UNIT-1 Working Fluid

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Introduction

Thermodynamic can be defined as the science of energy.
It deals with the most basic processes occuring in nature.
Thermodynamics is made up from two greek words:-
1)Thermo:- Hot or Heat
2)Dynamics:- study of matter in motion

System, surroundings and boundary

System: A quantity of matter or a region in space chosen for study.
Surroundings: The mass or region outside the system
Boundary: The real or imaginary surface that separates the system from its surroundings.

Type of system(isolated system)
Isolated system – neither mass nor energy can cross the selected boundary.
Example (approximate): coffee in a closed, well-insulated thermos bottle

Closed system – only energy can cross the selected boundary
Examples: a tightly capped cup of coffee, piston cylinder assembly, pressure cooker, motor car battery.

Open system – both mass and energy can cross the selected boundary
Example: an open cup of coffee, boiler.

Properties of a system

Properties of a system is a measurable characteristic of a system that is in equilibrium.
Properties may be intensive or extensive.
Intensive – Are independent of the amount of mass:e.g: Temperature, Pressure, and Density,
Extensive – varies directly with the mass e.g: mass, volume, energy, enthalpy

Specific properties – The ratio of any extensive property of a system to that of the mass of the system is called an average specific value of that property (also known as intensives property)

Control Volume:

- Its a system of fixed volume.
- This type of system is usually referred to as "open system" or a "control volume"
- Mass transfer can take place across a control volume.
- Energy transfer may also occur into or out of the system.
- **Control Surface-** Its the boundary of a control volume across which the transfer of both mass and energy takes place.
- The mass of a control volume (open system) may or may not be fixed.
- When the net influx of mass across the control surface equals zero then the mass of the system is fixed and vice-versa.
- The identity of mass in a control volume always changes unlike the case for a control mass system (closed system).
- Most of the engineering devices, in general, represent an open system or control volume.

Example:

Heat exchanger - Fluid enters and leaves the system continuously with the transfer of heat across the system boundary.

Pump - A continuous flow of fluid takes place through the system with a transfer of mechanical energy from the surroundings to the system.

INTERNAL ENERGY

As we know that internal energy (E) of a system is the energy that the system posses internally and it is the sum of potential and kinetic energy of all its components.

Any change in internal energy produces work and heat. From first law of thermodynamics we know $\Delta E = Q + W$, Where Q is heat supplied to the system and W is the work done to the system. Chemical reaction involves energy (heat) change with the surroundings where either heat is evolved (exothermic reaction) or heat is absorbed (exothermic reaction). To measure this energy changes, chemists usually use a thermodynamic quantity called enthalpy (H). The enthalpy or heat content of a system is defined as

$H = E + PV$ ……………………….(1)

Since E, pressure (P), volume (V) are all state functions, enthalpy is also a state function.

Suppose a system at constant pressure (P) undergoes a chemical change, then enthalpy change ΔH can be written as

$\Delta H = H$ final $-H$ initial $= (E2+PV2) - (E1+PV1) = (E2 - E1) + P(V2-V1)$

$\Delta H = \Delta E+P \Delta V$

$\Delta H = \Delta E-W$.........................(2)

Substituting, $\Delta E = Q_P + W$ in eqn(2)

we get $\Delta H = Q_P$,where Q_P is the heat change at constant pressure. So, the enthalpy change is defined as the heat change at constant pressure. Generally, all chemical reactions occur under constant atmospheric pressure (1 atm pressure) and hence heat change for a chemical reaction is measured in terms of enthalpy.

Enthalpy of a gaseous reaction:
Suppose n_1 moles of reactant gases react to form n_2 moles of gaseous products. The reaction occur at constant temperature and pressure and the volume changes from V_1 to V_2.
We know for ideal gas $PV = nRT$,
then $P(V_2-V_1) = (n_2-n_1)RT$
$P\Delta V = \Delta nRT$ Using first law of thermodynamics we can write $\Delta H = \Delta E + P\Delta V = \Delta E + \Delta nRT$

The first law of thermodynamics:

The total change in internal energy of a system is the sum of the heat added to it and the work done on it. (conservation of energy) Remember: U = Q -W
Qin is positive Qout is negative
W done by the system is positive W done on the system is negative.

The change in internal energy of a system during any thermodynamic process depends only on the initial and final states, not on the path leading from one to the other.

i.e. U is an intrinsic property of the system.

U for an ideal gas

We calculated U for a process at constant volume. But since the internal energy of an ideal gas only depends on temperature, the change in internal energy during any process must be determined only by the temperature change. For an ideal gas, the internal energy change in any process is given by

U = nC$_v$ ΔT whether the volume is constant or not.

What is Pure Substances?

❖ A substance that has a fixed chemical composition throughout is called a **pure substance.**

❖ A pure substance does not have to be of a single chemical element or compound, however. A mixture of various chemical elements or compounds also qualifies as a pure substance as long as the mixture is *homogeneous*.

N_2

AIR

VAPOR

LIQUID
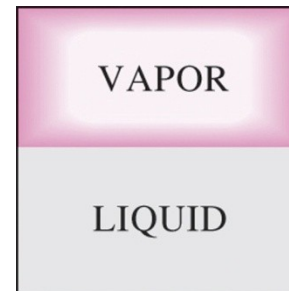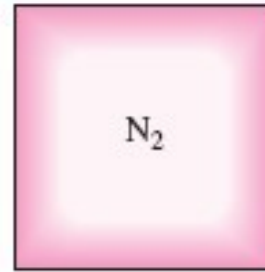
(a) H_2O
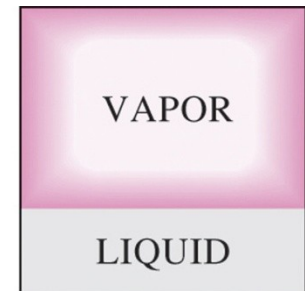
VAPOR

LIQUID

(b) AIR

❖ **A mixture of liquid and water vapor is a pure substance, but a mixture of liquid and gaseous air is not.**

Examples:

❖ Water (solid, liquid, and vapor phases)

❖ Mixture of liquid water and water vapor

❖ Carbon dioxide, CO_2

❖ Nitrogen, N_2

❖ Mixtures of gases, such as air, as long as there is no change of phase.

Phases of A Pure Substance

❖ The substances exist in different phases, e.g. at room temperature and pressure, copper is solid and mercury is a liquid.

❖ It can exist in different phases under variations of condition.

❖ There are 3 Principal phases
  - *solid*
  - *Liquid*
  - *gas*

  Each with different molecular structures.

Phase-change Processes of Pure Substances

❖ There are many practical situations where two phases of a pure substances coexist in equilibrium.

❖ E.g. water exists as a mixture of liquid and vapor in the boiler and etc.

  ❖ Solid: strong intermolecular bond
  ❖ Liquid: intermediate intermolecular bonds
  ❖ Gas: weak intermolecular bond
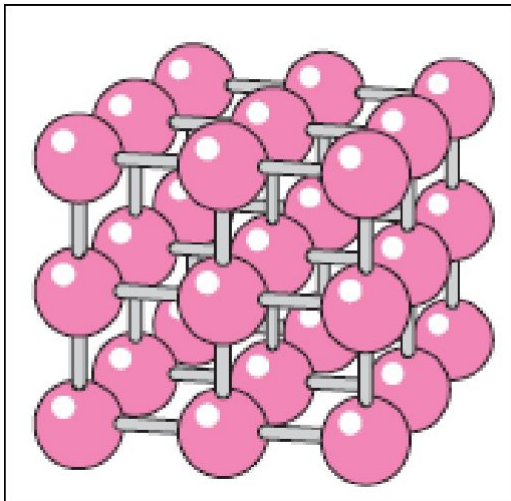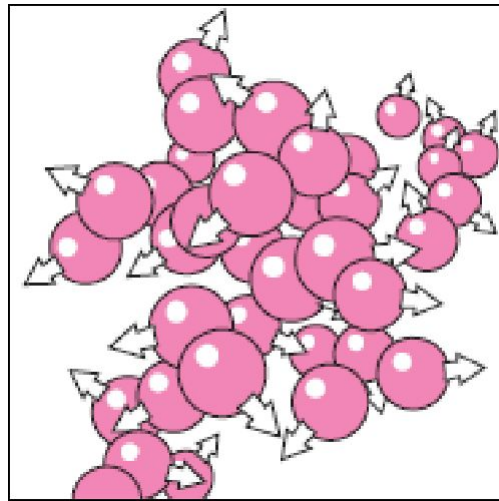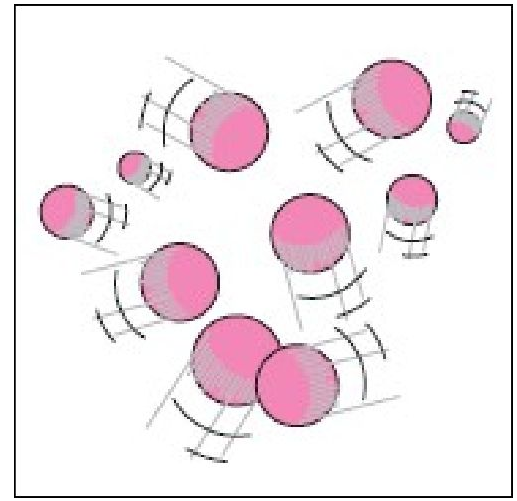
Solid   *Liquid*   *Gas*

Phase-change Processes
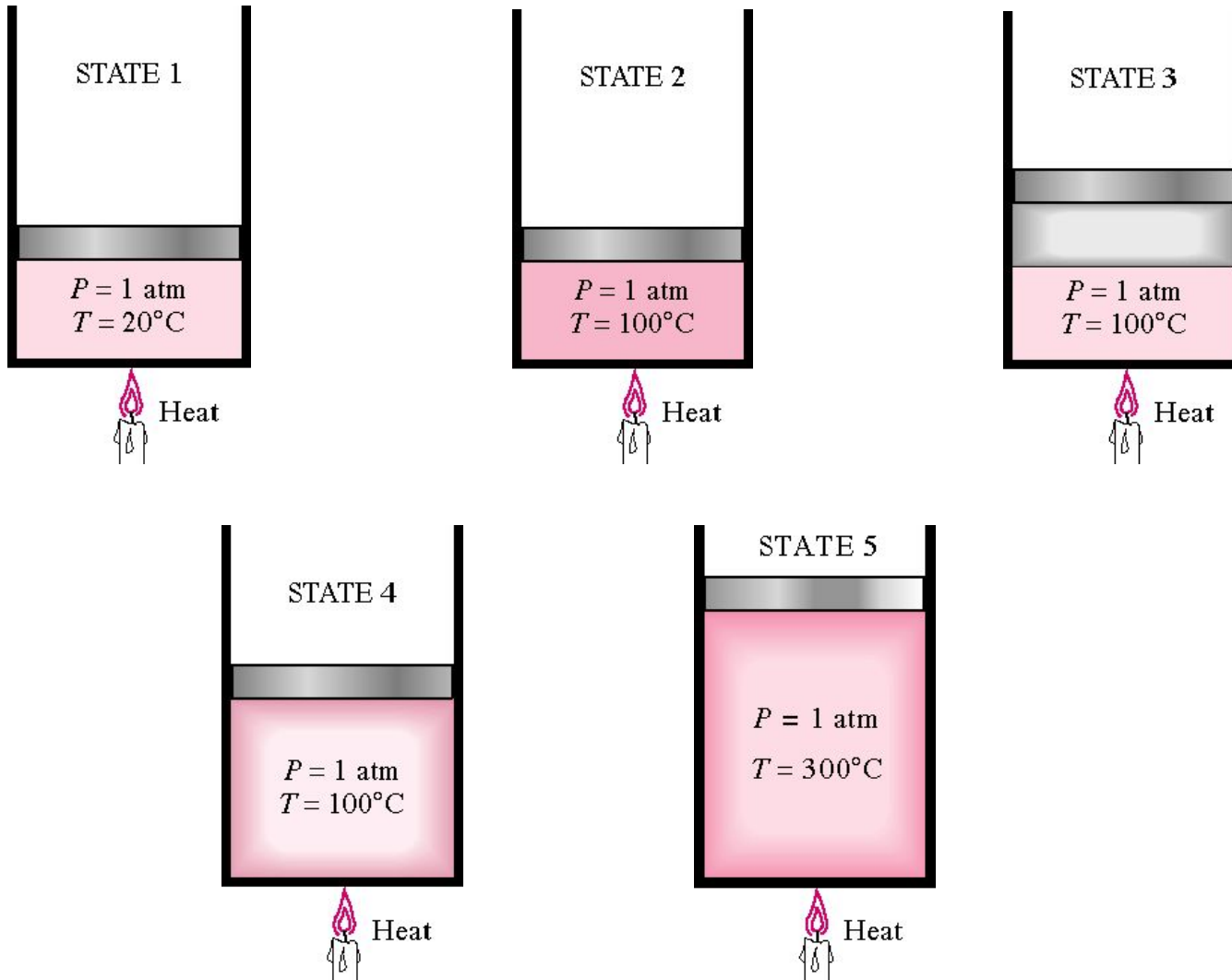
This constant pressure heating process can be illustrated as:
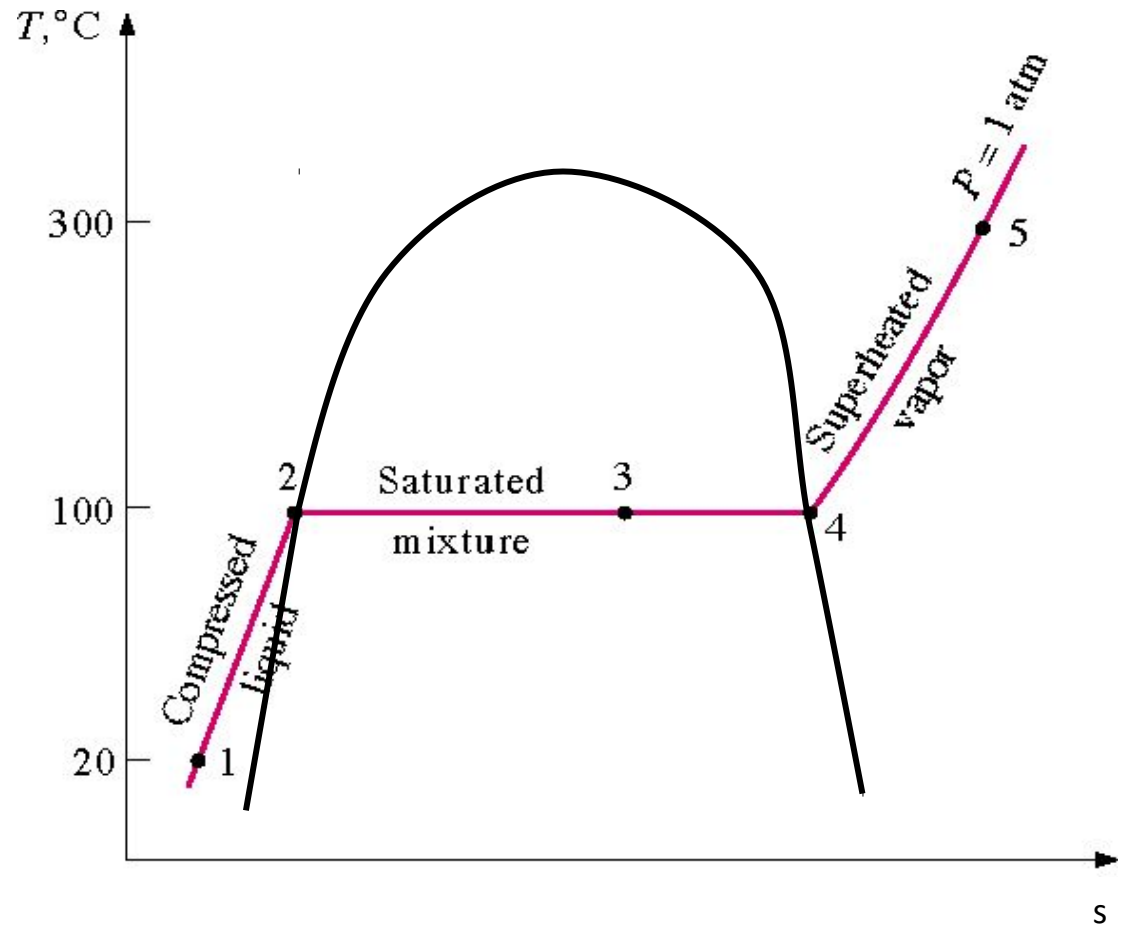
Property Diagram
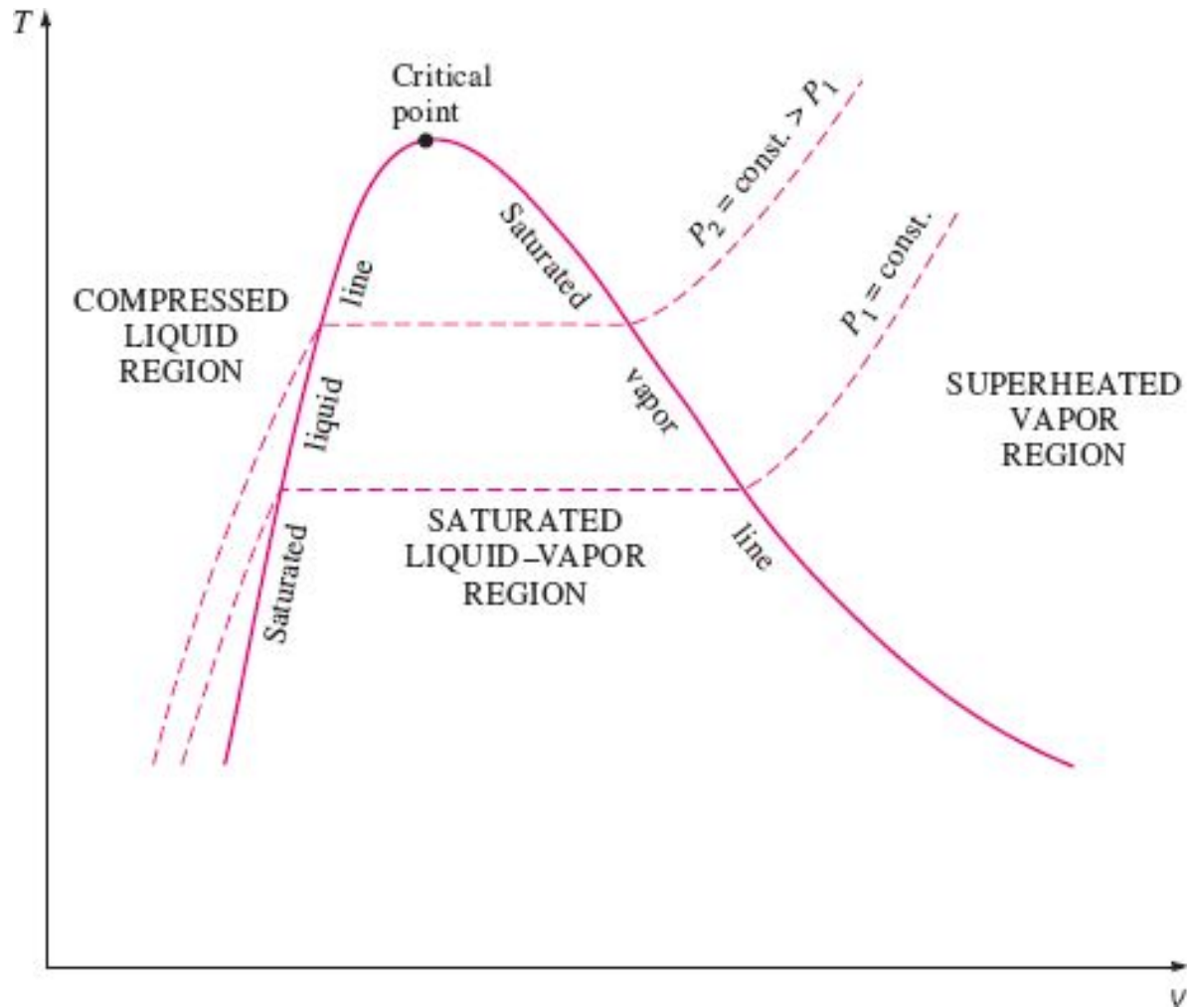
Saturation

❖ *Saturation* is defined as a condition in which a mixture of vapor and liquid can exist together at a given temperature and pressure.

❖ *Saturation pressure* is the pressure at which the liquid and vapor phases are in equilibrium at a given temperature

❖ For a pure substance there is a definite relationship between saturation pressure and saturation temperature. The higher the pressure, the higher the saturation temperature

The graphical representation of this relationship between temperature and pressure at saturated conditions is called the

vapor pressure curve

TABLE 3–1

Saturation (boiling) pressure of water at various temperatures

Temperature, T, °C	Saturation pressure, P_{sat}, kPa
−10	0.26
−5	0.40
0	0.61
5	0.87
10	1.23
15	1.71
20	2.34
25	3.17
30	4.25
40	7.39
50	12.35
100	101.4
150	476.2
200	1555
250	3976
300	8588

Saturated and Sub-cooled Liquids

❖ If a substance exists as a liquid at the saturation temperature and pressure, it is called a *saturated liquid*

❖ If the temperature of the liquid is lower than the saturation temperature for existing pressure, the is either a *subcooled liquid* called or a *compressed liquid*

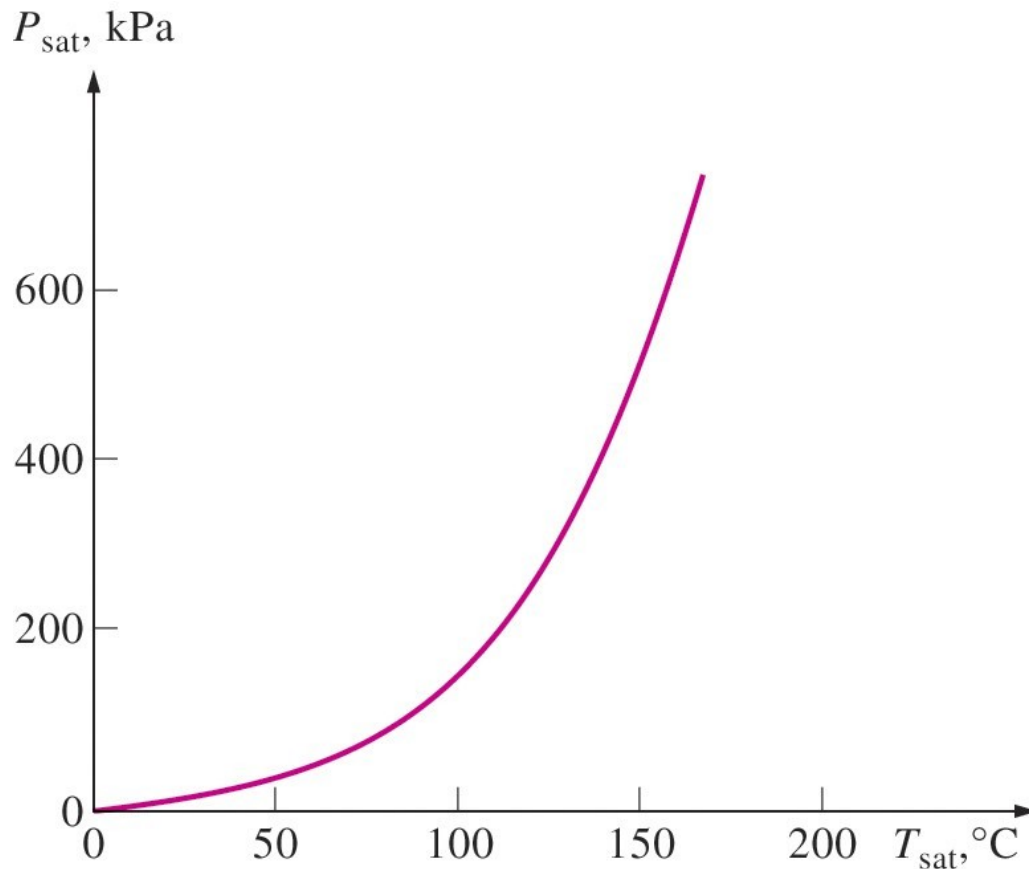**TABLE 3–1**

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300	8588

Saturated and Superheated Vapors

❖ If a substance exists entirely as vapor at saturation temperature, it is called *saturated vapor*.

❖ When the vapor is at a temperature greater than the saturation temperature, it is said to exist as *superheated vapor*.

❖ The pressure and temperature of superheated vapor are independent properties, since the temperature may increase while the pressure remains constant

Latent Heat

❖ **Latent heat**: The amount of energy absorbed or released during a phase-change process.

❖ **Latent heat of fusion**: The amount of energy absorbed during melting. It is equivalent to the amount of energy released during freezing.

❖ **Latent heat of vaporization**: The amount of energy absorbed during vaporization and it is equivalent to the energy released during condensation.

❑ *At 1 atm pressure, the latent heat of fusion of water is 333.7 kJ/kg and the latent heat of vaporization is 2256.5 kJ/kg.*

Quality

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

❖ The quality is zero for the saturated liquid and one for the saturated vapor ($0 \leq x \leq 1$)

❖ For example, if the mass of vapor is 0.2 g and the mass of the liquid is 0.8 g, then the quality is 0.2 or 20%.

$$x = \frac{mass_{\text{saturated vapor}}}{mass_{total}} = \frac{m_g}{m_f + m_g}$$

Quality
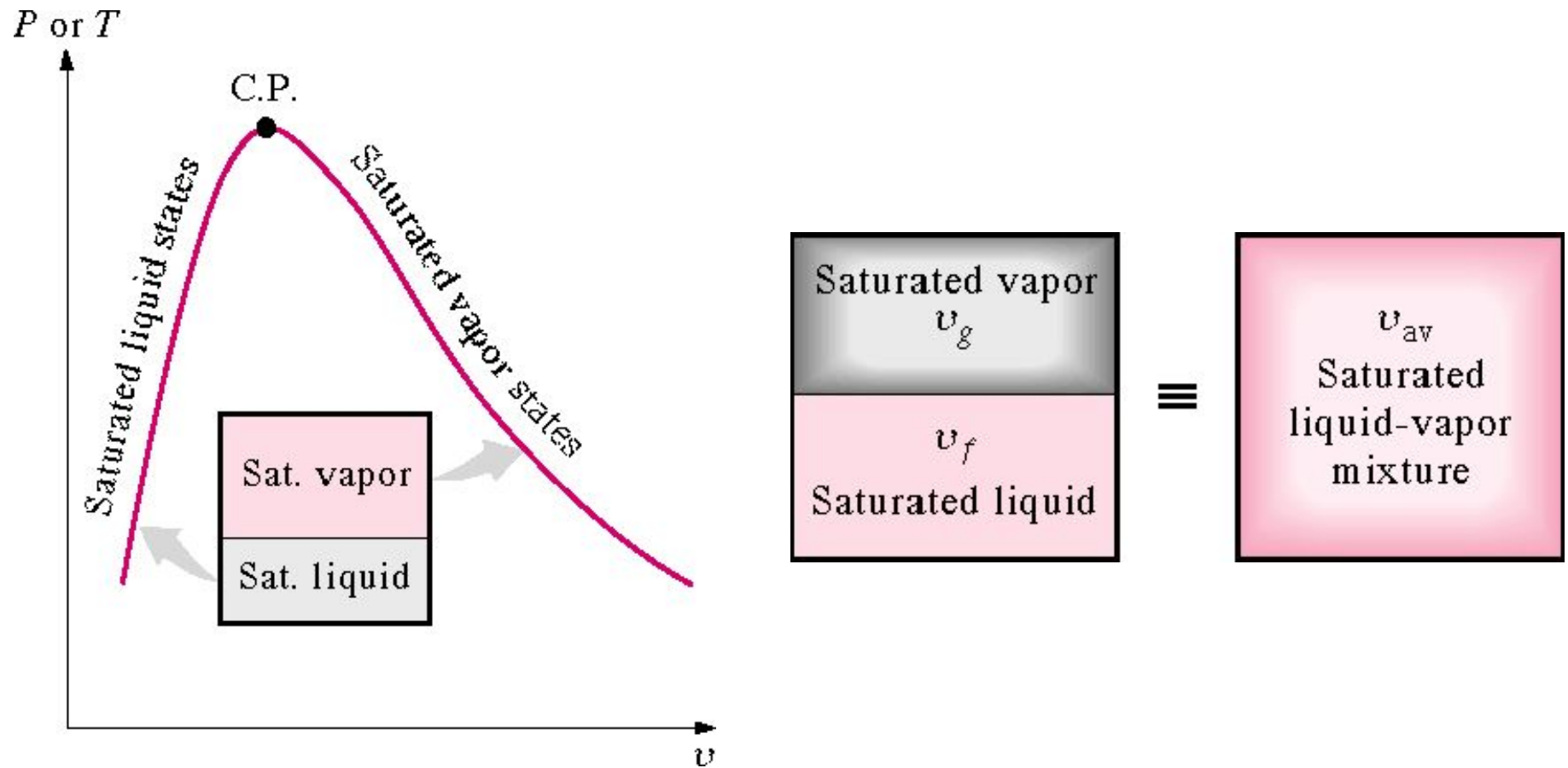
Mixture of liquid and vapor

Moisture Content

❑ The *moisture content* of a substance is the opposite of its quality. Moisture is defined as the ratio of the mass of the liquid to the total mass of both liquid and vapor

❑ Recall the definition of quality x

$$x = \frac{m_g}{m} = \frac{m_g}{m_f + m_g}$$

❑ Then

$$\frac{m_f}{m} = \frac{m - m_g}{m} = 1 - x$$

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Moisture Content

- Take specific volume as an example. The specific volume of the saturated mixture becomes

$$v = (1 - x)v_f + xv_g$$

- The form that is most often used

$$v = v_f + x(v_g - v_f)$$

- Let Y be any extensive property and let y be the corresponding intensive property, Y/m, then

$$y = \frac{Y}{m} = y_f + x(y_g - y_f)$$

$$= y_f + x\,y_{fg}$$

$$where\ y_{fg} = y_g - y_f$$

Property Table

❖ For example if the pressure and specific volume are specified, three questions are asked: For the given pressure,

Temp. °C T	Sat. press. kPa P_{sat}	Specific volume m^3/kg	
		Sat. liquid v_f	Sat. vapor v_g
85	57.868	0.001032	2.8261
90	70.183	0.001036	2.3593
95	84.609	0.001040	1.9808

Specific temperature

Specific volume of saturated liquid

Corresponding saturation pressure

Specific volume of saturated vapor

Property Table

❖ If the answer to the first question is yes, the state is in the compressed liquid, and the compressed liquid table is used to find the properties. (or using *saturation temperature table*)

$$v < v_f$$

❖ If the answer to the second question is yes, the state is in the saturation region, and either the saturation temperature table or the saturation pressure table is used.

$$v_f < v < v_g$$

❖ If the answer to the third question is yes, the state is in the superheated region and the superheated table is used.

$$v_g < v$$

Property Table

Sat. vapor v_g

Sat. liquid v_f

P or T

v_f $\quad$ $v_f < v < v_g$ $\quad$ v_g $\quad$ v
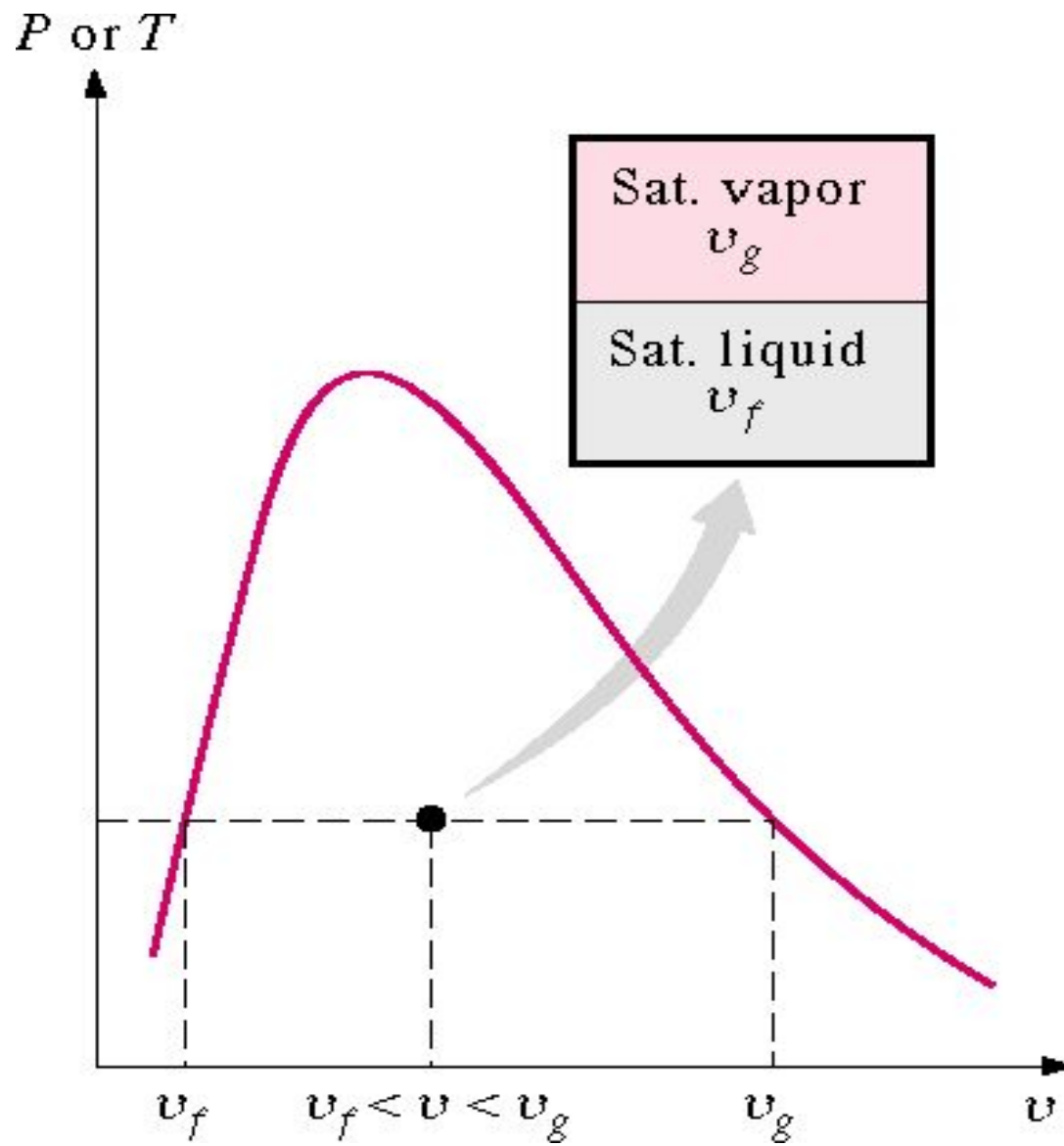
Example 2.1

Determine the saturated pressure, specific volume, internal energy and enthalpy for saturated water vapor at 45°C and 50°C.

Saturated water—Temperature table

Temp., T °C	Sat. press., P_{sat} kPa	Specific volume, m³/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg · K		
		Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
0.01	0.6117	0.001000	206.00	0.000	2374.9	2374.9	0.001	2500.9	2500.9	0.0000	9.1556	9.1556
5	0.8725	0.001000	147.03	21.019	2360.8	2381.8	21.020	2489.1	2510.1	0.0763	8.9487	9.0249
10	1.2281	0.001000	106.32	42.020	2346.6	2388.7	42.022	2477.2	2519.2	0.1511	8.7488	8.8999
15	1.7057	0.001001	77.885	62.980	2332.5	2395.5	62.982	2465.4	2528.3	0.2245	8.5559	8.7803
20	2.3392	0.001002	57.762	83.913	2318.4	2402.3	83.915	2453.5	2537.4	0.2965	8.3696	8.6661
25	3.1698	0.001003	43.340	104.83	2304.3	2409.1	104.83	2441.7	2546.5	0.3672	8.1895	8.5567
30	4.2469	0.001004	32.879	125.73	2290.2	2415.9	125.74	2429.8	2555.6	0.4368	8.0152	8.4520
35	5.6291	0.001006	25.205	146.63	2276.0	2422.7	146.64	2417.9	2564.6	0.5051	7.8466	8.3517
40	7.3851	0.001008	19.515	167.53	2261.9	2429.4	167.53	2406.0	2573.5	0.5724	7.6832	8.2556
45	9.5953	0.001010	15.251	188.43	2247.7	2436.1	188.44	2394.0	2582.4	0.6386	7.5247	8.1633
50	12.352	0.001012	12.026	209.33	2233.4	2442.7	209.34	2382.0	2591.3	0.7038	7.3710	8.0748
55	15.763	0.001015	9.5639	230.24	2219.1	2449.3	230.26	2369.8	2600.1	0.7680	7.2218	7.9898

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Example 2.2

Determine the saturated pressure, specific volume, internal energy and enthalpy for saturated water vapor at 47^0 C .

Saturated water—Temperature table

Temp., T °C	Sat. press., P_{sat} kPa	Specific volume, m³/kg		Internal energy, kJ/kg			Enthalpy, kJ/kg			Entropy, kJ/kg · K		
		Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
0.01	0.6117	0.001000	206.00	0.000	2374.9	2374.9	0.001	2500.9	2500.9	0.0000	9.1556	9.1556
5	0.8725	0.001000	147.03	21.019	2360.8	2381.8	21.020	2489.1	2510.1	0.0763	8.9487	9.0249
10	1.2281	0.001000	106.32	42.020	2346.6	2388.7	42.022	2477.2	2519.2	0.1511	8.7488	8.8999
15	1.7057	0.001001	77.885	62.980	2332.5	2395.5	62.982	2465.4	2528.3	0.2245	8.5559	8.7803
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55	15.763	0.001015	9.5639	230.24	2219.1	2449.3	230.26	2369.8	2600.1	0.7680	7.2218	7.9898

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Solution:

❑ Extract data from steam table

T	P_{sat}	v	u	h
45	9.5953	15.251	2436.1	2582.4
47	P_{sat}	v	u	h
50	12.352	12.026	2442.7	2591.3

❑ Interpolation for P_{sat}

$$\frac{P_{sat} - 9.5953}{12.352 - 9.5953} = \frac{47 - 45}{50 - 45}$$
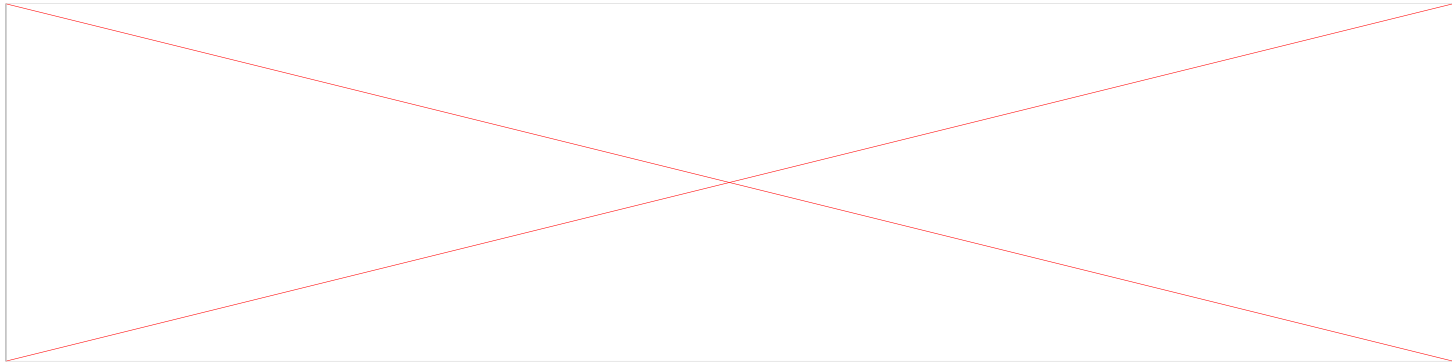
$$P_{sat \,@\, 47^\circ} = 10.698 \; kPa$$

Interpolation Scheme for P_{sat}

❑ Do the same principal to others!!!!

Exercises

1. Fill in the blank using R-134a

2. Determine the saturated temperature, saturated pressure and enthalpy for water at specific volume of saturated vapor at
10.02 m^3/kg .

Example 2.3

Determine the enthalpy of 1.5 kg of water contained in a volume of 1.2 m³ at 200 kPa.

Solution:

❏ Specific volume for water

$$v = \frac{Volume}{mass} = \frac{1.2 \ m^3}{1.5 \ kg} = 0.8 \quad \frac{m^3}{kg}$$

❏ From table A-5:

$$v_f = 0.001061 \ ^{m^3}\!/_{kg}$$
$$v_g = 0.8858 \ ^{m^3}\!/_{kg}$$

Is $v < v_f$? No

Is $v_f < v < v_g$? Yes

Is $v_g < v$? No

❏ Find the quality

$$v = v_f + x(v_g - v_f)$$

$$x = \frac{v - v_f}{v_g - v_f}$$

$$= \frac{0.8 - 0.001061}{0.8858 - 0.001061}$$

$$= 0.903 \ \text{(What does this mean?)}$$

❏ The enthalpy

$$h = h_f + x\, h_{fg}$$

$$= 504.7 + (0.903)(2201.6)$$

$$= 2492.7 \ \frac{kJ}{kg}$$

Example 2.4

Determine the internal energy of refrigerant-134a at a temperature of 0°C and a quality of 60%.

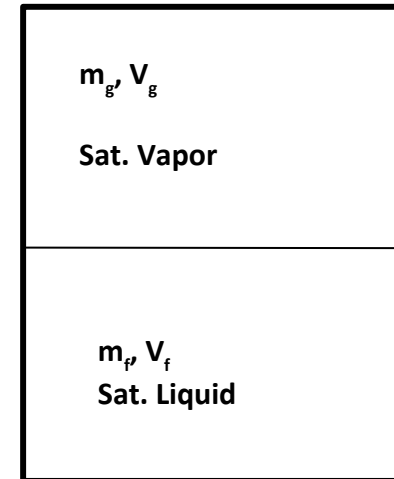*Solution:*

❖ From table A-5:

$$u_f = 51.63 \frac{kJ}{kg}$$

$$u_g = 230.16 \frac{kJ}{kg}$$

❖ The internal energy of R 134a at given condition:

$$u = u_f + x\,(u_g - u_f)$$

$$= 51.63 + (0.6)(230.16 - 51.63)$$

$$= 158.75 \frac{kJ}{kg}$$

Example 2.5

Consider the closed, rigid container of water as shown. The pressure is 700 kPa, the mass of the saturated liquid is 1.78 kg, and the mass of the saturated vapor is 0.22 kg.   Heat is added to the water until the pressure increases to 8 MPa.   Find   the final temperature, and internal energy of   the water enthalpy,

| m_g, V_g |
| Sat. Vapor |
| m_f, V_f |
| Sat. Liquid |

Solution:

❖ Theoretically:

$$v_2 = v_1$$

❖ The quality before pressure increased (*state 1*).

$$x_1 = \frac{m_{g1}}{m_{f1} + m_{g1}}$$

$$= \frac{m_{0.22}}{(1.78 + 0.22)\,kg} = 0.11$$

❖ Specific volume at *state 1*

$$v_1 = v_{f1} + x_1(v_{g1} - v_{f1})$$

$$= 0.001108 + (0.11)(0.2728 - 0.001108)$$

$$= 0.031\ \frac{m^3}{kg}$$

❖ Information :

$$P_2 = 8\ MPa \qquad v_2 = 0.031\ \frac{m^3}{kg}$$

❖ From table A-5:

$$v_{f,2} = 0.001384\ \frac{m^3}{kg}$$

$$v_{g,2} = 0.02352\ \frac{m^3}{kg}$$

$$v_{g\,2} < v_2$$

❖ Since that it is in superheated region, use table A-6:

$$T_2 = 361.8^o C$$

$$h_2 = 3024\ \frac{kJ}{kg}$$

$$u_2 = 2776\ \frac{kJ}{kg}$$

Exercises

1. Four kg of water is placed in an enclosed volume of 1m³. Heat is added until the temperature is 150°C. Find (a) the pressure, (b)the mass of vapor, and (c) the volume of the vapor.

2. A piston-cylinder device contains 0.1 m³ of liquid water and 0.9 m³ of water vapor in equilibrium at 800 kPa. Heat is transferred at constant pressure until the temperature reaches 350°C.
   (a)   what is the initial temperature of the water,
   (b)   determine the total mass of the water,
   (c)   calculate the final volume, and
   (d)show the process on a P-v diagram with respect to saturation lines.

Exercises

3. For a specific volume of 0.2 m³/kg, find the quality of steam if the absolute pressure is (a) 40 kPa and (b) 630 kPa. What is the temperature of each case?

4. Water is contained in a rigid vessel of 5 m³ at a quality of 0.8 and a pressure of 2 MPa. If the a pressure is reduced to 400 kPa by cooling the vessel, find the final mass of vapor m_g and mass of liquid m_f.

Important Definition

o **Critical point** - the temperature and pressure above which there is no distinction between the liquid and vapor phases.

o **Triple point** - the temperature and pressure at which all three phases can exist in equilibrium.

o **Sublimation** - change of phase from solid to vapor.

o **Vaporization** - change of phase from liquid to vapor.

o **Condensation** - change of phase from vapor to liquid.

o **Fusion or melting** - change of phase from solid to liquid.
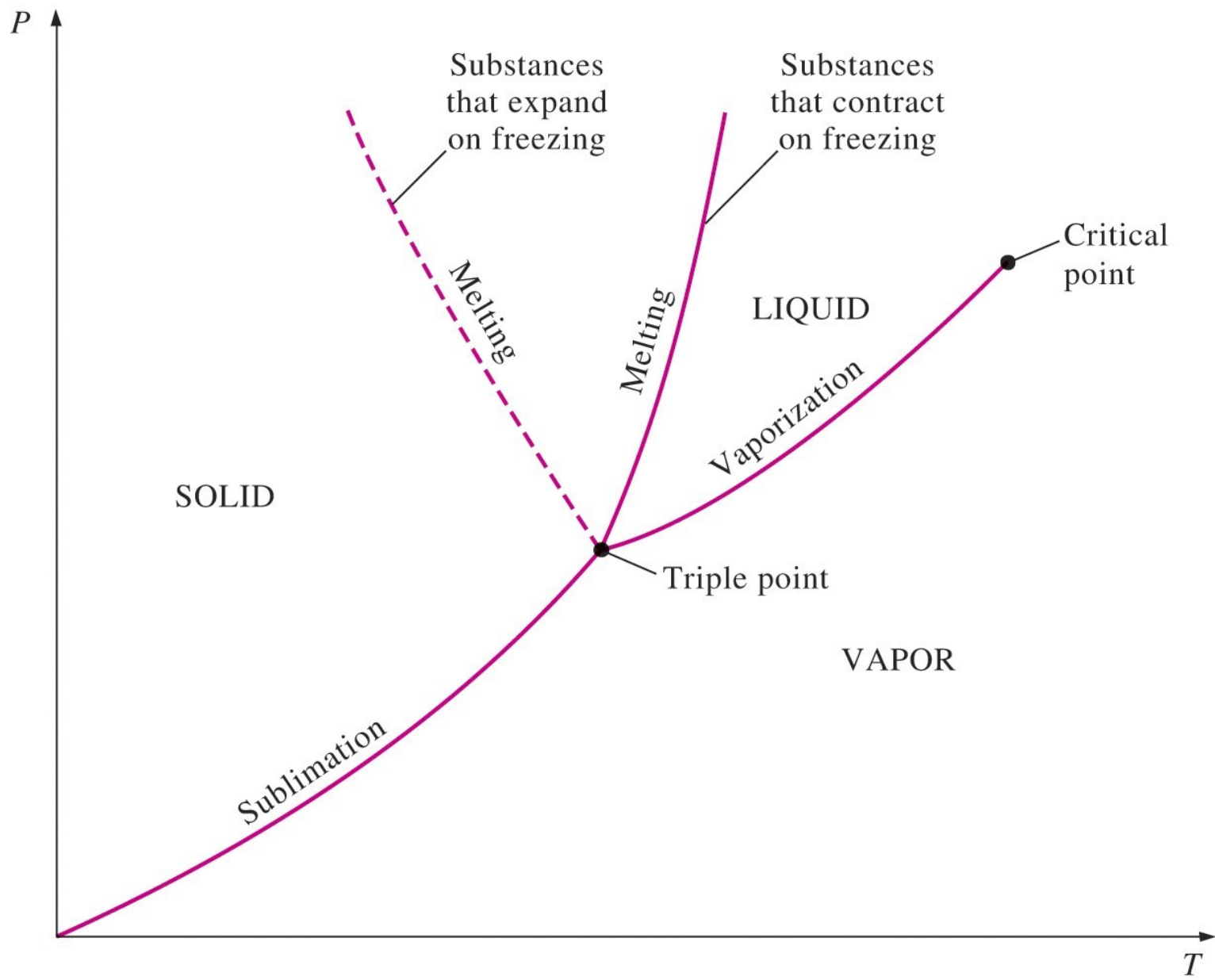
Ideal Gas Law

❖ *Robert Boyle* formulates a well-known law that states the pressure of a gas expanding at constant temperature varies inversely to the volume, or

$$P_1 V_1 = P_2 V_2 = \text{constant}$$

❖ As the result of experimentation, *Charles* concluded that the pressure of a gas varies directly with temperature when the volume is held constant, and the volume varies directly with temperature when the pressure is held constant, or

$$\frac{V_1}{V_2} = \frac{T_1}{T_2} \quad \frac{P_1}{P_2} = \frac{T_1}{T_2}$$

- ❖ By combining the results of Charles' and Boyle's experiments, the following relationship can be obtained

$$\frac{Pv}{T} = \text{constant}$$

- ❖ The constant in the above equation is called *the ideal gas constant* and is designated by R; thus the ideal gas equation becomes

$$Pv = RT \quad or \quad PV = mRT$$

- ❖ In order to make the equation applicable to all ideal gas, a universal gas constant R_U is introduced

$$R = \frac{R_U}{M}$$

❑ For example the ideal gas constant for air, R_{air}

$$R_{air} = \frac{(R_U)_{air}}{(M)_{air}} = \frac{8.3144}{28.96} = 0.2871 \, kJ/kg.K$$

❑ The amount of energy needed to raise the temperature of a unit of mass of a substance by one degree is called the *specific heat at constant volume C_v* for a constant-volume process and the *specific heat at constant pressure C_p* for a constant pressure process. They are defined as

$$C_v = \left(\frac{\partial u}{\partial T}\right)_v \quad and \quad C_p = \left(\frac{\partial h}{\partial T}\right)_P$$

❑ Using the definition of enthalpy ($h = u + Pv$) and writing the differential of enthalpy, the relationship between the specific heats for ideal gases is

$$h = u + Pv$$

$$dh = du +$$

$$RT$$

$$C_P dt = C_V dt +$$

$$RdT \quad C_P = C_V \quad +$$

❑ The *specific heat ratio, k* is defined as

$$R$$

$$k = \frac{C_P}{C_v}$$

➢ For ideal gases u, h, C_v, and C_p are functions of temperature alone. The Δu and Δh of ideal gases can be expressed as

$$\Delta u = u_2 - u_1 = C_v(T_2 - T_1)$$

$$\Delta h = h_2 - h_1 = C_P(T_2 - T_1)$$

Example 2.6

An ideal gas is contained in a closed assembly with an initial pressure and temperature of 220 kPa and 70⁰C respectively. If the volume of the system is increased 1.5 times and the temperature drops to 15⁰C, determine the final pressure of the gas.

Solution:

given

$\boxed{state1}$

$P_1 = 220 \ kPa$

$T_1 = 70 + 273K = 343 \ K$

$\boxed{state \ 2}$

$T_2 = 15 + 273 = 288 \ K$

$V_2 = 1.5V_1$

❖ From ideal-gas law:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$P_2 = \frac{V_1}{1.5V_1}\left(\frac{288}{343}\right)(220$$

$$= 123.15 \ kPa \qquad \times 10^3)$$

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Example 2.7

A closed assembly contains 2 kg of air at an initial pressure and temperature of 140 kPa and 210⁰C respectively.   If the volume of the system is doubled and temperature drops to 37⁰C, determine the final pressure of the air. Air can be modeled as an ideal gas.

Solution:

given

$$\boxed{state\,1}$$

$P_1 = 140\ kPa$

$T_1 = 210 + 273K = 483\ K$

$$\boxed{state\ 2}$$

$T_2 = 37 + 273 = 310\ K$

$V_2 = 2V_1$

❖ From ideal-gas law:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$P_2 = \frac{V_1}{2V_1}\left(\frac{310}{483}\right)(140)$$

$$= 44.93 \times 10\ kPa$$

Example 2.8

An automobile tire with a volume of 0.6 m³ is inflated to a gage pressure of 200 kPa. Calculate the mass of air in the tire if the temperature is 20°C.

Solution:

given

$$\boxed{state\,1}$$

$P = 200 + 100\ kPa$

$T = 20 + 273K = 293\ K$

❖ From ideal-gas law:

$$m = \frac{PV}{RT}$$

$$= \frac{300 \times 10^3\ \frac{N}{m^3}(0.6m^2)}{287\ \frac{Nm}{kg\ .K}(293)K}$$

$$= 2.14\ kg$$

Supplementary Problems

1. The pressure in an automobile tire depends on the temperature of the air in the tire. When the air temperature is 25°C, the pressure gage reads 210 kPa. If the volume of the tire is 0.025 m3, determine the pressure rise in the tire when the air temperature in the tire rises to 50°C. Also, determine the amount of air that must be bled off to restore pressure to its original value at this temperature. Assume the atmospheric pressure is 100 kPa.

    [26 kPa, 0.007 kg]

2. A 1-m^3 tank containing air at 25°C and 500 kPa is connected through a valve to another tank containing 5 kg of air at 35°C and 200 kPa. Now the valve is opened, and the entire system is allowed to reach thermal equilibrium with the surroundings, which are at 20°C. Determine the volume of the second tank and the final equilibrium pressure of air.

    [2.21 m³, 284.1 kPa]

3. A 1 m³ rigid tank has propane at 100 kPa, 300 K and connected by a valve to another tank of 0.5 m³ with propane at 250 kPa, 400 K. The valve is opened and the two tanks come to a uniform state at 325 K. What is the final pressure?

[*139.9 kPa*]

4. A cylindrical gas tank 1 m long, inside diameter of 20 cm, is evacuated and then filled with carbon dioxide gas at 25°C. To what pressure should it be charged if there should be 1.2 kg of carbon dioxide?

[*2152 kPa*]

Steam Generators Mountings & Accessories

The equipment used for producing and transferring steam is called

Steam generators/ Boilers.

Principle of Steam Generators/ Boilers:

The fluid (water) contained in the boiler called *shell* and the thermal energy released during combustion of fuel, which may be solid, liquid or gaseous, is transferred to water and this converts water into steam at the desired temperature and pressure.

Commercial usage of Steam

i) Power generation

ii) Heating the residential and commercial buildings in cold weather countries.

iii) Other industrial usages e.g. sugar industries and chemical industries etc.

iv) In Agriculture E.g Soil Sterilization

v) Wood bending, killing insects and increasing plasticity

Classification of boilers

Boilers may be classified according to the following-

1. ***Relative position of Hot gases and Water***

    a) **Fire tube boiler:**

    The hot gases passes through the tubes that are surrounded by water. Fire tube boilers are also known by certain common names-

    i) Horizontal return tubular

    ii) Locomotive fire box

    iii) Scotch marine and,

    iv) Vertical tubular

b) **Water tube Boiler**

The water passes through the tubes and the hot gases produced by combustion of fuel, flow outside. This type of Boilers designated by the following common names:

i)   Babcock and Wilcox Boiler (straight but inclined tubes which connect the headers).

ii)   Stirling Boiler (multitubular boiler having bent tubes that connect boiler drums to headers).

2. *Method of firing*

a) Internally fired Boilers:

     The furnace is provided *inside* the boiler shell and is completely surrounded by water cooled surfaces. This method of firing is used in:

- Lancashire Boilers
- Locomotive Boilers and
- Scotch Boilers

b) Externally fired Boilers:

The furnace is provided *outside/ under* the boiler. It has an advantage that its furnace is simple to construct and can easily be enlarged, as and when required. This method of firing is used in Babcock and Wilcox Boiler.

3) Pressure of Steam:

i)   **High pressure Boilers:**

Boilers producing steam *80 bar* and above are called High pressure boilers.

ii) Low pressure Boilers:

Boilers producing steam Lower than **80 bar** are called Low pressure boilers. E.g.

4. Method of circulation of water:

a) **Natural circulation method**

Circulation set up by convection current or by gravity.

b) **Forced circulation method**

Circulation set up for high pressure steam through pumps.

5. *Nature of service to be performed*

a)   Land Boilers:

Boilers which are used with stationary plants

b) Portable Boilers:

Boilers which can be readily dismantled and easily carried out from one site to another.

c) Mobile Boilers:

Boilers which are fitted on mobile carriages are called Mobile Boilers. E.g. marine and locomotive boilers.

6. Once through Boilers:

The boilers in which no circulation of water takes place i.e.the feed water leaves the tube as steam e.g. Benson Boilers.

7. Position and No. of Drums:

Single or multi-drums may be positioned longitudinally or crosswise.

8. Design of gas passages:

a) Single pass
b) Return pass
c) Multi-pass

9. *Nature of Draught:*

a) Natural Draught:

when the fuel burns in the furnace of the boiler, with the circulation of air, the draught is named as Natural Draught.

b) Artificial Draught:

When the air is forced by means of forced fan, the draught is named as Artificial Draught.

10. Heat Source:

a) Combustion of solid, liquid or gaseous fuel.

b) Electrical and nuclear energy.

c) Hot waste gases of other chemical reactions.

11. Fluid Used:

a) Steam Boilers- use *water* as a fluid.

b) Mercury Boilers- use *mercury* as a fluid.

c) Other Boilers- use *special chemicals* as a fluid.

12. Material of construction of Boiler Shell:

a)   **Cast Iron Boilers**

b)   **Steel Boilers**

c)   **Copper and Stainless steel Boilers**

Boiler Details

- **Shell**: main container usually of cylindrical shape, which contains water and steam

- **Combustion chamber**: it is the space generally below the boiler shell meant for burning fuel in order to produce steam from the water contained in the shell.

- **Grate**: it is a platform, in the combustion chamber upon which the fuel is burnt.

- **Furnace:** chamber in which combustion of fuel takes place. This may be a grate to burn coal or a burner to atomize and burn liquid fuel

- **Heating surface**: it is that part of boiler surface which is exposed to the fire or hot gases from the fire.

- **Water flow path**: it is the path followed by water in the boiler (particularly in water tube boiler) during the process of absorption of heat and conversion into steam. Water should be free from dissolved material in order to reduce **scaling** of heating surface

- **Gas flow path**: path followed by hot gases to transfer heat to the water. Boiler efficiency mainly depends on the gas flow path.

Steam path: in most of the boilers steam is taken out preferably at the top of the shell to avoid water particles being carried with the steam. Steam separators are employed for this purpose.

Mountings: Valves and gauges necessary for the safety of boiler. E.g. water level indicator, safety valve, fusible plug etc.

 Accessories: Devices attached to the boiler to improve its performance. E.g. Air pre-heater, economiser, super heater etc.

Requirement of a good boiler

1. The boiler should be capable of generating steam at the required pressure and of the required quality quickly and with minimum fuel consumption.

2. For efficient heat transfer , the water and flue gases should have maximum velocity without incurring heavy frictional losses.

3. The boiler should have light in weight, should need least amount of brick work construction and should occupy small floor area.

4. The intial cost, installation cost and maintainence cost of the boiler should not be too high.

5. The boiler should meet the flunctuating demands on steam supply without being overheated.

6. The boiler should have minimum joints and those too should be away from direct flames.

7. The boiler should offer ease of dismantling the parts and erection at site without resionable time and labour.

8. There should be no deposition of mud and other foreign particles on the heated surfaces.

9. The different parts of the boiler should be easily approachable for repairs.

10. the boiler should conform to the safely regulations.

Selection of a boiler

1. Rate of steam generation in kg/hour.
2. Pressure at which the boiler is required to operate and quality of steam required.
3. Whether the steam raised is to be used at a steady or fluctuating loads.
4. Type of fuel used.
5. Space available for erection and height of the building in which the boiler is to be accommodated.
6. Comparative initial cost.
7. Boiler efficiency.

FIRE TUBE BOILER

Simple Vertical Boiler is a boiler in which water is boiled inside a large vertical cylindrical shell and steam is produced.

This is the simplest type of firetube boiler.

This boiler produces low pressure and a small quantity of steam. This boiler produces a pressure of nearly 10 bar. The construction of this boiler is very simple and easier than any other boiler.

This boiler occupies very little space, so it is used where less land is available for operation.

The steam produces in this boiler is used in low working conditions like small power plants for producing current.
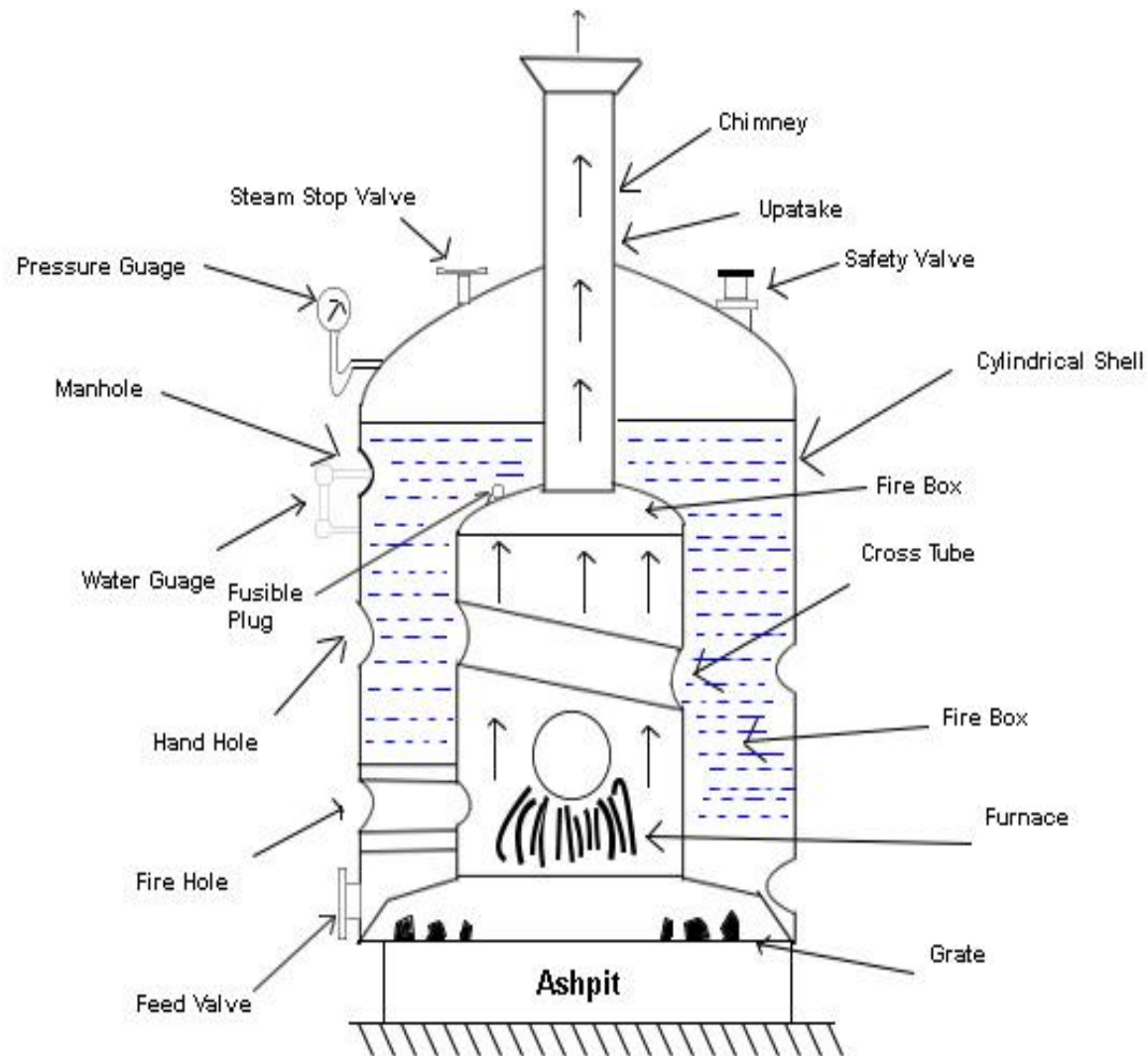
Simple Vertical Boiler

Parts of a Simple Vertical Boiler:-

1) Vertical Cylindrical Shell:-
This is the outermost cylindrical vertical shell of the boiler. Other parts of the boiler are inside this part. Most of the part of this cylindrical shell is filled with water and the rest part is for steam.

2) Cross Tubes
One or more cross tubes are riveted or flanged to increase the heating surface and to improve water circulations.

3) Furnace (or Firebox)
Furnace is used for the combustion of the coal. Coal is burnt here to produce heat.

4) Grate
It is present at the bottom of the furnace. It is the place in the furnace where coals are placed.

5) Fire Door or Fire Hole
Coal is inserted in the furnace through this hole or door.

6) Ashpit
It is available in the boiler to collect the ash deposited by the furnace.

7) Hand Holes
Hand Holes are present in the boiler opposite to the end of each cross tubes for cleaning the cross tubes.

8) Chimney
A chimney is a vertical cylindrical pipe that extends from the top of the firebox to 1the top of the shell. It is used to pass the smoke from the boiler to the atmosphere.

Apart from these parts some mountings are present. These are :-

1) Steam Stop Valve
2) Safety Valve
3) Pressure Guage
4) Water Guage
5) Water Feed Valve

Construction of Simple Vertical Boiler

The biggest part of the simple vertical boiler is the vertical cylindrical shell. It is the outermost part of the simple vertical boiler, other boiler parts are contained inside this part.

Inside this shell, there is a firebox at the bottom of the shell. This firebox consists of a grate, furnace and ashpit. Grate is present at bottom of the firebox where fuel or coal is kept and burnt in the furnace. Ashpit is below the grate where ash created by burning fuel is collected. Coal is introduced to the firebox through a fire hole.

The cross tube is present at the center of boiler and is placed horizontally. This tube transfer heat from flue gas to water.

Above the cross tube chimney is present. Flue gases from the cross tube is passed to the chimney where it leaves the boiler and goes into the atmosphere.

Working Of Simple Vertical Boiler

In the simple vertical boiler, at first the fuel is added through the fire hole into the furnace. Fuel is placed on the grate present at the bottom of the furnace. When the fuel burns hot gases are produced and the ash produced by burning of fuel is collected in the ashpit.
The hot gases produced by burning of fuel are then going to the cross tubes and then the waste gases are passed out to the atmosphere through the chimney.
Heat is transferred from flue gases in the cross tubes to the water and the water is heated to produce steam. Due to convection current water goes by natural circulation from the lower end of the cross tube to the higher end.
The steam which is produced by heat transfer from flue gas to water is then collected at the steam space of the boiler, steam is collected until a certain pressure is reached and then the steam is passed out to the gas turbine or engine or for any other use.

Advantages of Simple Vertical Boiler

•Occupy very less space on ground as it has vertical cylindrical shell.

•Very low initial cost is required due to less parts.

•Maintenance cost is low.

•Easy to install and operate.

•This boiler has water level tolerance.

Disadvantages of Simple Vertical Boiler

•Water impurities settle down and prevent water from heating.

•Vertical design limit its working by many ways.

•Due to small-sized grate, steam production is low.

•Boiler tubes are kept short to minimize height. Since boiler tubes are short, very less time is for the flue gas to heat the tube and hence less steam is produced.

WATER TUBE BOILERS

BABCOCK & WILCOX BOILERS
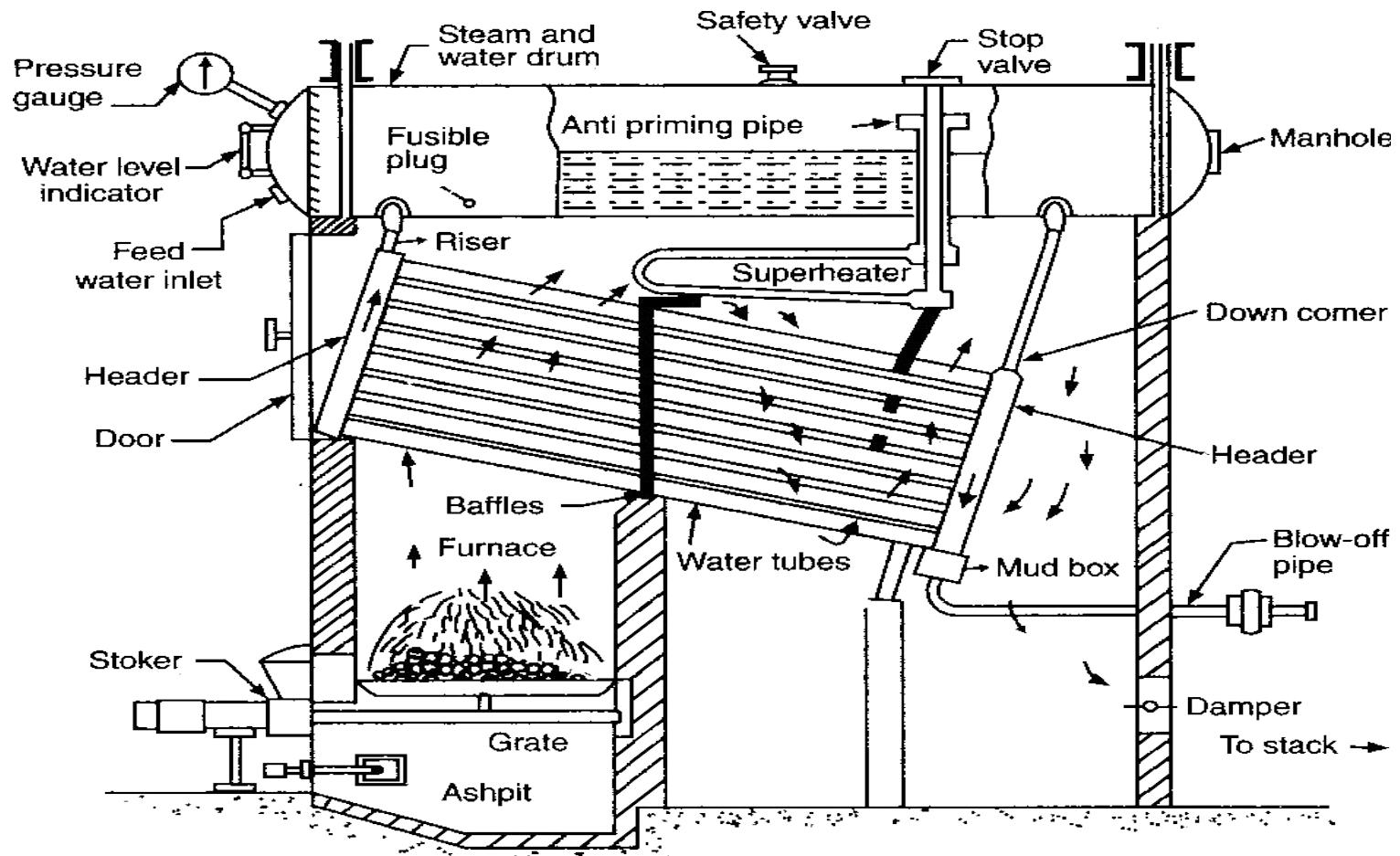
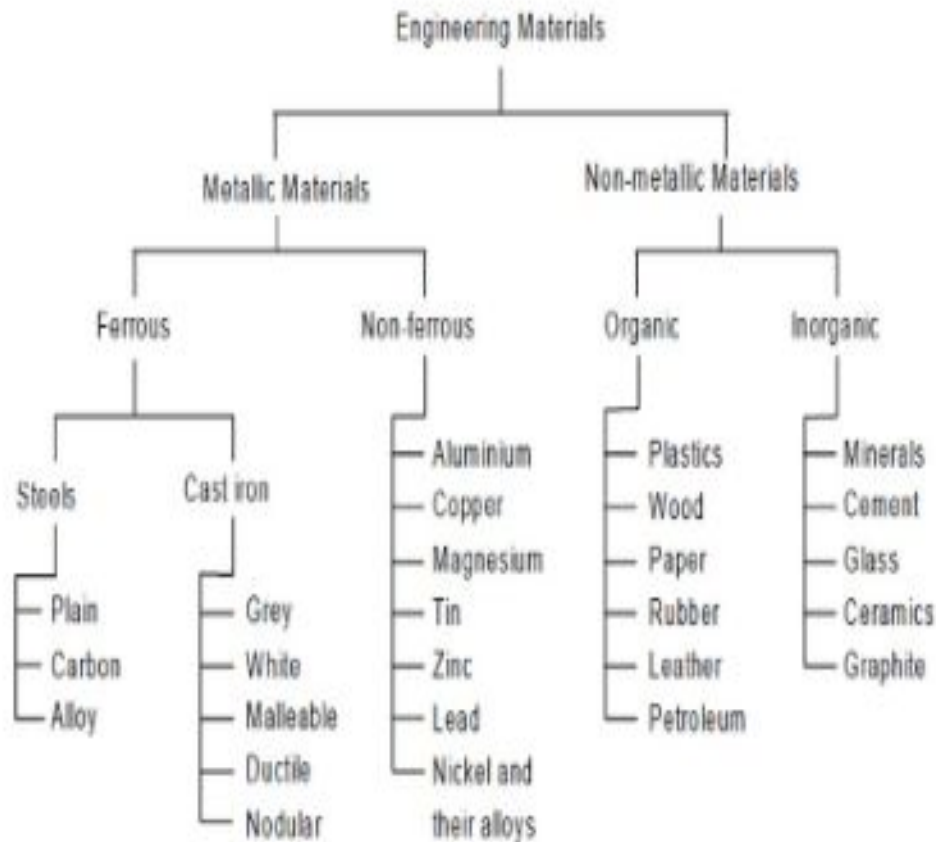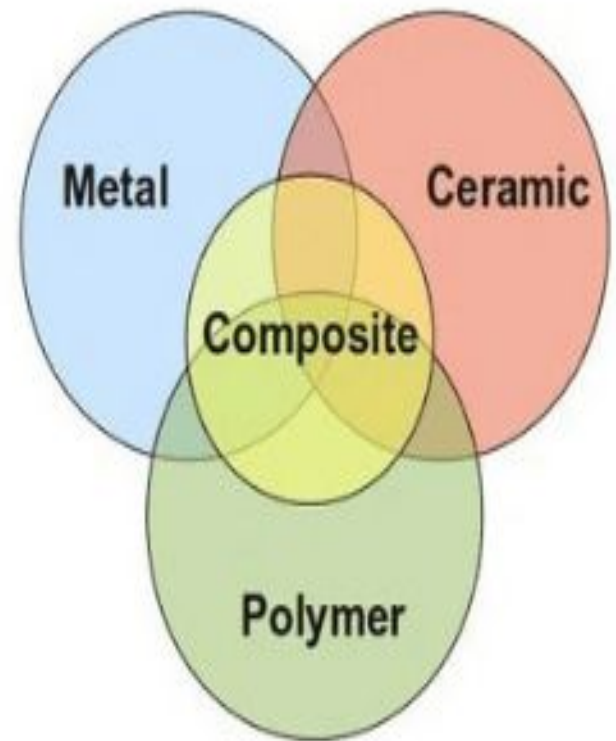A water tube, horizontal, multi-tubular boiler

BABCOCK & WILCOX BOILERS
(Constructional features)

❖ It consist of welded steel high pressure drum mounted at the top.

❖ Drum is connected with uptake header and down take header.

❖ Water tubes connected to the headers are inclined at 15^0 to the horizontal.

❖ Mud Box: To collect the sedimentation in water.

❖ Super heater tubes: To enhance the super heated steam.

❖ Vents provided: safety valve, pressure gauge, water level indicator, fusible plug and feed check valve.

❖ Evaporative capacity ranges from 20000 to 40000 kg/hr

❖ Operative pressure ranges from 11.5 to 17.5 bar.

❖ Steam formed from such boilers are primarily used to run ***steam turbines and generate electric power***.

WATER TUBE	FIRE TUBE
Water passes through water tubes.	Hot gases passes through flues .
steam capacity low	Steam capacity high
Complexity in design requires quick examination by skilled hands.	Simple & rigid construction hence greater reliability & low operating cost.
Higher operating pressure	Lower pressure range
Evaporation rate from ranges 20,000 to 50,000kg/hr.	Evaporation rate 900kg/hr.
Increased heating surface area.	Low heating surface area.
Low water to steam ratio	Large water to steam ratio
Bigger in size, suitable for large power plants	Smaller in size, used only for small power plants
Transportation and installation is difficult due to large size of shell.	Transportation and installation is easy due to handling of dismentaled parts
Externally fired boilers, furnace size can be varied.	Internally fired boilers, furnace size can not be varied.
Requires more floor area	Requires less floor area

What are the Classifications of Engineering Materials?

Engineering Materials

Metallic Materials

Ferrous
- Steels
  - Plain
  - Carbon
  - Alloy
- Cast iron
  - Grey
  - White
  - Malleable
  - Ductile
  - Nodular

Non-ferrous
- Aluminium
- Copper
- Magnesium
- Tin
- Zinc
- Lead
- Nickel and their alloys

Non-metallic Materials

Organic
- Plastics
- Wood
- Paper
- Rubber
- Leather
- Petroleum

Inorganic
- Minerals
- Cement
- Glass
- Ceramics
- Graphite

Metal

Ceramic

Composite

Polymer

E4U Electrical 4 U

Strength

- Strength, therefore, refers to **the ability of a material to accommodate a force without breaking**.

- It is a total measure of the capacity of the material to withstand the load placed on it before reaching the point of permanent deformation.

- A material's strength in a given application depends on many factors, including its resistance to deformation and cracking, and it often depends on the shape of the member being designed.

- It is usually defined as tensile strength, compressive strength, proof stress, shear strength etc.

Elasticity, Stiffness

- Elasticity describes a material's tendency to return to its original size and shape when a distorting force is removed. As opposed to materials that exhibit plasticity (where the change in shape is not reversible), an elastic material will return to its previous configuration when the stress is removed.
- The **stiffness** of a metal is often measured by the Young's Modulus, which compares the relationship between stress (the force applied) and strain (the resulting deformation).
- The higher the Modulus – meaning greater stress results in proportionally lesser deformation – the stiffer the material.
- Glass would be an example of a stiff/high Modulus material, where rubber would be a material that exhibits low stiffness/low Modulus. This is an important design consideration for applications where stiffness is required under load.

Plasticity

- Plasticity, the converse of elasticity, describes the tendency of a certain solid material to hold its new shape when subjected to forming forces.
- It is the quality that allows materials to be bent or worked into a permanent new shape.
- Materials transition from elastic behavior to plastic at the yield point.

Ductility

- Ductility is the ability of a material to deform plastically (that is, stretch) without fracturing and retain the new shape when the load is removed. Think of it as the ability to stretch a given metal into a wire.
- Ductility is often measured using a tensile test as a percentage of elongation, or the reduction in the cross sectional area of the sample before failure.

- The tendency of a material to resist cracking or breaking under stress makes ductile materials appropriate for other metalworking processes including rolling or drawing. Certain other processes like cold-working tend to make a metal less ductile.

Malleability

- Malleability is a property of solid materials which indicates that how easily a material gets deformed under compressive stress.
- Malleability is often categorized by the ability of material to be formed in the form of a thin sheet by hammering or rolling.
- This mechanical property is an aspect of plasticity of material.
- Malleability of material is temperature dependent. With rise in temperature, the malleability of material increases.

Toughness

- It is the ability of a material to absorb the energy and gets plastically deformed without fracturing. Its numerical value is determined by the amount of energy per unit volume. Its unit is Joule/ m^3.

- Value of toughness of a material can be determined by stress-strain characteristics of a material. For good toughness, materials should have good strength as well as ductility.

- For example: brittle materials, having good strength but limited ductility are not tough enough. Conversely, materials having good ductility but low strength are also not tough enough. Therefore, to be tough, a material should be capable to withstand both high stress and strain.

Brittleness

Brittleness of a material indicates that how easily it gets fractured when it is subjected to a force or load. When a brittle material is subjected to a stress it observes very less energy and gets fractures without significant strain. Brittleness is converse to ductility of material. Brittleness of material is temperature dependent. Some metals which are ductile at normal temperature become brittle at low temperature.

Malleability

Malleability is a property of solid materials which indicates that how easily a material gets deformed under compressive stress. Malleability is often categorized by the ability of material to be formed in the form of a thin sheet by hammering or rolling. This mechanical property is an aspect of plasticity of material. Malleability of material is temperature dependent. With rise in temperature, the malleability of material increases.

Creep

Creep is the property of a material which indicates the tendency of material to move slowly and deform permanently under the influence of external mechanical stress. It results due to long time exposure to large external mechanical stress with in limit of yielding. Creep is more severe in material that are subjected to heat for long time.

Resilience

Resilience is the ability of material to absorb the energy when it is deformed elastically by applying stress and release the energy when stress is removed. Proof resilience is defined as the maximum energy that can be absorbed without permanent deformation. The modulus of resilience is defined as the maximum energy that can be absorbed per unit volume without permanent deformation. It can be determined by integrating the stress-strain cure from zero to elastic limit. Its unit is joule/m^3.

Fatigue

- Fatigue is the weakening of material caused by the repeated loading of the material.
- When a material is subjected to cyclic loading, and loading greater than certain threshold value but much below the strength of material (ultimate tensile strength limit or yield stress limit), microscopic cracks begin to form at grain boundaries and interfaces. Eventually the crack reaches to a critical size. This crack propagates suddenly and the structure gets fractured. The shape of structure affects the fatigue very much.
- Square holes and sharp corners lead to elevated stresses where the fatigue crack initiates.

Machinability

Machinability defines the ease at which a material (mainly metal) can be cut or shaped while providing a satisfactory surface finish. A material with good machinability requires little power to cut, produces a smooth surface finish and minimizes wear on the tooling.

Formability

Formability is defined as **the degree of deformation that can be achieved in a metal forming process without creating an undesirable condition**, such as cracking, necking, buckling or the formation of folds and flaws.

Castability

Castability is **the ease of forming a quality casting**. A very castable part design is easily developed, incurs minimal tooling costs, requires minimal energy, and has few rejections. Castability can refer to a part design or a material property.

The ability of materials to set in a mould when mixed with water and a bonding agent.

Weldability

The weldability of a metal is **how easily it can be welded**. The criteria in deciding on the weldability of a metal are the weld quality and the ease with which it can be obtained.