ENERGY RESOURCES

- ***Energy*** is defined *as* the capacity to do work and *power* is *the* rate at which the *energy* is consumed.
- ***Energy resources*** are material objects that contain energy in usable quantities.
- Used *as* a quantitative measure of the motion of matter in its various mutually transformable forms, energy is classified into light, chemical, electrical, nuclear, etc.

•*Energy* resources are classified into ***renewable*** and ***non-renewable*** or *expendable* resources.

• Renewable energy resources are continuously restored by nature. It *is* so named because they recur, are seemingly inexhaustible, and are freely available.

Geothermal, solar, wind, hydro power and oceans are the examples of renewable resources.

The disadvantages of renewable energy resources are intermittence, lack of dependability, and low energy densities.

- The existence of non-renewable energy Source is extremely limited because the process of their *formulation* *(renewal)* needs a very long time (millions of years).
- The process of *formulation* takes a *long* time compared to its exploitation, thus this energy can expire.
- **Non-renewable sources** are classified in to fossil fuels and nuclear fuels. Fossil fuels constitute oil, natural gas and coal which over millions of years are formed and stored within the earth, originate from micro organisms, plants and animals.
- The formulation process of fossil energy sources requires high pressure and high temperature as they exist within the earth.

Comparison between renewable and non-renewable energy Sources

Renewable energy Sources	***Non-renewable energy Sources***
The energy can be renewed within a short time	The energy cannot regenerated on a human time scale
The energy sources can not be exhausted and are freely available	The energy sources are exhaustible
It is clean energy or 'green power' and does not produce harmful pollution to environment	Hazardous to environment
Low energy density and lack of dependability	High energy density and highly reliable
High initial investment & low maintenance cost	Initial & maintenance costs are high
Examples: **Solar, wind, tidal, hydel & geothermal energy**	***Examples:*** **Coal, petroleum, natural gas and** ***uranium***

- Another way of classifying the energy sources is *conventional* and *non-conventional* energy sources.
- Fossil fuels, hydro and nuclear energies are ***conventional.***
- Whereas direct solar energy, tidal, geothermal, wind energy, and ocean thermal energy are ***non-conventional.***

Comparison between conventional and non-conventional energy Sources

conventional energy Sources	***Non-conventional energy Sources***
They are widely used and are hazardous to environment	They are rarely used and environmentally clean sources of energy
Most of the energy sources are exhaustible	Inexhaustible energy sources
High extraction cost and are reliable	Freely available and not reliable
***Examples:* hydel, nuclear, fossil fuels**	***Examples:* Solar, wind, tidal, & geothermal energy**

CONVENTIONAL ENERGY SOURCES

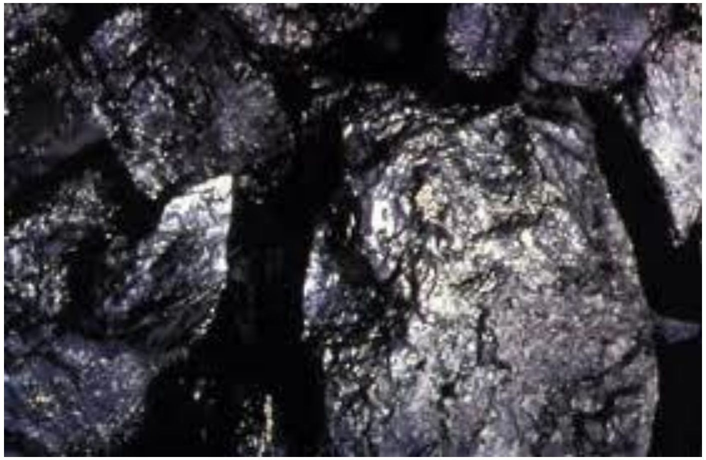
1. Fossil fuels (Coal, Petroleum)
2. Hydro energy
3. Nuclear energy

FOSSIL FUELS

Fossil fuels are fuels formed by natural processes such as anaerobic decomposition (*microorganisms break down biodegradable material in the absence of oxygen*) of buried dead organisms.

The age of the organisms and their resulting fossil fuels is typically millions of years and sometimes exceeds 650 million years.

The fossil fuels, which contain high percentages of carbon, include ***coal, petroleum, and natural gas.***

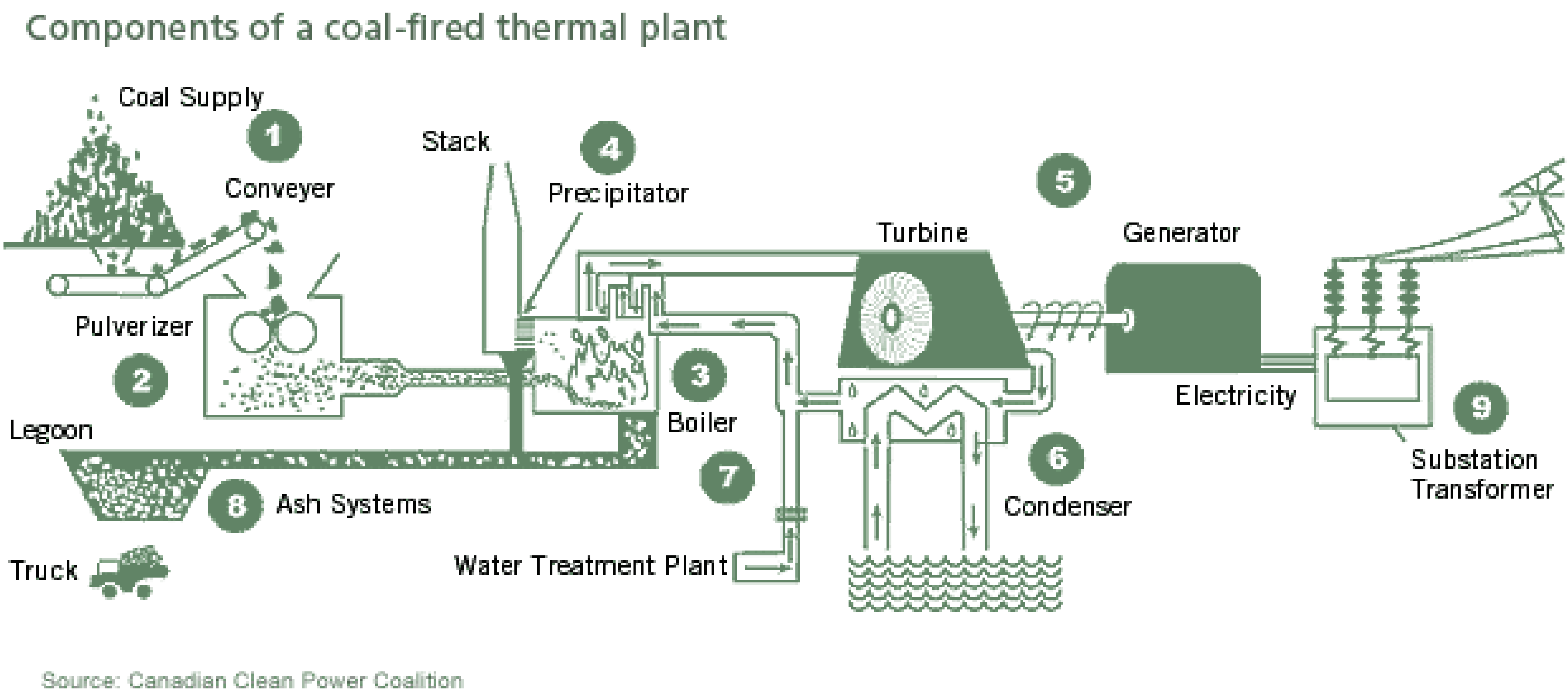


Coal

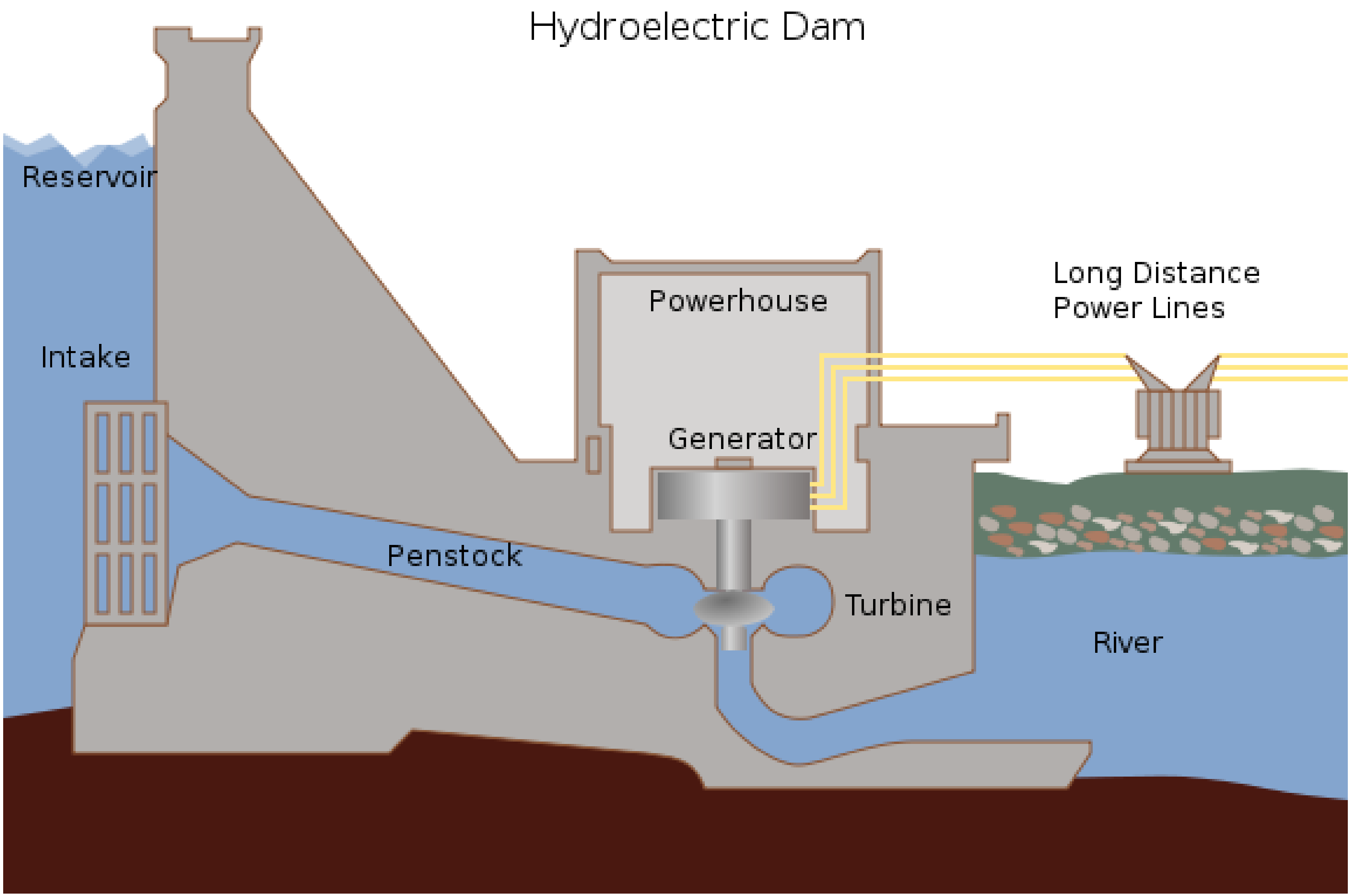
Bituminous Coal

Anthracite Coal

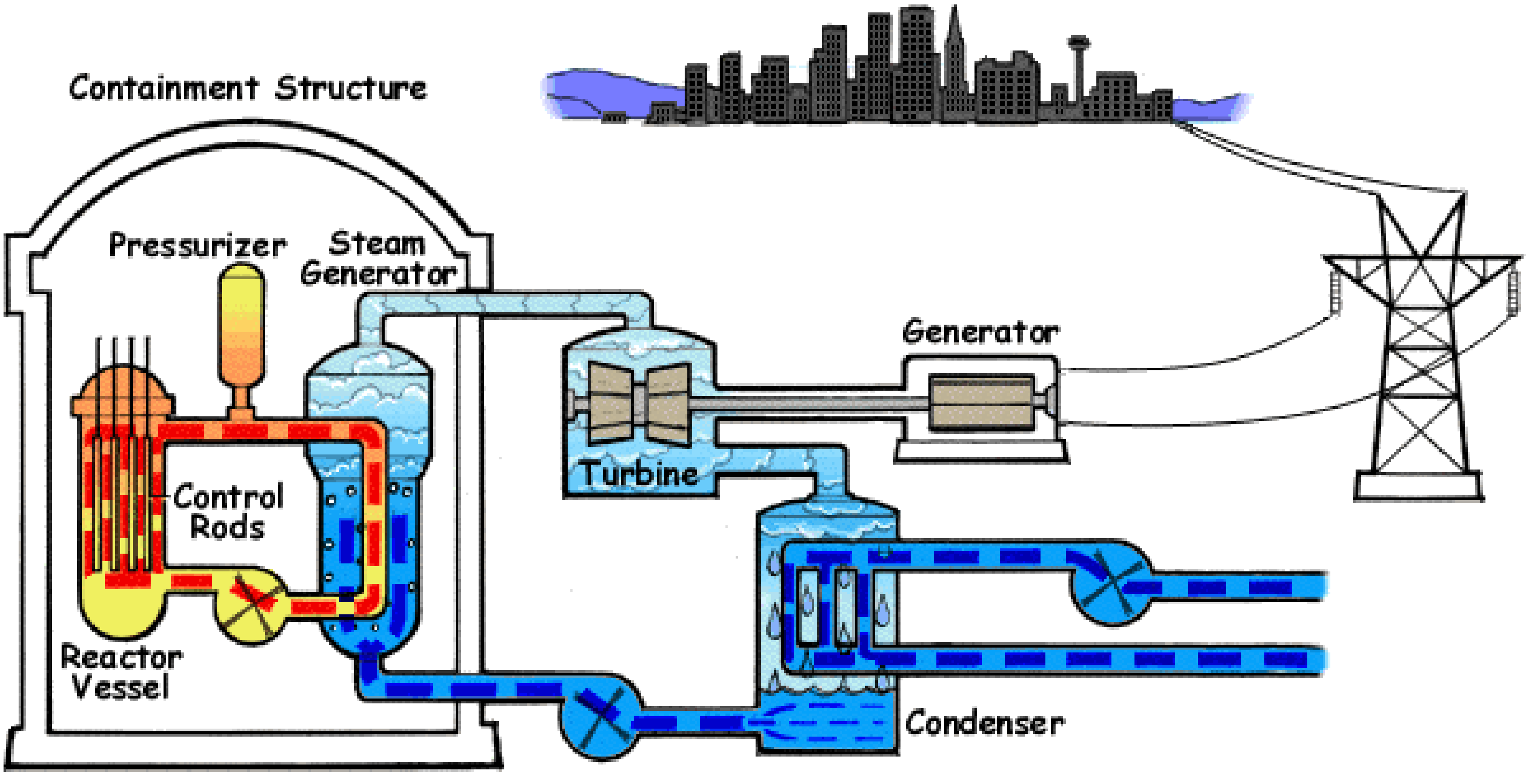
Coal Fired Thermal Power Plant



Hydro Energy

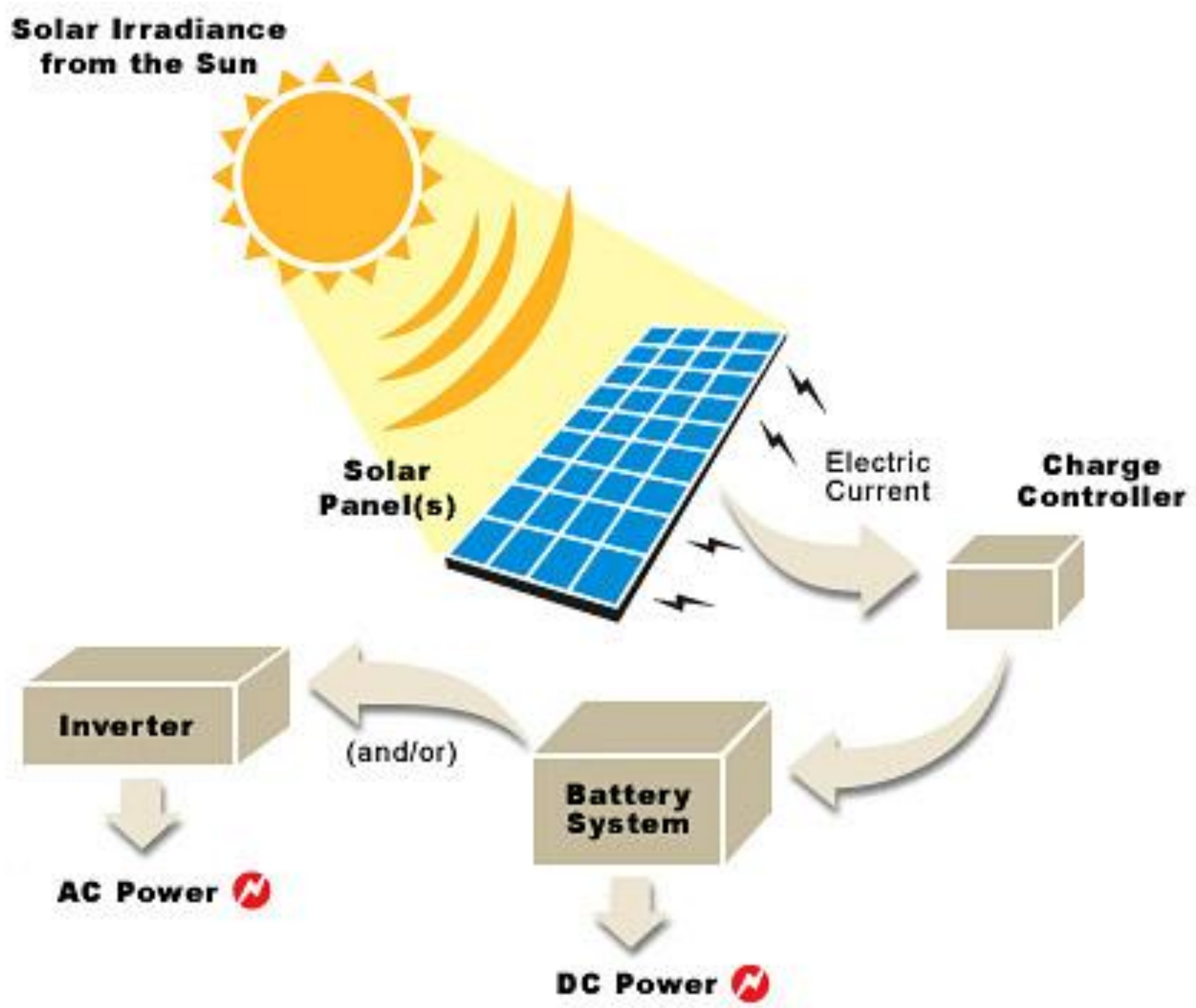


Nuclear Energy

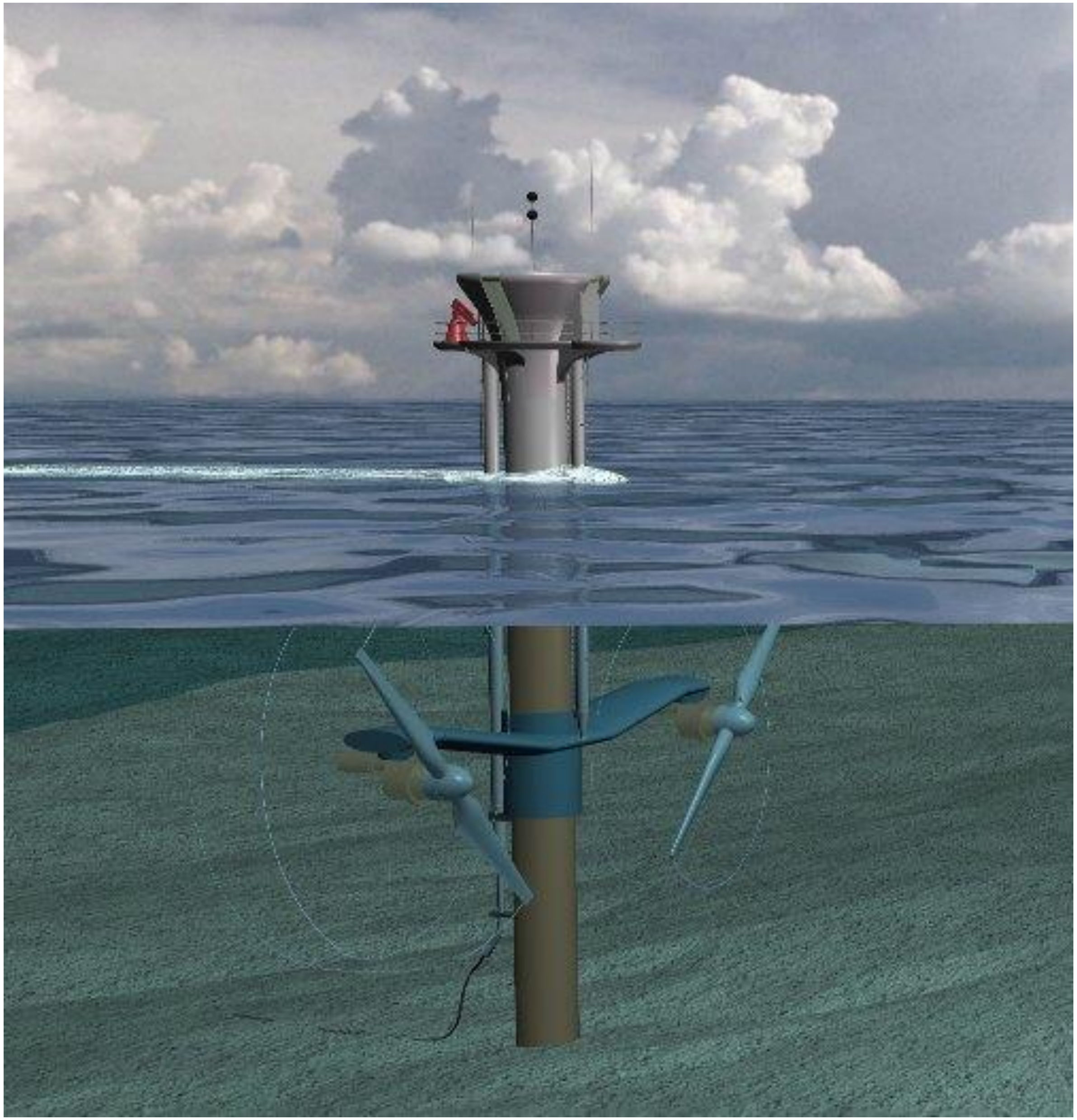


NON CONVENTIONAL ENERGY SOURCES

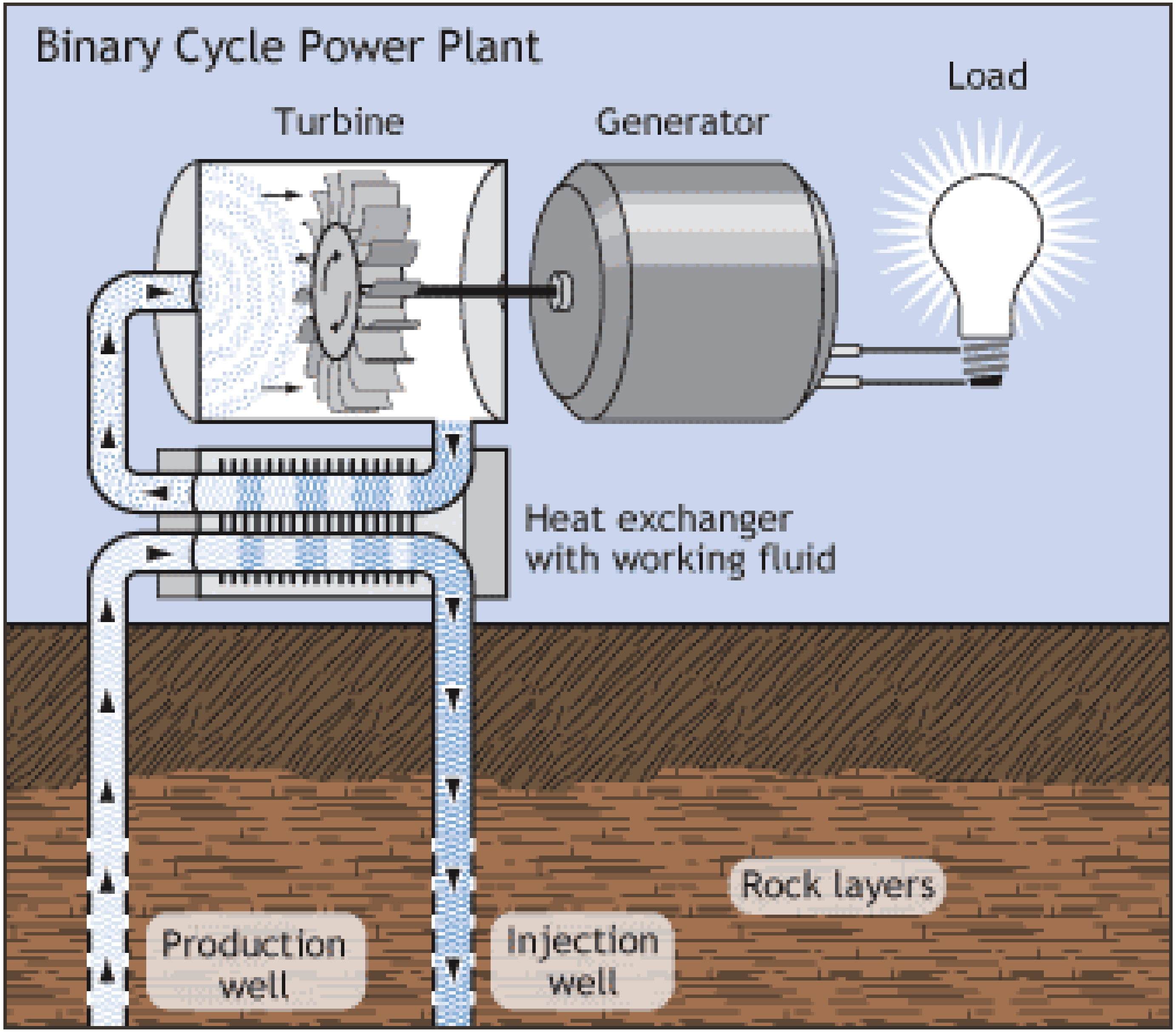
1. Solar
2. Tidal
3. Geothermal
4. Wind
5. Ocean thermal



Solar Energy

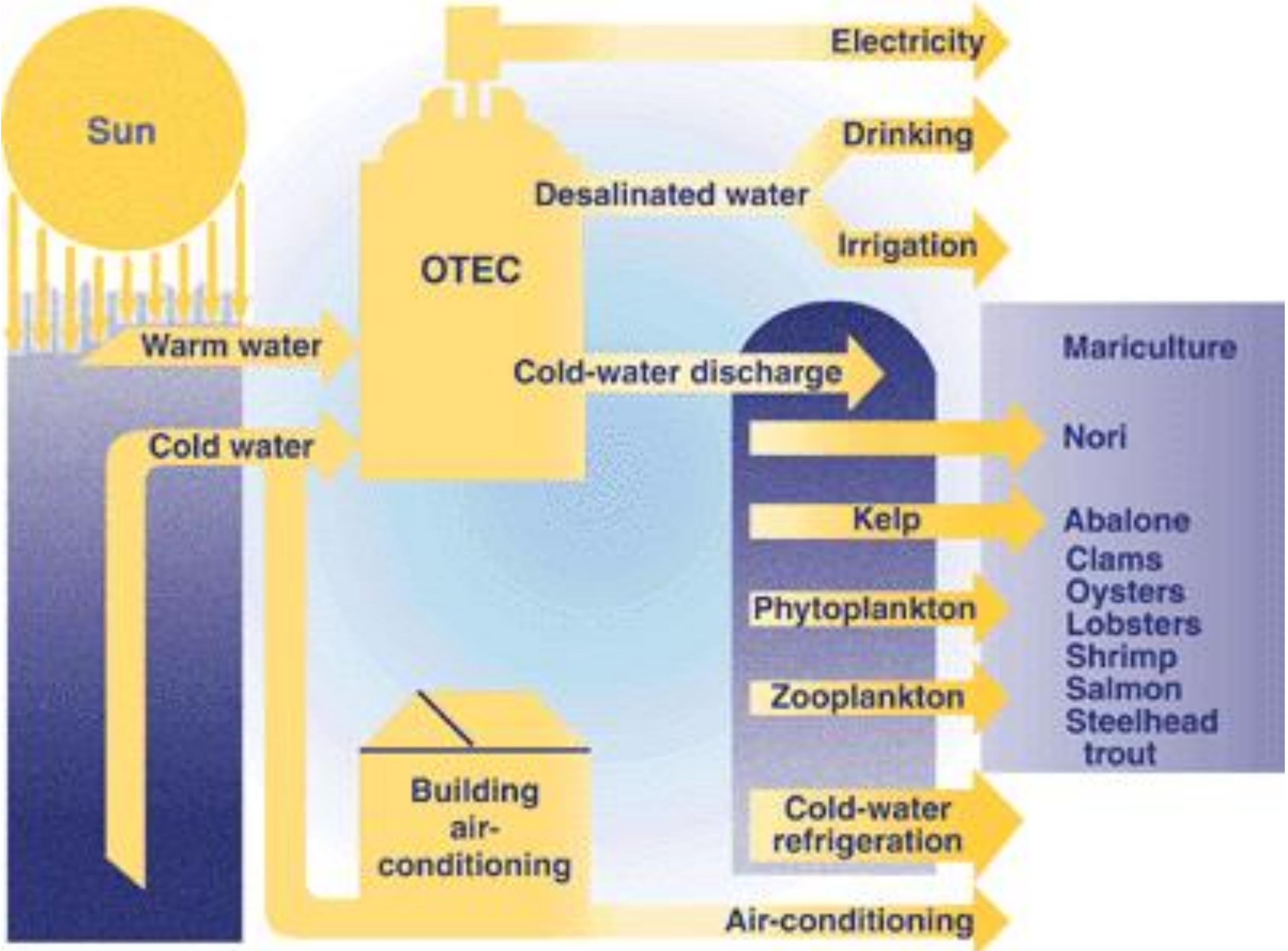


Tidal Energy



Geothermal Energy

Wind Energy



Ocean Thermal Energy

Steam & its properties

A ***vapour*** is partially evaporated liquid carrying particles of liquid in it.

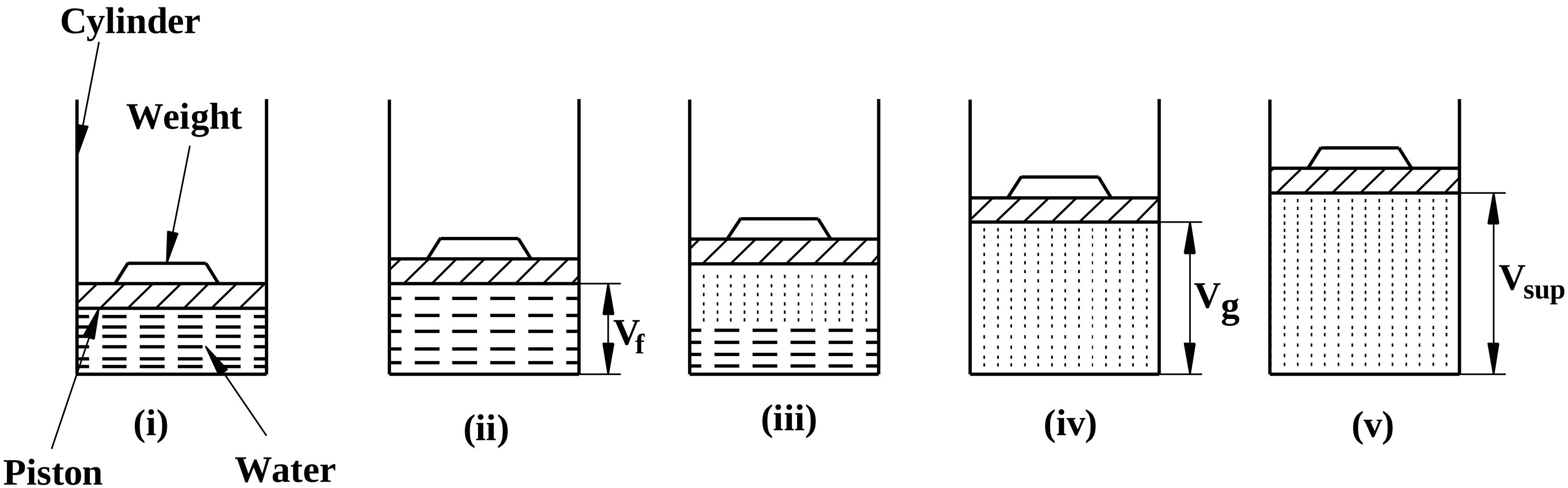
Vapours do not obey gas laws but at high temperatures and low pressures their behaviors are very similar to gases.

Steam is a vapour of water and is generated by supplying heat to water. Steam is most widely used as heat transport fluid. It is a pure substance and it has high thermal capacity.

Steam is used for heating and as working substance in the steam engines and steam turbines.

Formation of Steam at constant Pressure

The action of heat in the formation of steam from water is illustrated in fig below.



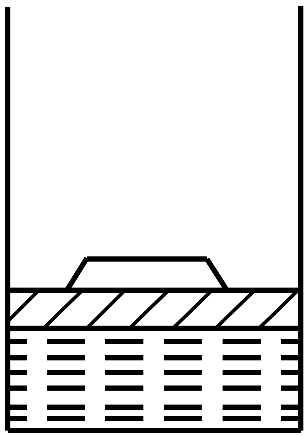
Water at 0°C

Saturated Water

Wet Steam

Saturated Steam

Superheated Steam



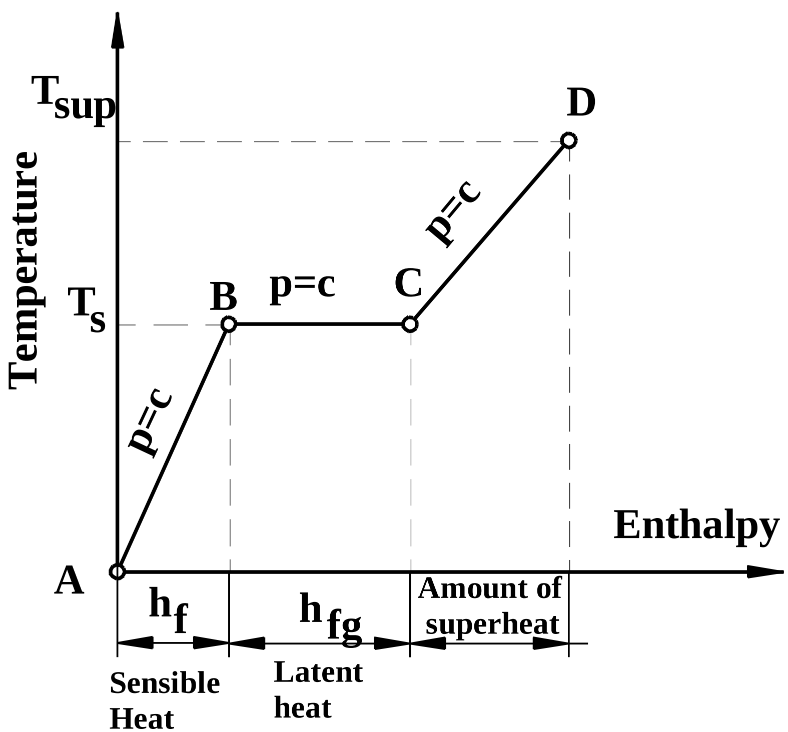
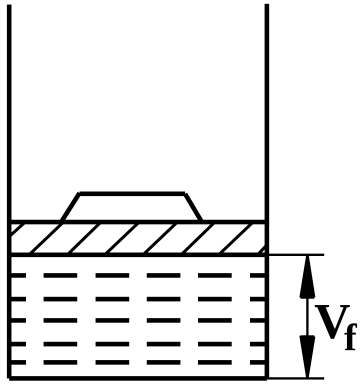


fig. 2

- Consider a cylinder fitted with a piston, which moves freely in it.
- One kilogram of water at 0°C is taken in the cylinder and the piston is loaded by the weight W to ensure constant pressure as shown in fig. (i).

The condition of water at is represented by a point A on the ***temperature-enthalpy*** diagram as shown in fig. 2



(ii)

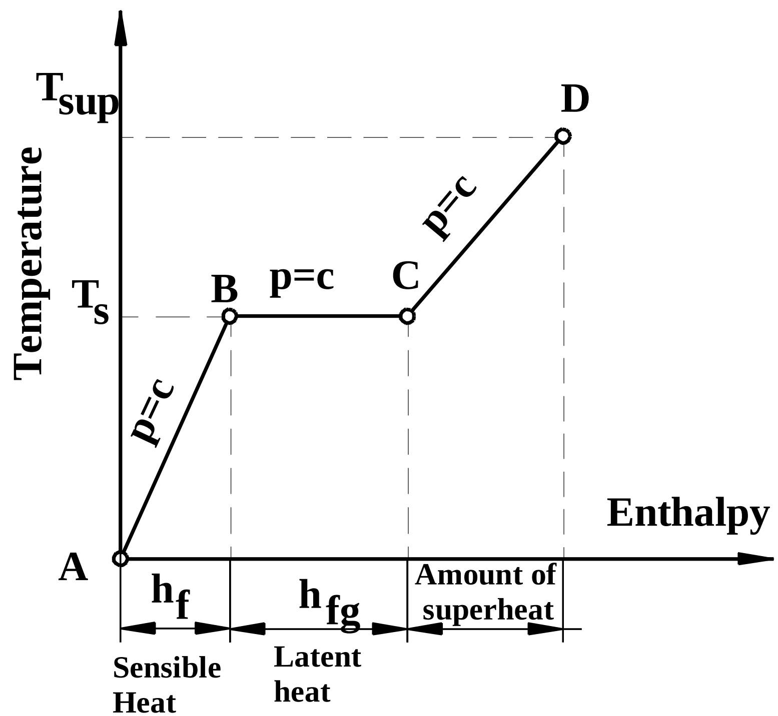
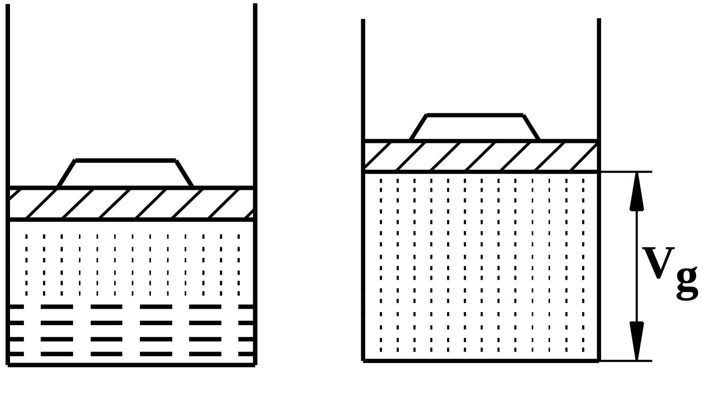


fig. 2

- When the water inside the cylinder is heated, there is a rise in temperature and this rise will continue till boiling point is reached. The temperature at which water starts boiling depends on the pressure acting on it.
- This boiling temperature is known as the temperature of formation of steam or saturation temperature.
- During heating of water up to boiling point there is a slight increase in volume of water as shown in fig. (ii)



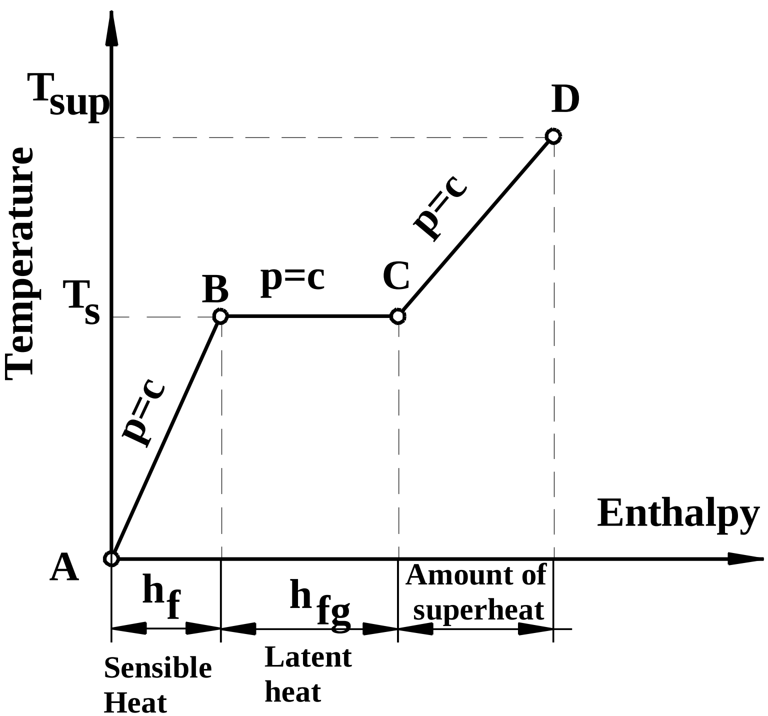
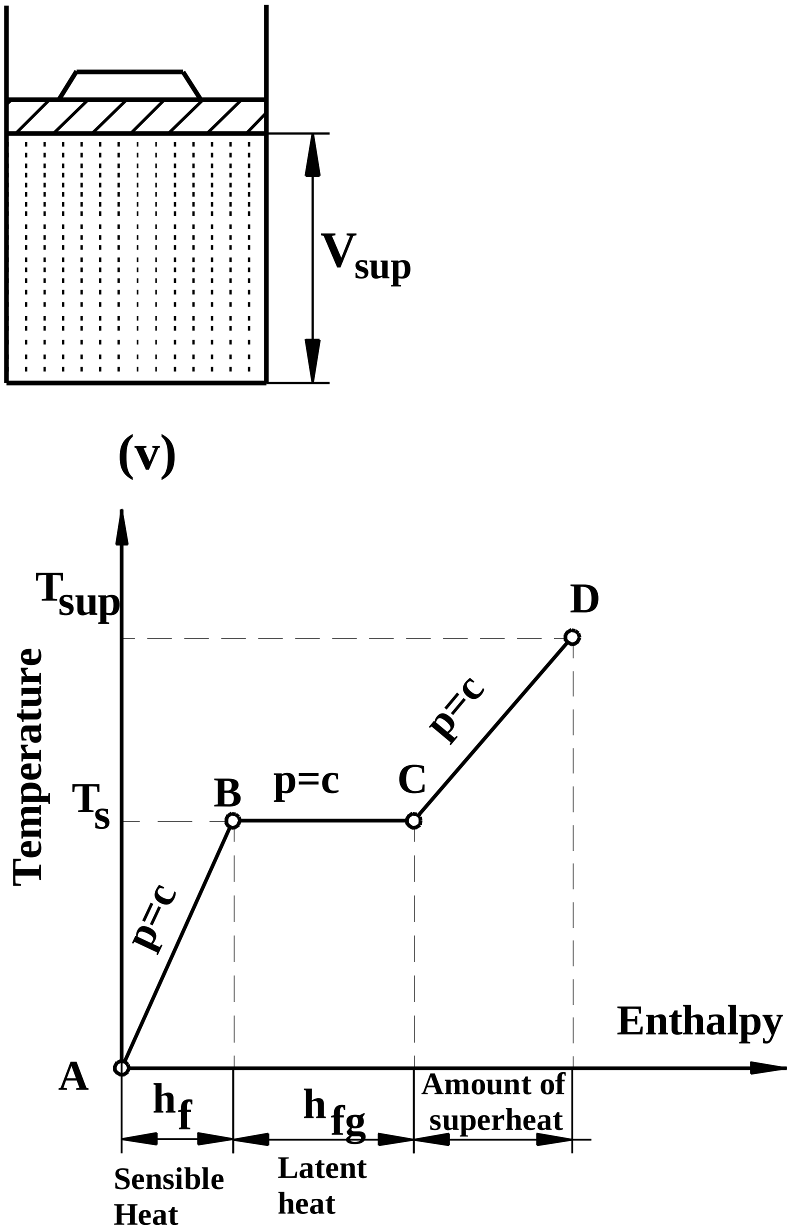


Fig 2

Further addition of heat to water at its saturation point does not cause any further increase of its temperature but there is only a change of state from water to steam until the whole amount of water is converted into steam.

So long as the steam is in contact with water, it is called *wet steam* as in fig. (iii) and if all the water particles associated with steam are evaporated as shown in fig(iv) the steam so obtained is called *dry saturated steam*.

The heating of water at the saturation temperature T_s into dry saturated steam at the same temperature is represented by line BC as shown in fig. 2



- If the dry saturated steam is further heated at constant pressure, its temperature and volume increases as shown in fig(v)
- The steam so obtained is called *superheated steam* which behaves like a prefect gas.
- The process of heating the dry saturated steam is called *super heating* and is represented by the curve CD as shown in fig. 2

Fig 2

Terms related to formation of steam

- *Sensible heat of water h_f :* The amount of heat required to raise the temperature of one kilogram of water from 0^0 C to saturation temperature is defined as ***sensible heat*** *or* ***enthalpy of saturated water.***
- ***Latent heat or hidden heat h_{fg} :*** The amount of heat required to convert one kilogram of water at saturation temperature into dry saturated steam at the same temperature and pressure is known as ***latent heat of evaporation*** or ***enthalpy of evaporation.***

Terms related to formation of steam

- ***Enthalpy of dry saturated steam h_g:***

  The amount of heat required to raise the temperature of one kilogram of water from 0^0 C to the saturation temperature, and to convert it into dry saturated steam at that temperature is known as ***enthalpy of dry saturated steam***. Thus the enthalpy of dry saturated steam is the sum of sensible heat and latent heat i.e., $h_g = h_f + h_{fg}$

Condition of steam

Steam may exist in any of the following conditions:

- Wet steam
- Dry saturated steam and
- Superheated steam

Wet steam: Steam which is generated when in contact with the water surface is ***wet steam***, as some of the water particles may leave the water surface and so it is a mixture of steam and water particles. The temperature of wet steam is equal to the saturation temperature.

Dryness fraction:

The quality of wet steam is indicated by dryness fraction. *Dryness fraction* is defined as the ratio of the mass of dry steam actually present to the mass of wet steam containing it.

In a sample of wet steam, let m_g = Mass of dry steam in kg

m_f = Mass of water in suspension in kg

$$\therefore \text{Dryness fraction, } x = \left(\frac{m_g}{m_g + m_f}\right)$$

Also, ***enthalpy of wet steam***

$$\mathbf{h} = \mathbf{h_f} + \mathbf{xh_{fg}}$$

Dry saturated steam : If saturated steam contains no water particles at its saturation temperature, it is called ***dry saturated steam***.

For dry saturated steam the dryness fraction is equal to ***unity or 1.***

$$\text{Hence,}\ \boldsymbol{\mathit{enthalpy\ of\ \ dry\ saturated\ steam}}$$

$$\mathbf{h_g = h_f + h_{fg}}$$

Superheated steam :

- If the temperature of steam is raised above the saturation temperature, then it is called *superheated steam.*
- Steam is generally superheated at constant pressure. Let T_{sup} be the temperature of the superheated steam and T_s its saturation temperature, then $(T_{sup}-T_s)$ is called ***degree of superheat.***
- The enthalpy of superheated steam is equal to the sum of the sensible heat, latent heat and amount of superheat.

Hence, ***enthalpy of superheated steam***

$$h_{sup} = h_g + C_{ps}(T_{sup} - T_s) \ \mathbf{kJ/kg}$$

OR

$$h_{sup} = h_f + h_{fg} + C_{ps}(T_{sup} - T_s) \ \mathbf{kJ/kg}$$

where C_{ps} is the specific heat of superheated steam at constant pressure, $\mathrm{KJ/Kg^0K}$

Advantages of superheated steam:

- Its capacity to do work is increased.
- Superheated steam results in an increase in thermal efficiency.

Superheating is done in a super heater, which receives its heat from waste furnace gases, which would have otherwise passed uselessly through the chimney.

Specific volume of steam:

The specific volume of steam is defined as the volume of unit mass of steam at a given temperature and pressure.

Specific volume of wet steam: If the steam has a dryness fraction of *x,* then 1 kg of this steam will contain *x* kg of dry steam and (1- *x)* kg of water. If v_f is the volume of 1 kg of water in m^3 and v_g is the volume of 1 kg of perfect dry steam in m^3 then

Vol of 1 kg of wet steam = Vol of dry steam + Vol of water

i.e. $v = xv_g + (1-x)v_f$

The value of V_f at low pressures is very small and is generally neglected.

Thus in general, the volume of 1 kg of wet steam or the specific volume of wet steam

$V = xv_g$ m^3/kg

Specific volume of dry saturated steam:

The specific volume V_g of dry saturated steam is the volume occupied by 1 kg of dry saturated steam.

Density of dry saturated steam $\rho = 1/v_g$ kg/m^3

Specific volume of superheated steam:

The specific volume of superheated steam is defined as the volume occupied by 1 kg of superheated steam at a given pressure and superheated temperature and is denoted by v_{sup}

As superheated steam behaves like a perfect gas, its volume can be determined in the same way as the gases.

Specific volume of superheated steam:

Let

v_g = Specific volume of dry saturated steam at pressure p

T_s=Saturation temperature at pressure p

T_{sup}=Superheat temperature

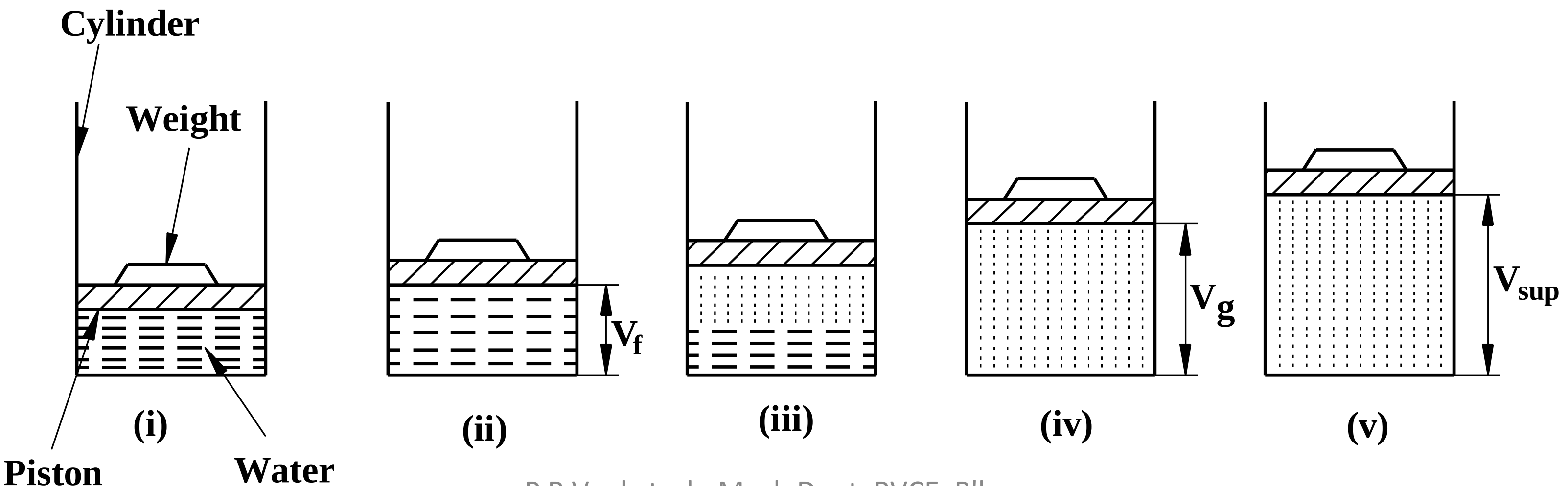
v_{sup}=Specific volume of superheated steam at pressure p

From Charles law,

$$\frac{v_g}{T_s} = \frac{v_{sup}}{T_{sup}} \Rightarrow v_{sup} = v_g\left(\frac{T_{sup}}{T_s}\right)$$

External work of Evaporation

- When heat is supplied at constant pressure to water at saturation temperature, it not only changes the phase of water to vapour (dry saturated steam) but also does an external work in moving the piston due to increase in volume.
- The fraction of latent heat of vapourization which does an external work is called ***external work of evaporation.***



External work of Evaporation

External work of evaporation per kg of dry saturated steam

$$=p(v_g - v_f) \text{ KJ/Kg}$$

At low pressures, v_f is very small & hence can be neglected,

$\therefore$ External work of evaporation per kg of dry saturated steam

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

External work of evaporation per kg of wet steam

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

where x = dryness fraction (or quality) of steam.

External work of evaporation per kg of superheated steam

$$=pv_{\text{sup}} \text{ KJ/Kg}$$

Internal Energy of Steam

- The ***actual energy*** stored in the steam is called '***internal energy'***
- *It may be defined as the difference between the enthalpy of steam and the external work of evaporation.*
- *It is denoted by **'u'***

Internal energy of dry saturated steam $u_g = h_g - pv_g$ KJ/Kg

Internal energy of wet steam $u = h_f + xh_{fg} - pxv_g$ KJ/Kg

Internal energy of superheated steam $u_{\sup} = h_{\sup} - pv_{\sup}$ KJ/Kg

STEAM TABLES

- Generally, the properties of steam which are likely to be used are ***Pressure, Saturation temperature, Specific volume, enthalpy, etc***.
- These properties have been determined experimentally at various pressures and tabulated in a table known as ***Steam Table***.
- The tabulations in steam tables may be on the ***pressure basis*** OR on the ***temperature basis.***

SATURATED WATER & STEAM TABLES (Pressure Basis)

Absolute Pressure, *bar*	Saturation Temperature ^0C	Specific Enthalpy KJ/Kg			Specific Volume m3/Kg	
		Water	Evaporation	Steam	Water at saturation temperature	Dry Saturated steam
p	T_S	h_f	h_{fg}	h_g	v_f	v_g

SATURATED WATER & STEAM TABLES (Temperature Basis)

Saturation Temperature ^0C	Absolute Pressure, *bar*	Specific Enthalpy KJ/Kg			Specific Volume m^3/Kg	
		Water	Evaporation	Steam	Water at saturation temperature	Dry Saturated steam
T_S	p	h_f	h_{fg}	h_g	v_f	v_g

Problem 1

Find the enthalpy of 1 kg of steam at 12 bar when;

(a) Steam is dry saturated

(b) Steam is 22% wet

(c) Superheated to 250^{0}C.

Use the steam tables. Assume the specific heat of superheated steam as 2.25 KJ/Kg-K

Data :

$$\boldsymbol{p = 12\ bar, T}_{\text{sup}} = 250^0 C,\ \text{C}_{ps} = 2.25 KJ / Kg^0 K$$

Solution :

From the steam tables at 12 bar,

the following values are noted

$$\text{T}_s = 188^0\text{C},\ \ \text{h}_\text{f} = 798.64 \text{ KJ/Kg}$$

$$\text{h}_{\text{fg}} = 1986.19 \text{ KJ/Kg},\ \text{h}_\text{g} = 2784.83 \text{ KJ/Kg}$$

Solution :

(a) ***Enthalpy of dry saturated steam*** $h_g = \mathbf{2784.83\,KJ/Kg}$

(OR)

$$h_g = h_f + h_{fg} \Rightarrow h_g = 798.64 + 1986.19 = \mathbf{2784.83\,KJ/Kg}$$

(b) ***Enthalpy of wet steam when steam is 22% wet***

22% wet $\Rightarrow$ the steam is 78% dry

$\Rightarrow$ ***Dryness fraction x = 0.78***

$$\therefore h = h_f + xh_{fg} = 798.64 + (0.78) \times 1986.19$$

$$h = \mathbf{2347.87\,KJ/Kg}$$

(c) *Enthalpy of superheated steam*

$$h_{sup} = h_g + C_{ps}(T_{sup} - T_s)$$

$$\Rightarrow \quad h_{sup} = 2784.83 + 2.25(250 - 188)$$

$$h_{sup} = 2924.33 KJ/Kg$$

Problem 2

Find the enthalpy required to produce 5 Kg of dry saturated at 6 bar from water at 30^0C. The specific heat of water at C_{pw}=4.18 KJ/Kg-K

Data :

$$\text{m=5 kg}, \boldsymbol{p = 6\ bar}, \boldsymbol{T} = 30^0 C,$$

$$C_{pw} = 4.18 KJ / Kg\text{-}K,$$

Solution :

From the steam tables, at a pressure of 6 bar, the following values are noted

$$T_s = 158.85^0 \text{C}, \quad h_f = 670.54 \text{ KJ/Kg}$$

$$h_{fg} = 2085.16 \text{ KJ/Kg}, \ h_g = 2755.70 \text{ KJ/Kg}$$

Solution :

Enthalpy required to convert 1 Kg of water

from $30^0 C$ to dry saturated steam $(T_s = 158.85^0 C)$

$$h = C_{pw}(T_s - T) + h_{fg}$$

$$\Rightarrow h = 4.18(158.85 - 30) + 2085.16$$

$$h = 538.593 + 2085.16 = \boldsymbol{2623.753\ KJ / Kg}$$

$\therefore$ ***Enthalpy required for 5 Kg of steam***

$$= 5 \times 2623.573 = \boldsymbol{13118.76\ KJ / Kg}$$

Problem 3

By actual measurement, the enthalpy of a steam sample at $190^{0}C$ is 2500 KJ/Kg. What is the quality of steam?

$$\textbf{\textit{Data :}}\ T_s = 190^0 C,\ h = 2500 KJ/Kg$$

Solution :

From the steam tables at 190^0C,

the following values are noted

$$h_f = 807.61 \text{ KJ/Kg}$$

$$h_{fg} = 1976.8 \text{ KJ/Kg},\ h_g = 2784.41 \text{ KJ/Kg}$$

Solution :

As the given enthalpy h is < h_g,

the steam is in wet condition

We know that $h = h_f + x h_{fg}$

where ***x*** is the dryness fraction of steam

$$\Rightarrow 2500 = 807.61 + x(1976.8)$$

$\therefore$ Dryness fraction or quality of steam ***x = 0.856***

i.e. the steam is 85.6% dry

Problem 4

Steam at 10 bar and dryness 0.98 receives 140 KJ/kg at the same pressure. What is the final state of steam?

Data :

$\boldsymbol{p = 10\ bar,}\ h = 140 KJ/Kg, \quad x = 0.98$

Solution :

From the steam tables, at a pressure of 10 bar, the following values are noted

$T_s = 179.9^0 C, \quad h_f = 762.79 \text{ KJ/Kg}$

$h_{fg} = 2014.29 \text{ KJ/Kg}, h_g = 2777.08 \text{ KJ/Kg}$

Solution :

As the steam is in wet condition (x = 0.98)

Enthalpy of wet steam $h = h_f + xh_{fg}$

$$\Rightarrow h = 762.79 + 0.98(2014.29)$$

$$h = 2736.8 \text{ KJ / kg}$$

When 140 KJ is added, enthalpy becomes

$$h = (2736.8 + 140) = 2876.8 \text{ KJ / kg}$$

Solution :

At 10 bar, the enthalpy of dry saturated steam

$\boldsymbol{h_g} = 2777.08$

As h > h_g, the steam is in superheated state.

Enthalpy of superheated steam

$$h_{sup} = h_g + C_{ps}(T_{sup} - T_s)$$

$$\Rightarrow \quad 2876 = 2777.08 + 2.25(T_{sup} - 179.9)$$

$$\therefore \mathbf{T_{sup}} \quad \mathbf{= 224.22}^0 C$$

Problem 5

One Kg of ***superheated steam*** at 1.5 Mpa contains 3000 KJ of heat energy. Find the superheat temperature. If 500 KJ of heat energy is removed at the same temperature, what is the condition of steam? The specific heat of superheated steam C_{ps}=2.25 KJ/Kg-K

Data :

$$p = 1.5\ MPa = 1.5 \times 10^{6}\ Pascals = 1500\ Kpa$$

$$\Rightarrow p = 15\ \ bar\ (1\ bar = 100\ KPa)$$

$$h_{sup} = 3000 KJ/Kg,\ \ C_{ps} = 2.25 KJ/Kg$$

Solution :

From the steam tables, at a pressure of 15 bar, the following values are noted

$$T_s = 198.29^{0}C,\ \ h_f = 844.6\ KJ/Kg$$

$$h_{fg} = 1945.2\ KJ/Kg,\ h_g = 2789.9\ KJ/Kg$$

Solution :

(a) ***Temperature of superheated steam***

We know that Enthalpy of superheated steam

$$\mathrm{h}_{\mathrm{sup}} = h_g + \mathrm{C}_{\mathrm{ps}}(T_{\mathrm{sup}} - T_s)$$

$$\Rightarrow \quad 3000 = 2789.9 + 2.25(\mathrm{T}_{\mathrm{sup}} - 198.29)$$

$$\therefore \mathrm{T}_{\mathrm{sup}} = 291.66^0 C$$

(b) ***Condition of steam after removing 500 KJ of heat***

When 500 KJ is removed,

the remaining heat is (3000-500)=2500 KJ.

This enthalpy is less than h_g (=2789.9KJ/Kg)

$\Rightarrow$ The condition of steam is ***wet***

$$\therefore h = h_g + xh_{fg}$$

$$2500 = 844.6 + x(1945.2)$$

i.e. Dryness fraction of steam x = 0.85

Problem 6

5 Kg of ***wet steam*** of dryness fraction 0.8, passes from a boiler to a superheater at constant pressure of 1 Mpa Absolute. In the superheater its temperature is raised to 350^0C. Determine the amount of heat supplied in the superheater. The specific heat of superheated steam C_{ps}=2.25 KJ/Kg-K.

Data :

$$p = 1.0\ MPa = 1.0 \times 10^6\ Pascals = 1000\ Kpa$$

$$\Rightarrow p = 10\ \ bar\ (1\ bar = 100\ KPa)$$

$x = 0.8$ C_{pw} =2.25KJ/Kg

Solution :

From the steam tables, at a pressure of 10 bar, the following values are noted

$$T_s = 179.88^0 C,\ \ h_f = 762.61\ KJ/Kg$$

$$h_{fg} = 2013.6\ KJ/Kg,\ h_g = 2776.21\ KJ/Kg$$

$$(a)\ \textbf{Enthalpy of wet steam}$$

$$h = h_f + xh_{fg}$$

$$h = 762.61 + 0.8(2013.6)$$

$$\mathbf{h = 2373.5\ KJ / Kg}$$

$$(b)\ \textbf{Enthalpy of superheated steam}$$

$$h_{sup} = h_g + C_{ps}(T_{sup} - T_s)$$

$$h_{sup} = 2776.21 + 2.25(350 - 179.88)$$

$$\mathbf{h_{sup} = 3159\ KJ / Kg}$$

$$(c)\ \textit{Amount of heat supplied in the superheater}$$

$$= (h_{sup} - h) = (3159 - 2373.5)$$

$$= 785.5\ KJ / Kg$$

$$\therefore \textit{For 5 Kg of steam, heat supplied}$$

$$\textit{in the superheater} = 5 \times 785.5$$

$$= 3927.5\ KJ$$

Problem 7

A mixture of saturated water and saturated steam of 250^0C is contained in a closed vessel of 0.1 m^3 capacity. If the mass of saturated water is 2 Kg, find the mass of the steam in the vessel. Also find the pressure, specific volume, dryness fraction and the enthalpy of the mixture.

Data : $\boldsymbol{m}_f = 2kg,\ \mathrm{T}_s = 250^0 C,\ V = 0.1m^3$

Corresponding to a saturation temperature of $250^0 C$, the following properties are noted.

$p = 39.77\ bar, v_f = 0.0012513\ m^3 / Kg$

$v_g = 0.05004\ m^3 / Kg, h_f = 1085.8\ KJ / Kg$

$h_{fg} = 1714.6\ KJ / Kg, h_g = 2800.4\ KJ / Kg$

(a) ***Mass of the mixture***

Volume of Vessel = $m_f v_f + m_g v_g$

$$0.1 = (2 \times 0.0012513) + (m_g \times 0.05004)$$

$$\boldsymbol{m_g = 1.95\ Kg}$$

$\therefore$ Total mass of the mixture

$$\mathrm{m}_g + \mathrm{m}_f = 1.95 + 2 = \boldsymbol{3.95\ Kg}$$

(b) ***Dryness fraction of steam***

$$\boldsymbol{x} = \frac{m_g}{m_f + m_g} = \frac{1.95}{3.95} = \boldsymbol{0.4937}$$

(c) Specific Volume of the mixture

$$v = \frac{Volume}{Mass} = \frac{0.1}{3.95} = \mathbf{0.02531\, m^3 / Kg}$$

(d) Enthalpy of the mixture

$$h = h_f + xh_{fg}$$

$$h = 1085.8 + 0.493(1714.6)$$

$$h = 1931\ KJ / Kg$$

$$\therefore Total\ enthalpy\ \ h_{total} = 3.95 \times 1931$$

$$h_{total} = 7627.45\ KJ$$