UNIT-III: PURE SUBSTANCE AND PERFECT GAS

1. Pure Substance

Definition

A **pure substance** is a material that has a **uniform and fixed chemical composition** throughout its mass.

It may exist in more than one phase but its chemical composition remains the same.

Examples

- Water (Ice + Water + Steam)
- Oxygen (O_2)
- Nitrogen (N_2)
- Carbon dioxide (CO_2)

Not Pure Substance

- Air (mixture of gases)
- Sea water
- Milk

2. Phases of a Pure Substance

A pure substance may exist in three phases:

1. Solid
2. Liquid
3. Gas (Vapour)

Example:

Water exists as

Ice → Water → Steam

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3. Phase Change Process

Heating of Water

```
Ice
 |
Melting
 |
Water
 |
Boiling
 |
Steam
```

Important Temperatures

Melting Point
Temperature at which solid changes into liquid.

Boiling Point
Temperature at which liquid changes into vapour.

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4. Saturation States

Saturated Liquid

Liquid just before boiling.

Quality $(x)=0$

Saturated Vapour

Vapour just after complete evaporation.

Quality $(x)=1$

Wet Region

Mixture of liquid and vapour.

$0<x<1$

Superheated Vapour

Vapour heated above saturation temperature.

Compressed (Subcooled) Liquid

Liquid below saturation temperature.

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5. P-V-T Surface

Pressure, Volume and Temperature are related by a three-dimensional surface.

```
              Temperature
                  ▲
                  |
                 /\
                /  \
               /    \
              /      \
             /        \
            /          \
Pressure--------------------► Volume
```

Importance

- Shows all thermodynamic states.
- Represents phase change.
- Used in power plants and refrigeration.

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6. T-S Diagram (Temperature-Entropy)

```
Temperature
▲
|          /\
```

```
|         /   \
|        /     \
|       /       \
|______/_________\____► Entropy
```

Uses

- Heat transfer analysis
- Rankine cycle
- Refrigeration cycle
- Steam power plant

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7. h-s Diagram (Mollier Chart)

Mollier Chart is a graph between

Enthalpy (h)

vs

Entropy (s)

Used mainly for steam calculations.

Applications

- Steam turbines
- Boilers
- Nozzles
- Refrigeration

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8. Critical Point

The highest temperature and pressure at which liquid and vapour coexist.

Beyond this point,

Liquid and vapour become indistinguishable.

Critical Properties

Critical Temperature (Tc)

Highest temperature at which gas can be liquefied.

Critical Pressure (Pc)

Pressure required to liquefy gas at Tc.

Critical Volume (Vc)

Specific volume at critical point.

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9. Triple Point

Temperature and pressure where

Solid

Liquid

Gas

exist together in equilibrium.

For water

Temperature = **0.01°C**

Pressure = **0.611 kPa**

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10. Dryness Fraction (Quality)

Represents amount of dry steam.

Symbol

x

Formula

$$x=\frac{Mass\ of\ Vapour}{Total\ Mass}$$

Range

$0 \le x \le 1$

$x=0$

Saturated liquid

$x=1$

Dry saturated steam

Property Relations

Specific Volume

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

Enthalpy

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

where

$$h_{fg}=h_g-h_f$$

Internal Energy

$$u=u_f+xu_{fg}$$

Entropy

$$s=s_f+xs_{fg}$$

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11. Clapeyron Equation

Used during phase change.

$$\frac{dP}{dT} = \frac{h_{fg}}{T(v_g-v_f)}$$

Applications

- Steam tables
- Phase equilibrium
- Refrigeration

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12. Clausius-Clapeyron Equation

Simplified equation for vapour pressure.

$$\ln\left(\frac{P_2}{P_1}\right) = -\frac{h_{fg}}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right)$$

Applications

- Vapour pressure calculation
- Refrigeration
- Meteorology

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13. Property Tables

Steam tables provide

Pressure

Temperature

Specific volume

Enthalpy

Entropy

Internal energy

Types

Saturated tables

Superheated tables

Compressed liquid tables

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14. Steam Calorimetry

Used to determine

Dryness fraction of steam.

Types

Bucket Calorimeter

Simple method.

Separating Calorimeter

Separates water droplets.

Throttling Calorimeter

Uses throttling process.

Combined Calorimeter

Combination of separating and throttling calorimeter.

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15. Perfect Gas

Definition

A perfect gas obeys

Boyle's law

Charles' law

Ideal gas equation

at all temperatures and pressures.

Examples

Helium

Hydrogen

Nitrogen (approximately)

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16. Ideal Gas Equation

$PV=mRTPV=mRTPV=mRT$

Where

P = Pressure

V = Volume

m = Mass

R = Gas constant

T = Absolute temperature

Per unit mass

Pv=RTPv=RTPv=RT

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17. Universal Gas Constant

PV=nRuTPV=nR_uTPV=nRuT Ru=8.314 kJ/(kmol.K)R_u=8.314\ kJ/(kmol.K)Ru =8.314 kJ/(kmol.K)

Relationship

R=RuMR=\frac{R_u}{M}R=MRu

where

M = Molecular weight

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18. Specific Heat

At Constant Volume

CvC_vCv

Heat required to raise unit mass by 1 K at constant volume.

At Constant Pressure

CpC_pCp

Heat required at constant pressure.

Relation

Cp>CvC_p>C_vCp>Cv

Gas Constant

R=Cp−CvR=C_p-C_vR=Cp−Cv

Specific Heat Ratio

$\gamma=\frac{C_p}{C_v}$

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19. Internal Energy

For ideal gas

$u=C_vT$

Change

$\Delta U=mC_v(T_2-T_1)$

Depends only on temperature.

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20. Enthalpy

$h=u+Pv$

For ideal gas

$h=C_pT$

Change

$\Delta H=mC_p(T_2-T_1)$

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21. Heat Transfer

Conduction

Heat transfer through solids.

Fourier's law

$Q=-kA\frac{dT}{dx}$

Convection

Heat transfer by fluid motion.

Newton's law

$Q=hA(T_s-T_f)$

Radiation

Heat transfer without medium.

Stefan-Boltzmann law

$Q=\sigma A(T^4)$

22. Throttling Process

Flow through valve or porous plug.

Characteristics

- No work
- No heat transfer
- Enthalpy constant

$h_1=h_2$

Applications

- Refrigeration
- Expansion valve

23. Free Expansion

Gas expands into vacuum.

Characteristics

- No work
- No heat transfer

Ideal gas

$\Delta U=0$

24. Flow Process

Occurs in turbines, compressors, nozzles and pumps.

Steady Flow Energy Equation

$$Q-W= m\left[(h_2-h_1) +\frac{V_2^2-V_1^2}{2} +g(z_2-z_1) \right]$$