Non-Flow Processes

Presentation Outline

- Overview
- Standard Non-flow Processes

Overview

- The standard non-flow processes show how the energy quantities of heat and work that are interacting between system and surroundings are linked to the internal thermal energy levels of the system through the mathematical expressions of the 1st Law of Thermodynamics.

Perfect Gases

- Gases that obey perfect gas laws
- Perfect gas equation

$$pV = mRT$$

p – Pressure (N/m^2 or Pa)
V – Volume (m^3)
m – Mass (kg)
R – Specific Gas Constant (J/kgK)
T – Temperature (K)

Perfect Gases

Specific Gas Constant

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

R_u - Universal Gas Constant (8.3145 kJ/kmol K)
M - Molar mass of gas (kg/kmol)

$$R_{O_2} = \frac{8.3145}{32} = 0.260 kJ/kgK = 260 J/kgK$$

Specific Heat Capacities

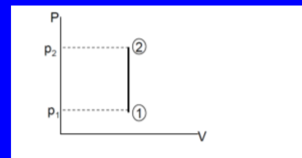
- Specific Heat Capacity at constant pressure (c_p)
- c_p for air = 1.005 kJ/kgK
- Specific Heat Capacity at constant volume (c_v)
- c_v for air = 0.718 kJ/kgK

$$\frac{c_p}{c_v} = \gamma \qquad c_p - c_v = R$$

Standard Non-flow Processes

- Constant Volume Process
- Constant Pressure Process
- Constant Temperature Process
- Polytropic Process
- Adiabatic Process
- Isentropic Process

Constant Volume Process (Isochoric Process)



Constant Volume process on a P-V Diagram

- This process takes place between two states (state 1 and state 2) maintaining the volume of the system constant and hence called the constant volume process.

Constant Volume Process (Isochoric Process)

Work Transfer

$$W_{12} = \int_1^2 pdV$$

For Constant Volume Process $dV = 0$ $\quad \frac{p}{T} = c$

Hence $W_{12} = 0$

For constant volume processes expansion or compression work term will be zero.

Constant Volume Process (Isochoric Process)

From First Law of Thermodynamics

$$Q_{12} - W_{12} = U_2 - U_1$$

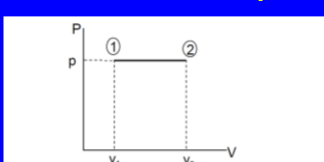
Hence

$$Q_{12} = U_2 - U_1$$

For a perfect gas

$$Q_{12} = mc_v(T_2 - T_1)$$

Constant Pressure Process (Isobaric Process)



Constant Pressure process on a P-V Diagram

$dp = 0$

$\frac{V}{T} = c$

- This process will take place between two states (state 1 and state 2) maintaining the pressure of the system constant and hence called a *Constant Pressure Process.*

Constant Pressure Process (Isobaric Process)

Work Transfer

$$W_{12} = \int_1^2 pdV \qquad W_{12} = p\int_1^2 dV \qquad W_{12} = p(V_2 - V_1)$$

Apply First Law of Thermodynamics

$$Q_{12} - W_{12} = U_2 - U_1$$

Hence

$$Q_{12} - p(V_2 - V_1) = U_2 - U_1$$

Constant Pressure Process (Isobaric Process)

$$Q_{12} = p(V_2 - V_1) + (U_2 - U_1)$$

Hence $Q_{12} = (U_2 + pV_2) - (U_1 + pV_1)$

However $h = u + pv$ or $H = U + pV$

Hence $q_{12} = h_2 - h_1$ or $Q_{12} = H_2 - H_1$

For a perfect gas $Q_{12} = mc_p(T_2 - T_1)$

13

Ratio of Specific Heat Capacities

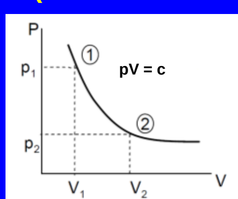
$$\frac{c_p}{c_v} = \gamma \qquad c_p - c_v = R$$

Dividing through by c_v $\quad \frac{c_p}{c_v} - 1 = \frac{R}{c_v} \qquad \gamma - 1 = \frac{R}{c_v}$

Hence $c_v = \frac{R}{(\gamma - 1)}$ and $c_p = \gamma c_v = \frac{\gamma R}{(\gamma - 1)}$

14

Constant Temperature Process (Isothermal Process)



$$dT = 0$$

$$pV = c$$

- This process takes place between state 1 and state 2 maintaining the temperature of the system constant and hence called a *Constant Temperature Process.*

15

Constant Temperature Process (Isothermal Process)

Work Transfer

$$W_{12} = \int_1^2 p dV \qquad W_{12} = \int_1^2 \frac{c}{V} dV \qquad W_{12} = c.\ln\left|\frac{V_2}{V_1}\right|$$

For an Isothermal Process

$$p_1V_1 = p_2V_2 = c$$

Hence $W_{12} = p_1V_1 \ln\left|\frac{V_2}{V_1}\right| = p_2V_2 \ln\left|\frac{V_2}{V_1}\right|$

16

Constant Temperature Process (Isothermal Process)

When the fluid is a perfect gas dU=0

Applying First Law $Q_{12} - W_{12} = U_2 - U_1$

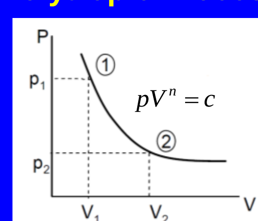
Hence

$$Q_{12} - W_{12} = 0$$

$$Q_{12} = W_{12} = p_1V_1 \ln\left|\frac{V_2}{V_1}\right| = p_2V_2 \ln\left|\frac{V_2}{V_1}\right| = mRT \ln\left|\frac{V_2}{V_1}\right| = mRT \ln\left|\frac{p_1}{p_2}\right|$$

17

Polytropic Process



- Polytropic process is one in which pressure-volume relationship is given by the expression pV^n= const.
- n is called the polytropic index and in general it varies between 1.2 to 1.5.

18

Polytropic Process

Work Transfer

$$W_{12} = \int_1^2 p dV \qquad W_{12} = \int_1^2 \frac{c}{V^n} dV \qquad W_{12} = \frac{c\left(V_2^{1-n} - V_1^{1-n}\right)}{(1-n)}$$

For a Polytropic Process

$$p_1 V_1^n = p_2 V_2^n = c$$

Hence $W_{12} = \dfrac{\left(p_1 V_1 - p_2 V_2\right)}{(n-1)}$

19

Polytropic Process

If the working fluid is a perfect gas

$$pV = mRT$$

Hence

$$W_{12} = \frac{mR\left(T_1 - T_2\right)}{(n-1)}$$

and

$$U_2 - U_1 = mc_v\left(T_2 - T_1\right)$$

20

Polytropic Process

Hence from First Law $Q_{12} - W_{12} = U_2 - U_1$

For a unit mass

$$Q_{12} - \frac{R\left(T_1 - T_2\right)}{(n-1)} = c_v\left(T_2 - T_1\right)$$

It is proved that $c_v = \dfrac{R}{(\gamma - 1)}$

Hence $Q_{12} = c_v\left(T_2 - T_1\right) + \dfrac{R\left(T_1 - T_2\right)}{(n-1)}$

21

Polytropic Process

Hence $Q_{12} = c_v\left(T_2 - T_1\right) - \dfrac{R\left(T_2 - T_1\right)}{(n-1)}$

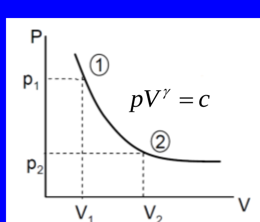
$$Q_{12} = \frac{R}{(\gamma - 1)}\left(T_2 - T_1\right) - \frac{R}{(n-1)}\left(T_2 - T_1\right)$$

$$Q_{12} = R\left(T_2 - T_1\right)\left[\frac{1}{(\gamma - 1)} - \frac{1}{(n-1)}\right]$$

Hence $Q_{12} = \left(\dfrac{n-\gamma}{\gamma - 1}\right)\dfrac{R\left(T_2 - T_1\right)}{(n-1)}$ $\qquad Q_{12} = -\left(\dfrac{n-\gamma}{\gamma - 1}\right) W_{12}$

22

Adiabatic Process



$$\gamma = \frac{c_p}{c_v}$$

- In an *Adiabatic Process* heat transfer between the system and the surroundings is zero (dQ = 0).
- For air $\gamma = 1.4$

23

Adiabatic Process

By applying First Law of Thermodynamics

$$Q_{12} - W_{12} = U_2 - U_1$$

$$Q_{12} = 0$$

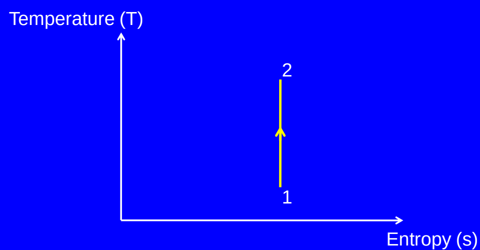
Hence $W_{12} = U_1 - U_2$

When the working fluid is a perfect gas

$$W_{12} = mc_v\left(T_1 - T_2\right)$$

24

Isentropic Process



- In an *Isentropic Process,* entropy of the system is kept constant throughout the process. (ds = 0).
- *Isentropic* = Reversible + Adiabatic

25

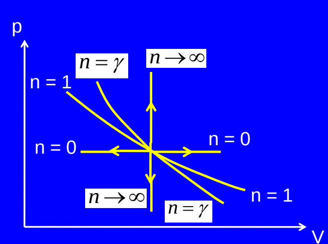
Generalization of Polytropic Processes

$$pV^n = c$$

Process	Governing Equation	Polytropic Index (n)
Constant Volume	$V = c$	$n \to \infty$
Constant Pressure	$p = c$	0
Isothermal	$pV = c$	1
Adiabatic	$pV^{\gamma} = c$	γ

26

Generalization of Polytropic Processes



27