? Nov/Dec-2007

- Ø To inject the fuel at correct moment, and quantity at various load conditions
- Ø To inject the fuel in a finely atomized condition.
- Ø To distribute the fuel uniformly in the combustion chamber.
- Ø To control the rate of fuel injection.

49. List the requirements of ignition system.

- Ø Ignition should take place at the end of compression stroke.
- Ø There should be no missing cycle due to the spark failure.
- Ø Ignition must add sufficient energy for starting and sustaining the charge burning
- Ø Ignition system should supply the minimum required energy within a small volume in a very short time.

50. Which engine will have more cooling requirement two-stroke engine or four-stroke engine? Why?

Two stroke-engines will have more cooling requirements since power is developed for each revolution of crank. So, for each crank revolution, Combustion occurs and more heat will be generated inside the cylinder