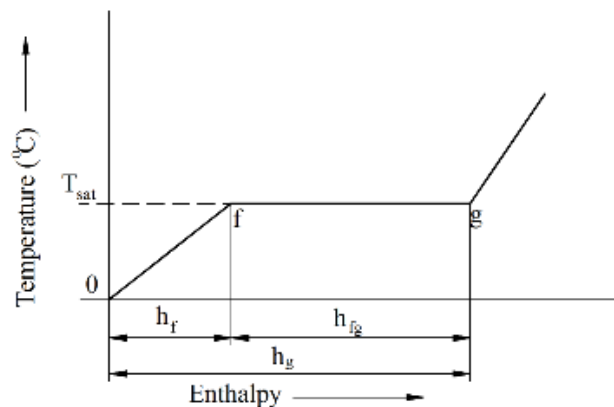


Lecture 1 to 4:

Objective: Discussion about steam formation and its properties.

Properties of Steam

Take one kg of water at 0°C in a cylinder fitted with piston. Place a known weight on the piston to have constant pressure acting on the piston. Insert a thermometer to monitor the temperature. Start heating the cylinder at a constant rate and note down the temperature along with the quantity of heat added. Plot the values on a graph with the quantity of heat supplied taken along x – axis and the temperature along y – axis. The nature of the graph is shown in the figure 1.13.



Graph showing temperature v/s enthalpy

Initially the temperature starts increasing steadily with heat addition. This continues up to the point 'f' on the graph. At this point water is no more able to take in heat in liquid phase. Water starts changing its phase to vapor (steam). This change in phase from liquid to vapor is called boiling. The change of phase occurs at constant temperature and at point 'g' the water is completely vaporized. Further heating, results in steady increase in temperature of steam.

The water is saturated at point 'f'. We call the point 'f' saturated liquid point. Similarly, the steam is saturated at point 'g', and we call the point 'g' the saturated vapor point. The constant temperature at which boiling takes place is called the saturation temperature (T_{sat})

By definition heat added at constant pressure is given the name enthalpy denoted by 'h'. The variable along horizontal axis now becomes enthalpy. We can define enthalpy at salient points on the graph as follows

$h_f =$ Enthalpy of saturated liquid

(heat added from 00°C till the point 'f')

$h_{fg} =$ Enthalpy of evaporation

(amount of heat added to convert saturated liquid to saturated vapour)

$h_g =$ Enthalpy of saturated steam
(amount of heat added from 00 C till the point 'g')

The quantity h_f is also called the sensible heat because we can sense the change in temperature from 0 to f. The quantity h_{fg} is also called latent heat (latent = hidden) because we are unable to sense the change during this period.

Condition of the fluid at different states

The fluid which has its state between '0' and 'f' is called sub-cooled liquid, the fluid which has its state between 'f' and 'g' is called wet steam, and the fluid which has its state beyond 'g' is called super-heated steam.

The boiling process starts at 'f' and ends at 'g'. At 'f' we have 1kg of water and no vapour, similarly, at 'g' we have 1 kg of steam and no water. In between 'f' and 'g' we have a mixture of water and steam and this mixture is called wet steam. The ratio of the mass of steam present in the mixture to the total mass of the mixture is called the dryness fraction denoted by 'x'.

Dryness fraction, $x = m_g / (m_f + m_g)$

Where, m_f = mass of water in the mixture.

m_g = mass of steam in the mixture.

$(m_f + m_g)$ = total mass of the mixture.

The steam, which is super-heated, has its temperature above the saturation temperature. The amount by which the temperature is raised above the saturation temperature is called the degree of superheat.

Degree of superheat, $\Delta T = T_{sup} - T_{sat}$

Where, T_{sat} = saturation temperature

T_{sup} = superheated temperature.

Different states of steam (Types of steam)

Wet steam:

When the water is heated beyond the saturation state at constant pressure it starts evaporating. The steam evolving from the surface of the water entrains finely divided water molecules in it. This entrained water molecules suspended in the steam will be at the saturation temperature and will not yet have been absorbed the latent heat and evaporated into steam. Both the entrained water molecules and steam coexist to form a two phase mixture, called wet steam

which will be in thermal equilibrium because both of them will be at same saturation temperature.

Thus a wet steam is defined as a two phase mixture of entrained water molecules and steam in thermal equilibrium at the saturation temperature corresponding to a given pressure.

Dry fraction of steam:

A wet steam can be of different quality. i.e. having different proportion of water molecules and dry steam. Hence the quality of steam can be indicated by using a term called dryness fraction.

Dry ness fraction can be defined as the ratio of mass of the actual dry steam present in a known quality of wet steam to the total mass of the wet steam.

$$X = \frac{\text{mass of the dry steam present in wet steam } (m_g)}{\text{total mass of wet steam } (m_f + m_g)}$$

Dry saturated steam:

Steam which is in contact with water from which it has been formed will be in thermal equilibrium with the water (i.e., the heat passing from steam into the water is balanced by the equal quantity of heat passing from the water into the steam) is said to be a saturated steam.

A saturated steam at the saturation temperature corresponding to a given pressure and having no water molecules entrained in it is defined as dry saturated steam or simply dry steam.

Since the dry saturated steam does not contain any water molecules in it, its dryness fraction will be unity.

Super-heated steam:

When a dry saturated steam is heated further at the given constant pressure, its temperature rises beyond its saturation temperature. The steam in this state is said to be superheated.

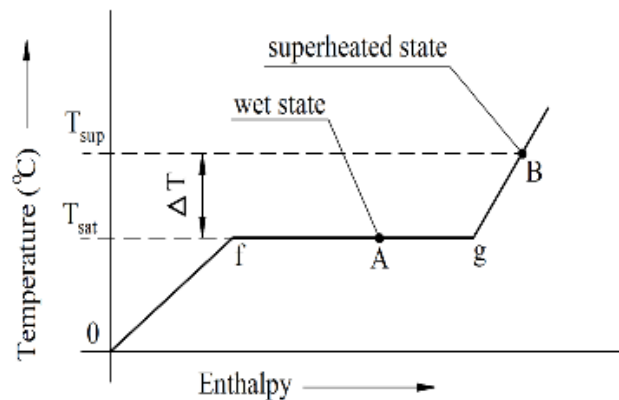
A superheated steam is defined as the steam which is heated beyond its dry saturated state to temperatures higher than the saturated temperature at the given pressure.

Lecture 2:

Objective: Discussion about steam properties and steam tables.

Properties of steam at different states

We can calculate some of the important properties of steam such as enthalpy, specific volume and internal energy when the steam exists in wet state and superheated state. To do this, we need to know the values of the properties at 'f' and 'g'.



Graph of temperature vs enthalpy showing different steam states

Enthalpy

Enthalpy of wet steam with dryness fraction 'x': We know that enthalpy is the amount of heat added at constant pressure. Therefore,

h_A = amount of heat added from '0' to 'A'.

= amount of heat added from '0' to 'f' + amount of heat added from 'f' to 'A'.

= h_f + amount of heat added from 'f' to 'A'.

A dryness fraction of 'x' means that out of 1 kg of water initially taken, x kg is converted into steam, and (1-x) kg still remains as water.

Amount of heat added to convert

1 kg saturated water into steam = h_{fg}

Therefore,

Amount of heat added to convert

x kg saturated water into steam = $x.h_{fg}$

and,

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

Enthalpy of superheated steam: In the superheated region steam obeys the ideal gas equation very closely. We can calculate the properties of steam in this region using the ideal gas equation.

h_B = amount of heat added from '0' to 'B'.

= amount of heat added from '0' to 'g' + amount of heat added from 'g' to 'B'.

$$h_B = h_g + c_{ps} (\Delta T)$$

Where c_{ps} = Specific heat of steam

$$\Delta T = \text{Degree of superheat} = (T_{sup} - T_{sat})$$

Specific Volume

Specific volume is the volume occupied by unit mass of a substance

Let v_f = volume occupied by 1 kg of saturated liquid

v_g = volume occupied by 1 kg of saturated vapor

Specific volume of wet steam v_A with dryness fraction (x)

We have taken 1 kg of water at 0° C initially. The total mass of the mixture at any state is 1 kg. When the dryness fraction of steam is x , we have x kg of steam and $(1 - x)$ kg of water.

Volume occupied by $(1 - x)$ kg of water = $(1 - x) v_f$

Volume occupied by x kg of steam = $x v_g$

Therefore, total volume occupied by the mixture is

$$v_A = (1 - x) v_f + x v_g$$

But the specific volume of saturated water (v_f) is negligible compared to the specific volume of saturated vapour (v_g). Neglecting the first term the specific volume of the mixture is approximately and very closely given by

$$v_A = x v_g$$

Specific volume of superheated steam (v_B)

We know that steam behaves like an ideal gas in the superheated region. Applying the ideal gas equation at states 'g' and 'B' we have,

$$p v_g = R T_{sat}$$

$$p v_B = R T_{sup}$$

dividing, $\frac{v_B}{v_g} = \frac{T_{sup}}{T_{sat}}$

$$v_B = \frac{T_{sup} \cdot v_g}{T_{sat}}$$

Internal energy (u)

All forms of energy possessed by the system, except the kinetic and potential energies, are collectively called as internal energy.

Total energy content of the system,

$$\text{Energy} = \text{Internal energy } (u) + \text{Kinetic energy} + \text{Potential energy.}$$

By definition, enthalpy,

$$h = u + pv$$

Therefore, internal energy,

$$u = h - pv$$

We can calculate the internal energy of the system at any given state by substituting the values of h, p and v corresponding to that state.

Internal energy of saturated liquid,

$$u_f = h_f - pv_f$$

Internal energy of saturated vapour,

$$u_g = h_g - pv_g$$

Internal energy of wet steam,

$$u_A = h_A - pv_A$$

Internal energy of superheated steam,

$$u_B = h_B - pv_B$$

Steam tables

(a) Saturated water and steam (temperature) table

It contains values of pressure, specific volume, specific enthalpy (and specific entropy) corresponding to different temperatures. A sample of the table is given below.

Temperature in °C (<i>t</i>)	Absolute pressure in bar (<i>p</i>)	Specific volume in m ³ /kg		Specific enthalpy in kJ/kg		
		<i>v_f</i>	<i>v_g</i>	<i>h_f</i>	<i>h_{fg}</i>	<i>h_g</i>
20	0.023 37	0.001002	57.838	83.9	2454.3	2538.2
40	0.073 75	0.001008	19.546	167.5	2406.9	2574.4
100	1.0133	0.001044	1.6730	419.1	2256.9	2676.0
175	8.9244	0.001121	0.21654	741.1	2030.7	2771.8

(b) Saturated water and steam (pressure) table

It contains values of pressure, specific volume, specific enthalpy (and specific entropy) corresponding to different pressures (absolute). A sample of the table is given below.

Absolute pressure in bar (<i>p</i>)	Temperature in °C (<i>t</i>)	Specific volume in m ³ /kg		Specific enthalpy in kJ/kg		
		<i>v_f</i>	<i>v_g</i>	<i>h_f</i>	<i>h_{fg}</i>	<i>h_g</i>
0.15	54.00	0.001014	10.023	226.0	2373.2	2599.2

1.0133 25	100	0.001044	1.6730	419.1	2256.9	2676.0
10.0	179.9	0.001127	0.19430	762.6	2013.6	2776.2
125	327.8	0.001547	0.013518	1511.9	1166.5	2678.4

Choice of the table depends on whether we know the operating temperature or the operating pressure.

Lecture 3:

Objective: solving numerical on steam properties.

Problem 1: Determine the density of 1 kg of steam initially at a pressure of 10 bar absolute, having a dryness fraction of 0.78. If 500 kJ of heat is added at constant pressure, determine the condition and internal energy of the final state of steam. Take specific heat of saturated steam as 2.1 kJ/kgK. (VTU January 2003)

Solution:

Given, $m=1$ kg, $p=10$ bar = 1000 kPa., $x=0.78$, heat added = 500 kJ.

We know that heat added at constant pressure is nothing but increase in enthalpy.

Let, h_1 = initial enthalpy,

h_2 = final enthalpy,

then, $h_2 = h_1 + \text{heat added.}$

Initial enthalpy:

From steam tables, at 10 bar,

$$h_f = 762.6 \text{ kJ/kg}$$

$$v_g = 0.19430 \text{ m}^3/\text{kg}$$

$$h_{fg} = 2013.6 \text{ kJ/kg}$$

$$h_1 = h_f + x h_{fg} = 762.6 + 0.78 \times 2013.6 = 2333.2 \text{ kJ/kg}$$

Final enthalpy:

$$h_2 = h_1 + \text{heat added} = 2333.2 + 500 = 2833.2 \text{ kJ/kg.}$$

From steam tables, at 10 bar

$$h_g = 2776.2 \text{ kJ/kg}, \quad t_{sat} = 179.9^\circ\text{C.}$$

Since h_2 is greater than h_g , steam is superheated.

Enthalpy of superheated steam:

$$h_2 = h_g + c_{ps} (T_{sup} - T_{sat})$$

$$2833.2 = 2776.2 + 2.1 (T_{sup} - 179.9)$$

$$\text{therefore, } T_{sup} = 207^\circ\text{C}$$

Specific volume of steam:

Specific volume of superheated steam,

$$v_2 = v_g \cdot T_{sup} / T_{sat}$$

$$T_{sat} = 179.9 + 273 = 452.9 \text{ K}$$

$$T_{sup} = 207 + 273 = 480 \text{ K}$$

$$v_2 = 0.19430 \times 480/452.9 = 0.20592 \text{ m}^3/\text{kg}.$$

Internal energy:

Internal energy of superheated steam,

$$u_2 = h_2 - pv_2 = 2833.2 - 1000 \times 0.20592 = 2627.2 \text{ kJ/kg}.$$

Problem 2: What is the enthalpy of 5 kg of steam under the following conditions? (i) 0.8 bar absolute pressure and 90% dry, and (ii) 20 bar absolute pressure at 300°C. Take specific heat of superheated steam as 2.25 kJ/kg. (VTU January 2004)

Solution:

(i) $p = 0.8 \text{ bar}$, $x = 90\% = 0.9$.

Enthalpy of wet steam per kg

$$h = h_f + x h_{fg} \text{ kJ/kg}$$

For m kg,

$$H = m(h_f + x h_{fg}) = 5(391.7 + 0.9 \times 2274.1) = 12191.95 \text{ kJ}.$$

(ii) Pressure = 20 bar, temperature = 300°C

From steam tables at 20 bar, $t_{sat} = 212.4^\circ\text{C}$

Since t_{sat} is less than the temperature of steam, the steam is superheated.

From steam tables at 20 bar, $h_g = 2797.2 \text{ kJ/kg}$.

Enthalpy of superheated steam per kg

$$h_{sup} = h_g + c_{ps}(T_{sup} - T_{sat})$$

For m kg,

$$H_{sup} = m\{h_g + c_{ps}(T_{sup} - T_{sat})\} = 5\{(2797.2 + 2.25(300 - 212.4))\} = 14971.5 \text{ kJ}.$$

Problem 3: Find the internal energy of 2.5 kg of steam at 20 bar when (i) it is wet and its dryness fraction is 0.9, (ii) it is superheated to 350°C. Take specific heat of steam as 2.3 kJ/kgK (VTU February 2005)

Solution:

Given, $m = 2.5 \text{ kg}$, $p = 20 \text{ bar}$.

(i) steam is wet, $x = 0.9$

From steam table at 20 bar,

$$h_f = 908.5 \text{ kJ/kg}.$$

$$h_{fg} = 1888.7 \text{ kJ/kg}$$

Enthalpy of wet steam

$$h = h_f + x h_{fg} = 908.5 + 0.9 \times 1887.7 = 2608.33 \text{ kJ/kg.}$$

From steam tables at 20 bar,

$$v_g = 0.09955 \text{ m}^3/\text{kg.}$$

Specific volume of wet steam,

$$v = x v_g = 0.9 \times 0.09955 = 0.089595 \text{ m}^3/\text{kg.}$$

Specific internal energy,

$$u = h - pv = 2608.33 - 2000 \times 0.089595 = 2429.14 \text{ kJ/kg.}$$

Therefore, internal energy for m kg of steam,

$$U = mu = 2.5 \times 2429.14 = 6072.85 \text{ kJ.}$$

(ii) steam is superheated to 350°C:

From steam tables, at 20 bar,

$$t_{sat} = 212.4^\circ\text{C}, h_g = 2797.2 \text{ kJ/kg}, v_g = 0.09955 \text{ m}^3/\text{kg.}$$

Enthalpy of superheated steam,

$$h_{sup} = h_g + c_{ps}(T_{sup} - T_{sat}) = 2797.2 (350 - 212.4) = 3113.68 \text{ kJ/kg.}$$

Specific volume of superheated steam,

$$v_{sup} = v_g \cdot T_{sup} / T_{sat}$$

$$T_{sup} = 350 + 273 = 623 \text{ K}$$

$$T_{sat} = 212.4 + 273 = 485.4 \text{ K}$$

$$v_{sup} = 0.09955 \times 623 / 485.4 = 0.12777 \text{ m}^3/\text{kg.}$$

Specific internal energy,

$$u_{sup} = h_{sup} - pv_{sup} = 3113.68 - 2000 \times 0.12777 = 2858.13 \text{ kJ/kg.}$$

Therefore, internal energy for m kg of steam,

$$U_{sup} = mu_{sup} = 2.5 \times 2858.13 = 7145.34 \text{ kJ.}$$

Lecture 4:

Objective: Continuation of solving numerical on steam properties.

Problem 4: Steam is at 9 bar pressure and dryness fraction 0.98. Find the quality and temperature of steam when (i) the steam loses 50 kJ/kg at constant pressure, and (ii) steam receives 150 kJ/kg at constant pressure. (VTU July 2005)

Solution:

From steam tables, at 9 bar,

$$h_f = 742.6 \text{ kJ/kg},$$

$$h_{fg} = 2029.5 \text{ kJ/kg},$$

$$h_g = 2772.1 \text{ kJ/kg},$$

$$t_{sat} = 175.4^\circ\text{C},$$

Given,

$$x_1 = 0.98.$$

Initial enthalpy of steam,

$$h_1 = h_f + x_1 h_{fg} = 742.6 + 0.98 \times 2029.5 = 2731.51 \text{ kJ/kg}.$$

(i) Steam loses 50 kJ/kg at constant pressure,

$$h_2 = h_1 - 50 = 2731.51 - 50 = 2681.51 \text{ kJ/kg}.$$

Since h_2 is less than h_g , steam is wet.

Enthalpy of wet steam,

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

$$2681.51 = 742.6 + x_2 \times 2029.5$$

$$x_2 = 0.955.$$

(ii) Steam receives 150 kJ/kg of heat.

$$h_2 = h_1 + 150 = 2731.51 + 150 = 2881.51 \text{ kJ/kg}.$$

Since h_2 is greater than h_g , steam is superheated.

Enthalpy of superheated steam,

$$h_2 = h_g + c_{ps}(t_{sup} - t_{sat})$$

$$2881.51 = 2772.1 + 2.1 (t_{sup} - 175.4)$$

$$t_{sup} = 227.5^\circ\text{C}.$$

Problem 5: 2 kg of wet steam is heated at a constant pressure of 2 bar until its temperature increases to 150°C. The heat transferred is 2100 kJ. Find the initial dryness fraction of steam. Take the specific heat of steam as 2.1 kJ/kg. The properties of steam at 2 bar pressure are given below-

p (bar)	t_s (°C)	v_f (m ³ /kg)	v_g (m ³ /kg)	h_f (kJ/kg)	h_g (kJ/kg)
2	120.23	0.001061	0.8857	504.5	2706.5

(VTU January 2006)

Solution:

Given, $m=2$ kg, $p = 2$ bar = 2000 kPa. $T_2=150^\circ\text{C}$, heat added = 2100 kJ.

$$h_{fg} = h_g - h_f = 2706.5 - 504.5 = 2202 \text{ kJ/kg.}$$

Since t_2 is greater than t_{sat} , steam is superheated in the final state.

Enthalpy of superheated steam,

$$h_2 = h_g + c_p (t_{\text{sup}} - t_{\text{sat}}) = 2706.5 + 2.1 (150 - 120.3) = 2769.2 \text{ kJ/kg.}$$

Total heat added = 2100 kJ.

Heat added per kg of steam = $2100/2 = 1050$ kJ/kg.

Final enthalpy of steam,

$$h_2 = h_1 + 1050 \text{ kJ/kg.}$$

Therefore,

$$h_1 = h_2 - 1050 = 2769.2 - 1050 = 1719.2 \text{ kJ/kg.}$$

Since h_1 is less than h_g , steam is wet.

Enthalpy of wet steam,

$$h_1 = h_f + x_1 h_{fg}$$

$$1719.2 = 504.5 + x_1 \times 2202$$

Initial dryness fraction,

$$x_1 = 0.5516$$

Turbines: Classification, Principle operation of Impulse and reaction turbines, Delaval's

turbine, Parson's turbine. (No compounding of turbines).

Water turbines: Classification, Principles and operations of Pelton wheel, and Kaplan turbine

Self-Study Content: Francis turbine, Gas turbines: Classification, working principles and Operations of Open cycle and closed cycle gas turbines.

Lecture 5: Turbines

Objective: Introduction to turbines, its types and discussion about its principle of operation.

Introduction

‘Turbo Machine’ is defined as a device that extracts energy from a continuously flowing fluid by the dynamic action of one or more rotating elements. The prefix ‘turbo’ is a Latin word meaning ‘spin’ or ‘whirl’ implying that turbo machines rotate in some way.

A Turbine is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work. A turbine is a turbo-machine with at least one moving part called a rotor assembly, which consists of shaft or drum with blades attached to it. Moving fluid acts on the blades so that they move and impart rotational energy to the rotor. Examples of early turbine are windmills and waterwheels.

Types of Turbines

- Steam Turbines
- Gas Turbines (Combustion Turbines)
- Water (Hydraulic) Turbines

A steam turbine is a mechanical device that extracts thermal energy from high temperature and high pressure steam, and converts it into useful mechanical work. A steam turbine is a prime mover in which rotary motion is obtained by the gradual change of momentum of the steam. Steam turbines are primarily used to run alternators or generators in thermal power plants. It is also used to rotate the propellers of ships through reduction gearing.

Main parts of a steam turbine.

Nozzle: In steam turbines, normally, convergent-divergent type of nozzle is used. When steam flows through the nozzles, the inlet pressure of the working fluid in the nozzle is converted into velocity or kinetic energy. The nozzles also guide the steam in the proper direction to strike the blades. The nozzles are kept very close to the blades to minimize the losses.

Rotor: The rotor or runner consists of a circular disc fixed to a horizontal shaft.

Blade: On the periphery of the rotor, a large no of blades are fixed. The steam jet from the nozzles impinges on the surface of the blades and transfers kinetic energy steam to the blades due to which the rotor rotates.

Casing: It is a steam tight steel casing, which encloses the rotor, blades etc. In a multistage turbine, the casing also accommodates the fixed blades.

Classification of steam turbine: Steam turbines can be classified in to two types.

- i) Impulse turbine
- ii) Reaction turbine

Design consideration:

As almost all parts of the turbine are coming in contact with the water there is some concern of corrosion hence proper material need to be selected for avoiding corrosion or proper type of paints need to be applied on all parts of the turbine.

High impact forces need to be handled by the rotor blades

Apart from that care need to be taken for reducing noise and vibration

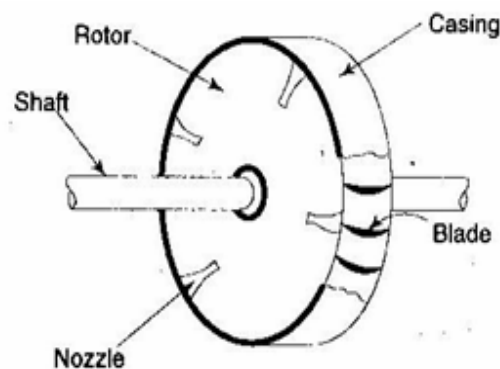
Lecture 6:

Objective: Discussion about working of impulse and reaction turbine.

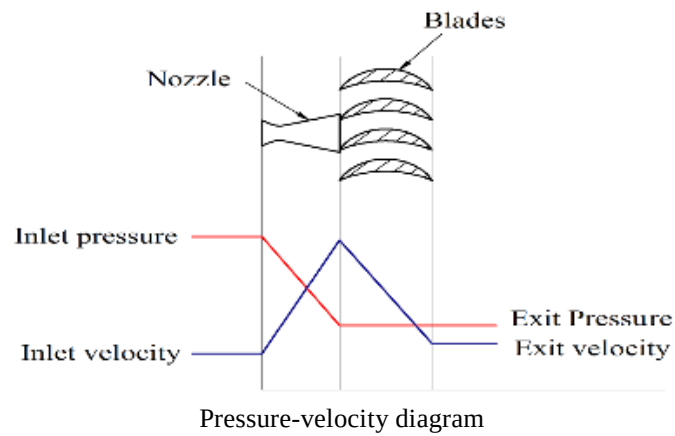
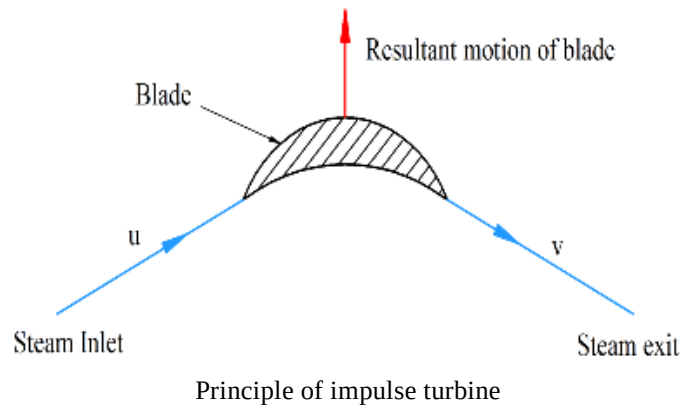
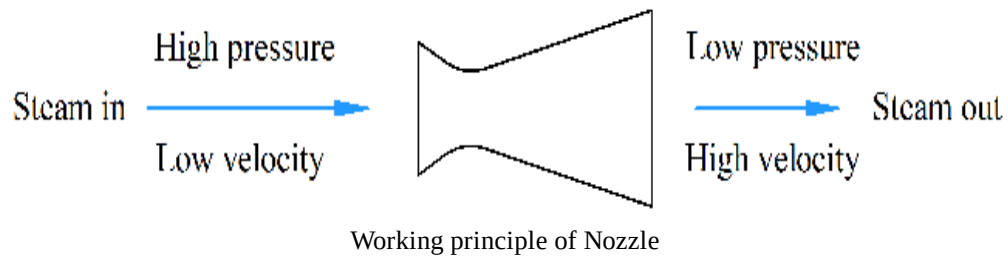
Impulse turbine (De-Laval).

The pressure energy is converted into kinetic energy by the expansion of steam through a set of nozzles. Normally, in steam turbines, convergent-divergent nozzles are used. The kinetic energy is converted into mechanical energy with the help of moving blades, fixed on the rotor. The rotor is connected to the output shaft. All these parts are enclosed in a casing.

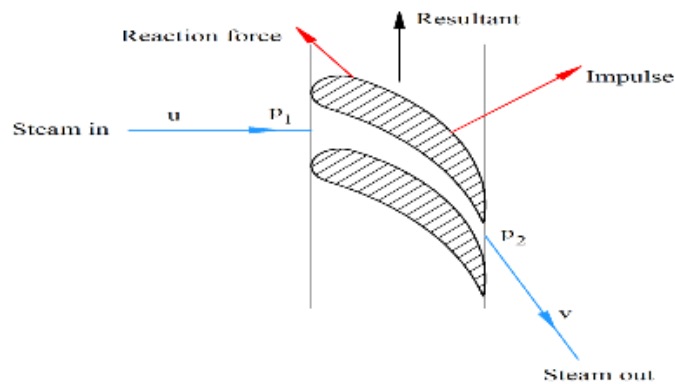
This turbine is not suitable for practical purposes, since high-pressure steam expands in one set of nozzles and get converted to very high velocity steam, due to this the rotor will rotate at a very high speed. So in practice, multistage impulse turbines or compound turbines are used.



Impulse turbine



Reaction turbine



Principle of reaction turbine

As mentioned earlier, **Parsons developed a steam turbine based on the reaction principle while de Laval developed one based on the impulse principle.** Since then turbines based on these principles have evolved in parallel and in fact merged to some degree

The reaction turbine, as the name implies, is turned by reactive force rather than by a direct push or impulse. In reaction turbines, the blades that project radially from the periphery of the rotor are formed and mounted so that the space between the blades will have the nozzle shape. Since these blades are mounted on the revolving rotor, they are called moving blades. Fixed or stationary blades of the same shape as the moving blades are fastened to the casing in which the rotor revolves. The fixed blades guide the steam into the moving blade. Three main forces move a reaction turbine: (1) the reactive force produced on the moving blades as the steam increases in velocity as it expands through the fixed blades. (2) The reactive force produced on the moving blades when the steam changes its direction.

Difference between impulse turbine and reaction turbine

Impulse turbine	Reaction turbine
Complete expansion of steam takes place in the nozzle	Partial expansion of steam takes place in the fixed blades and further expansion takes place in the moving blades.
Blades are symmetrical in shape	Blades are non symmetrical in shape i.e., aerofoil section
The rotor runs at higher speeds	The rotor runs at relatively low speed.
The impulse turbines are used for small power generation plant.	The reaction turbines are used in large power generation plant.
Less floor area is required.(small power plant)	More floor area is required.(Medium and large power plant)
The pressure of steam remains constant from inlet to the outlet of the blade.	The pressure of steam drops from inlet to the outlet of the blade

Lecture 7:

Objective: Introduction to water turbines. Discussion about working of different types of water turbine.

Water turbines

Introduction

Water turbines were developed in the nineteenth century and were widely used for industrial power prior to electrical grids. Now they are mostly used for electric power generation. They harness a clean and renewable energy source.

A hydraulic turbine is a machine, which converts potential energy into mechanical work. It uses the kinetic energy and potential energy of water and sets the rotor in motion by the dynamic action of water flowing from high head.

Classification of hydraulic turbines

The classification of water turbines are as follows.

1. According to the type of energy at inlet
 - i) Impulse turbine
 - ii) Reaction turbine
2. According to the direction of flow of water through the runner
 - i) Tangential flow
 - ii) Radial inward flow
 - iii) Radial outward flow
 - iv) Axial flow
 - v) Mixed flow
3. According to the head under which turbine works
 - i) High head, Impulse turbine Ex: Pelton wheel.
 - ii) Medium head, reaction turbine Ex: Francis turbine.
 - iii) Low head, reaction turbine: Ex: Kaplan turbine.
4. According to the specific speed of the turbine
 - i) Low specific speed turbine, impulse turbine. Ex: Pelton wheel.
 - ii) Medium specific speed, reaction turbine. Ex: Francis turbine.
 - iii) High specific speed, reaction turbine. Ex: Kaplan turbine
5. According to the position of the shaft
 - i) Horizontal shaft.
 - ii) Vertical shaft.

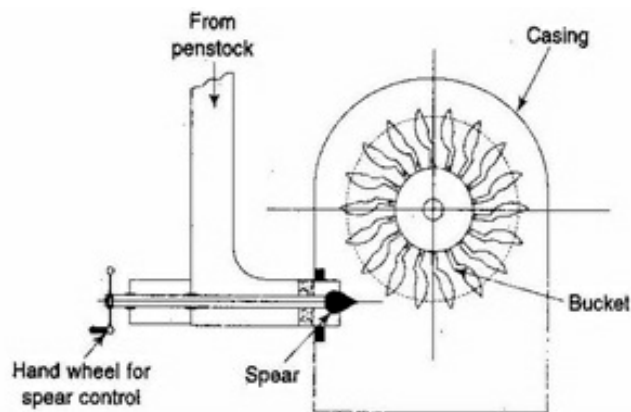
Impulse turbine

In impulse turbine a high-velocity jet of water hits a series of specially shaped cups on the runner. Impulse turbines change the direction of flow of a high velocity fluid or gas jet. The

resulting impulse spins the turbine and leaves the fluid flow with diminished kinetic energy. There is no pressure change of the fluid or gas in the turbine blades (the moving blades), as in the case of a steam or gas turbine, all the pressure drop takes place in the stationary blades (the nozzles). Before reaching the turbine, the fluid's *pressure head* is changed to *velocity head* by *accelerating the fluid with a nozzle*. **Pelton wheels and de Laval turbines use this process exclusively. Impulse turbines do not require a pressure casement around the rotor since the fluid jet is created by the nozzle prior to reaching the blades on the rotor. Newton's second law** describes the transfer of energy for impulse turbines.

Pelton wheel

(High head, tangential flow, horizontal shaft, impulse turbine)



Working of Pelton Wheel

Pelton wheel, a type of impulse turbine, named after L. A. Pelton who invented it in 1880. Water passes through nozzles and strikes cups arranged on the periphery of a runner, or wheel, which causes the runner to rotate, producing mechanical energy. The runner is fixed on a shaft, and the shaft to a generator transmits the rotational motion of the turbine. Pelton turbines are suited to high head, low flow applications; they are used in storage power stations (dams) with downward gradients above 300 meters.

Lecture 8:

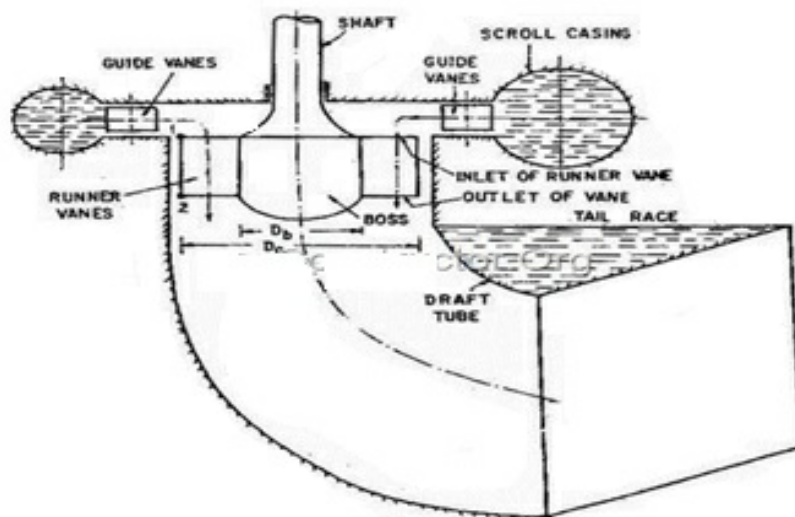
Objective: Discussion about working of reaction types of water turbine.

Reaction turbines

Reaction turbines are acted on by water, which changes pressure as it moves through the turbine and gives up its energy. They must be encased to contain the water pressure (or suction), or they must be fully submerged in the water flow. Newton's third law describes the transfer of energy for reaction turbines. Most water turbines in use are reaction turbines. They are used in low and medium head applications.

Kaplan turbine

The Kaplan turbine is an inward flow reaction turbine, which means that the working fluid changes pressure as it moves through the turbine and gives up its energy. The design combines radial and axial features. The inlet is a scroll-shaped tube that wraps around the turbine's wicket gate (guide vanes). Water is directed tangentially, through the guide vanes, and spirals on to a propeller shaped runner, causing it to spin. The outlet is a specially shaped draft tube that helps decelerate the water and recover kinetic energy. The turbine does not need to be at the lowest point of water flow, as long as the draft tube remains full of water. Variable geometry of the guide vanes and turbine blades allow efficient operation for a range of flow conditions. Kaplan turbine efficiencies are typically over 90%, but may be lower in very low head applications.



Kaplan Turbine.

Comparison of impulse and reaction water turbines

Impulse Turbine	Reaction Turbine
Available energy is completely converted in to kinetic energy in the nozzle	The available energy is Partially converted in to kinetic energy in the fixed blade and partially in the moving blades
The water comes out from the nozzle and directly impinges on the runner.	In reaction turbine, water first enters the fixed blades and then enters the moving blades.
The pressure of the water flowing from inlet to the outlet of runner remains constant (atmospheric pressure).	The pressure of the water reduces while flowing from inlet to the outlet of runner (less than atmospheric).
Turbine can be installed above the tailrace.	Turbine is submerged in water below tail race.
Casing is provided to prevent splashing of water	Airtight casing is provided to prevent the pressure leakage.
Power developed is mainly due to kinetic energy.	Power developed is partly by change in kinetic energy and partly due to pressure energy.
Impulse turbine requires high head	Reaction turbine requires low head.

