MODULE II

STEAM NOZZLES PROBLEM

1) 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,

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

∴ Velocity of steam at throat,

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

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

or $$A_3 = \frac{m x_3 \upsilon_{g3}}{V_3} = \frac{m \times 0.902 \times 1.159}{787.4} = 0.001.33m$$

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

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

2. Dry saturated steam at a pressure of 11 bar enters a convergent divergent nozzle and leaves at at 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,

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

and

Corresponding to a pressure of 0.1 bar,

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

∴ Enthalpy or total heat of steam of exit,

$h_2 = h_{f2} + x_2 h_{fg2}$

$= 191.8 + 0.791 \times 2392.2$

$= 2084.6$ kJ/kg

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

$= 691.6$ kJ/k

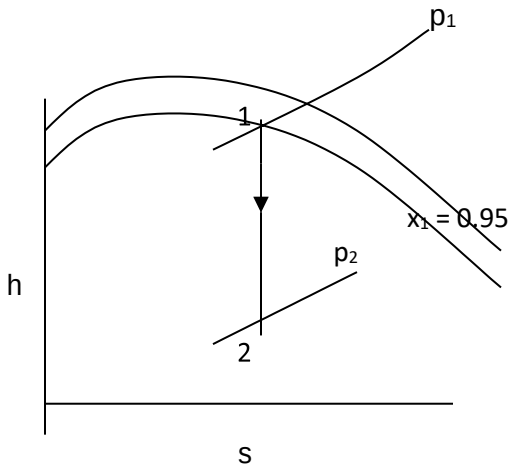
3 Steam approaches a nozzle with velocity of 250 m/s, pressure of 3.5 bar and dryness fraction of 0.95. If the isentropic expansion in the nozzle proceeds till the pressure of the exit is 2 bar, determine the change in enthalpy and the dryness fraction of steam. Calculate also the exit velocity from the nozzle and the area of the exit of the nozzle for the flow of 0.75 kg/s.

Given

Type = Convergent
Velocity of steam at inlet (V_1) = 250 m/s
Pressure at inlet (p_1) = 3.5 bar with x_1 = 0.95
Pressure at outlet (p_2) = 2 bar
Mass flow rate (m) = 0.75 kg/s

Required: ($h_1 – h_2$), x_2, V_2 & A_2

Solution



From Chart,

h_1 = 2625 kJ/kg h_2

= 2540 kJ/kg x_2

=**0.92 --- Ans**

∴ ($h_1 – h_2$) = 2625 – 2540 = **85 kJ/kg ---------- Ans**

$(V_2^2 – V_1^2) / 2 = h_1 - h_2$

$(V_2^2 – 250^2) / 2 = 85 \times 10^3$

V_2 = **482.2 m/s**

A_2 = Area of the nozzle at outlet

$m = A_2V_2 / v_2$

v_2 = 0.8 m^3/kg from chart at point (2)

$\therefore \quad 0.75 = A_2 \times 482.2 / 0.8$

$A_2 = 0.0012443\ m^2 =$ **$12.443\ cm^2$---------- Ans**

4. Dry saturated steam at pressure of 8 bar flows through nozzles at the rate of4.6 kg/s and discharges at a pressure of 1.5 bar. The loss due to friction occursonly in the diverging portion of the nozzle and its magnitude is 12 % of the total isentropic enthalpy drop. Assume the isentropic index of expansion n = 1.135, determine the cross sectional area at the throat and exit of the nozzles.

Given

Type = Con-div type
Inlet pressure (p_1) = 8 bar, dry
Mass flow rate of steam (m) = 4.6 kg/s
Discharge pressure (p_3) = 1.5 bar
$h_3 - h_{3'}$ = 0.12 ($h_1 - h_{3'}$)
n = 1.135

Required: A_2, A_3

Solution

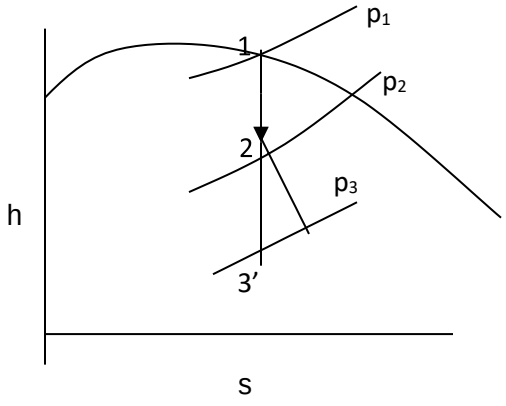
$$M = A_2V_2 / v_2 = A_3V_3 / v_3$$

Inlet velocity is not given, $\therefore \ V_1 = 0$

$$\therefore \quad V_2^{\ 2}/2 = h_1 - h_2$$

From chart,

$h_1 = 2770$ kJ/kg



We can write,

$$P2/p1 = \left[\frac{2}{n+1}\right]^{n/(n+1)}$$

$$\therefore \quad p_2 / 8 = [2 / (1.135 + 1)]^{1.135./\ (1.135\ -\ 1)}$$

$p_2 = 4.62$ bar

From Chart, $h_2 = 2545$ kJ/kg

$v_2 = 0.42\ m^3/kg$

$\therefore \quad V_2^2/2 = (2770 - 2545) \times 10^3$

$V_2 = 670.8$ m/s

$\therefore \quad 4.6 = A_2 \times 670.8 / 0.42$

$A_2 = 0.00288\ m^2$ **$= 28.8\ cm^2$ ---------- Ans**

From chart, $h_{3'} = 2455$ kJ/kg

$v_{3'} = 1.1\ m^3/kg \approx v_3$

$h_3 - h_{3'} = 0.12\ (h_1 - h_{3'})$

$h_3 - 2455 = 0.12\ (2770 - 2455)$

$h_3 = 2492.8$ kJ/kg

$V_3^2/2 = (2770 - 2492.8) \times 10^3$

$V_3 = 744.6$ m/s

$\therefore\ 4.6 = A_3 \times 744.6 / 1.1$

$A_3 = 0.0067956\ m^2$ **$= 67.956\ cm^2$ -------- Ans**

5. Steam at a pressure of 10 bar and dryness fraction of 0.98 is discharged through a convergent divergent nozzle to a back pressure of 0.1 bar. The massflow rate is 10 kg/kWh. If the power developed is 200 kW, determine, (a)Pressure at the throat (b) Number of nozzles required, if each nozzles has a throat of rectangular cross section of 5 mm x 10 mm and (c) exit area of nozzle if 10 % the overall isentropic enthalpy drop reheats the steam by friction in the divergent portion.

Given

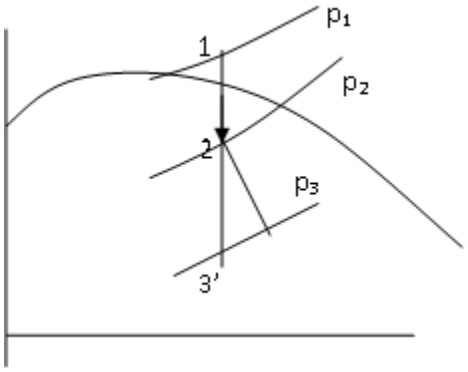
Type	= Con-div
Inlet pressure (p_1)	= 10 bar with $x_1 = 0.98$
Back pressure (p_3)	= 0.1 bar
Mass flow rate (m)	= 10 kg/kWh
Power (P)	= 200 kW
Size of nozzle	= 5 mm x 10 mm
$h_3 - h_{3'}$	= 0.1 ($h_1 - h_{3'}$)

Required: (a) p_2

(b) Number of nozzles

(c) A_3

Solution



(a) Pressure at throat (p_2)

$$P2/p1 = \left[\frac{2}{n+1}\right]^{n/(n+1)}$$

$$n = 1.035 + 0.1\,(x_1)$$

$$= 1.035 + (0.1 \times 0.98) = 1.133$$

$$\therefore\ p_2 / 10 = [2 / (1.133 + 1)]^{1.133./\,(1.133 - 1)}$$

p_2 = **5.78 bar --- Ans**

(b) Number of nozzles = Total area / Area per nozzle = A_2 / A_2 per nozzle

$$A_2/\text{nozzle} = 0.005 \times 0.01 = 0.00005\ m^2$$

$$m = A_2V_2 / v_2$$

$$m\ (kg/s) = \frac{m\ (kg/kWh) \times P}{3600}$$

$$= 10 \times 200 / 3600 = 0.5556\ kg/s$$

$$V_2^2/2 = h_1 - h_2$$

From chart, $h_1 = 2735$ kJ/kg

$h_2 = 2625$ kJ/kg

$v_2 = 0.32\ m^3/kg$

$\therefore V_2^2 = (27735 - 2625) \times 10^3$

$V_2 = 469.04$ m/s

$\therefore \quad 0.5556 = A_2 \times 469.04 / 0.32$

$A_2 = 0.00037905\ m^2$

$\therefore$ Number of nozzles = 0.00037905 / 0.00005 = 7.58 = **8------ Ans**

$$m = A_3V_3 / v_3$$

$$V_3^2/2 = h_1 - h_3$$

From chart, $h_{3'} = 2055$ kJ/kg

$v_{3'} = 13\ m^3/kg = v_3$

$h_3 - h_{3'} = 0.1\ (h_1 - h_{3'})$

$h_3 - 2055 = 0.1 \times (2735 - 2055)$

$h_3 = 2123$ kJ/kg

$\therefore \quad V_3^2/2 = (2735 - 2123) \times 10^3$

$V_3 = 1106.3$ m/s

$\therefore \quad 0.5556 = A_3 \times 1106.3 / 13$

$A_3 = 0.0065276\ m^2$

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 = (p2/p1) = (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 steamnozzle?

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 (P2/P1), 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 isentropic ally, 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. 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,whem under load or when it is accelerating

35.How are SI and Ci engione 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 sub devided into two types.1.physical delay 2.Chemical delay.
The phycial delay period is the time between beginning of injection and attainment of chemical of chemical reaction conditions.Durimg this period,fuel is atomised,vapourised,mixed with air and raised to its self-ignition tenperature.

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 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.

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