

**24AG301- APPLIED THERMODYNAMICS AND THERMAL
SYSTEMS IN AGRICULTURAL ENGINEERING**

**UNIT 1 BASICS OF THERMODYNAMICS FOR
AGRICULTURAL MACHINERY**

HANDLED BY

MS SWETHA S



Perpetual Motion Machine of first kind (PMM-1)

PMM-1 is a machine which delivers work or heat continuously without any input. Thus the machine violates the first law of thermodynamics. It is impossible to construct such a machine.

7. A fluid in a piston and cylinder executes 220 cycles per min with four processes. The net heat transfer during a cycle is -300 kJ . Complete the following table showing the method for each item and compute the net rate of work output in kW.

Process	$Q \text{ (kJ/min)}$	$W \text{ (kJ/min)}$	$\Delta E \text{ (kJ/min)}$
1-2	0	4350	?
2-3	42000	0	?
3-4	-4200	?	-73500
4-1	?	?	?

Sol:-

$$\begin{aligned}\text{For process 1-2} \quad \Delta E &= Q - W = 0 - 4350 \\ &= -4350 \text{ kJ/min}\end{aligned}$$

$$\begin{aligned}\text{For process 2-3} \quad \Delta E &= Q - W = 42000 - 0 \\ &= 42,000 \text{ kJ/min}\end{aligned}$$

$$\begin{aligned}\text{For process 3-4} \quad \Delta E &= Q - W = -4200 - W \\ -73500 &= -4200 - W \\ W_{3-4} &= 73500 - 4200 \\ &= 69300 \text{ kJ/min}\end{aligned}$$

Net Heat transfer during a cycle = -300 kJ

Number of cycles per minute = 220

Total Heat transfer per minute = -300×220

$$\Sigma Q = -66000 \text{ kJ/min}$$

W.K.T

$$\Sigma Q = Q_{1-2} + Q_{2-3} + Q_{3-4} + Q_{4-1}$$

$$-66,000 = 0 + 42,000 + (-4200) + Q_{4-1}$$

$$Q_{4-1} = -103800 \text{ kJ/min}$$

W.K.T

$$\Sigma Q = \Sigma W \text{ for a cycle}$$

$$\Sigma W = W_{1-2} + W_{2-3} + W_{3-4} + W_{4-1}$$

$$-66,000 = 4350 + 0 + 69300 + W_{4-1}$$

$$W_{4-1} = -139650 \text{ kJ/min}$$

$\Sigma \Delta E = 0$ because ΔE is a property

$$0 = \Delta E_{1-2} + \Delta E_{2-3} + \Delta E_{3-4} + \Delta E_{4-1}$$

$$0 = (-4350) + 42000 + (-73500) + \Delta E_{4-1}$$

$$\Delta E_{4-1} = 35850 \text{ kJ/min}$$

By Substitution :-

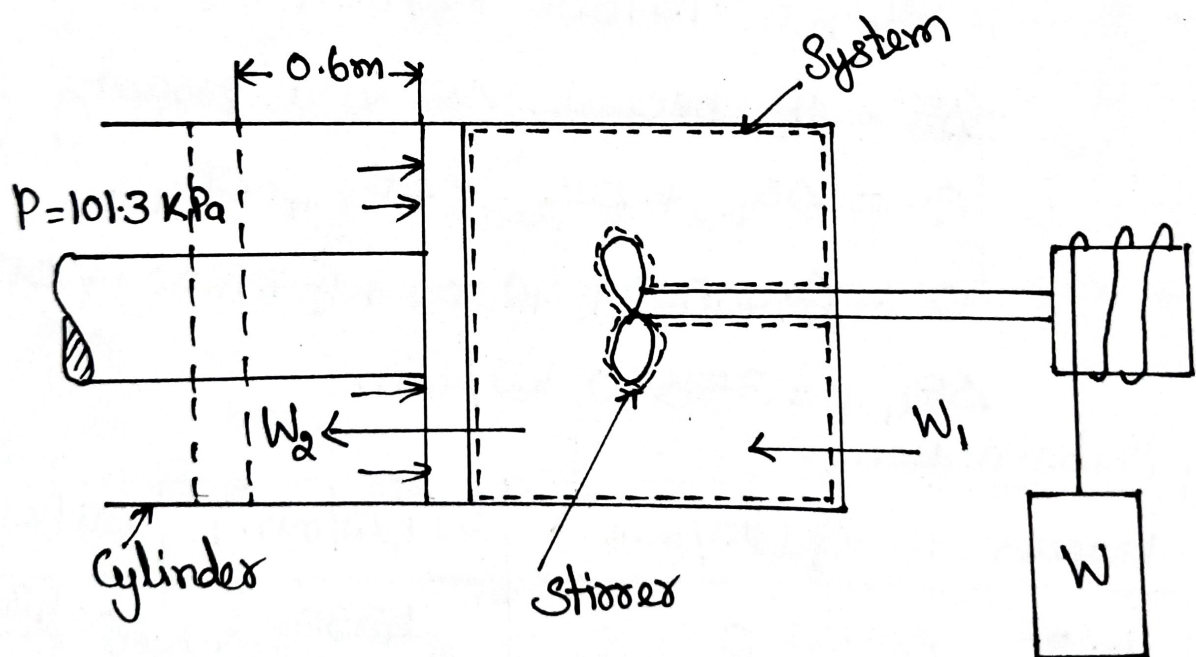
Process	$Q \text{ (kJ/min)}$	$W \text{ (kJ/min)}$	$\Delta E \text{ (kJ/min)}$
1-2	0	4350	-4350
2-3	42,000	0	42,000
3-4	-4200	69300	-73500
4-1	-103800	-139650	35850
	$\Sigma Q = -66,000$	$\Sigma W = -66,000$	$\Sigma \Delta E = 0$

$$\text{Total work output } \Sigma W = -66,000 \text{ kJ/min}$$

$$= \frac{-66,000}{60} = -1100 \text{ kW}$$

$$\text{Net rate of work output} = -1100 \text{ kW}$$

8. A piston and cylinder machine containing a fluid system has a stirring device as shown in fig. The piston is frictionless, and it is held down against the fluid due to atmospheric pressure of 101.3 kPa . The stirring device is turned 9500 revolutions with an average torque against the fluid of 1.25 Nm . Meanwhile the piston of 0.65 m diameter moves out 0.6 m . Find the net work transfer for the system.



Sol:-

W_1 = Work done by the stirring device upon the system (- negative work)

W_2 = Work done by the system upon the surroundings (+ positive work)

$$W_1 = 2\pi NT$$

where $T = \text{torque} = 1.25 \text{ Nm}$

$N = \text{number of revolution} = 9500$

$$W_1 = 2 \times \pi \times 9500 \times 1.25 = 74612.82 \text{ Nm}$$

$$W_1 = -74.612 \text{ kJ}$$

$$W_2 = P(A \cdot L)$$

where $A = \text{Area of the piston} = \frac{\pi}{4} d^2 = \frac{\pi}{4} \times (0.65)^2$

$$A = 0.3318 \text{ m}^2$$

$$1 \text{ Pa} = 1 \text{ N/m}^2$$

$$W_2 = 101.3 \times 0.3318 \times 0.6$$

$$W_2 = 20.167 \text{ kJ}$$

$$\text{Net work transfer } \Sigma W = W_1 + W_2$$

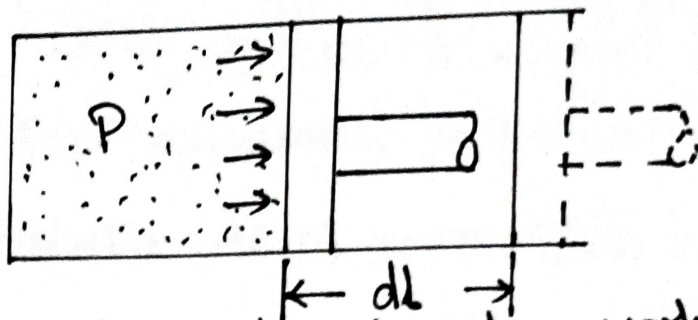
$$= -74.612 + 20.167$$

$$\Sigma W = -54.455 \text{ kJ}$$

9. a. Derive the expression for displacement work or.

b. Derive the expression for boundary work..

Consider a piston cylinder arrangement as shown in fig. If the pressure of the fluid is greater than that of the surrounding, there will be an unbalanced force on the face of the piston. Hence the piston will move towards right. Here the work is done by the displacement of the piston or movement of the boundary. Hence this work is called displacement work or boundary work.



Displacement or boundary work

The force acting on the piston = Pressure $\times$ Area

$$F = P \times A$$

$$\therefore \text{Work done (W)} = \text{Force} \times \text{displacement}$$

$$= P \times A \times dl$$

$$W = P dV$$

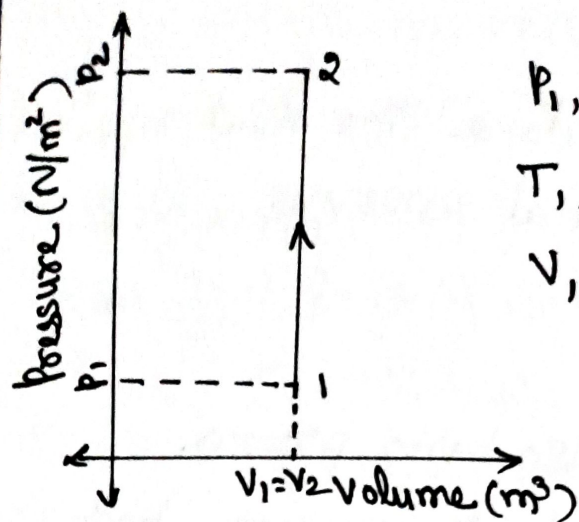
where dV - change in volume in m^3

10. a. Derive the equation for work done, change in Internal energy, and Heat transfer for the following processes. i) Isochoric ii) Isothermal iii) Isobaric iv) Isentropic v) Polytropic.

or
b. Derive the relationship between p, v, T for the following processes i) Constant volume ii) Constant pressure, iii) Constant temperature iv) Adiabatic and v) Polytropic processes.

1. Constant volume or Isochoric process.

When a gas is heated at a constant volume, its temperature and pressure will increase. This is called as constant volume process. Here the gas is heated in a fixed space, no work is done by the system. The entire heat supplied is stored in gas itself as internal energy.



P_1, P_2 are pressure at initial and final states.
 T_1, T_2 are temperature at "
 V_1, V_2 are volume at "

Relation between P, V and T .

From characteristic gas equation,

$$\frac{PV}{T} = C \Rightarrow \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

In this process $V_1 = V_2$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \Rightarrow \boxed{\frac{P_1}{P_2} = \frac{T_1}{T_2}}$$

Work done (W):

Work done during any process is given by

$$W = \int_1^2 p dv \Rightarrow p \int_1^2 dv = p[v]_1^2 = p[v_2 - v_1]$$

$$W = 0$$

$$(\because V_1 = V_2)$$

change in internal energy (ΔU):

For any process change in internal energy is

$$\Delta U = \int_1^2 m C_v dT = m C_v \int_1^2 dT$$

$$\Delta U = m C_v (T_2 - T_1)$$

Heat transfer (Q):

From First law of thermodynamics.

$$Q = \Delta U + W$$

$$Q = \Delta U = m C_v (T_2 - T_1)$$

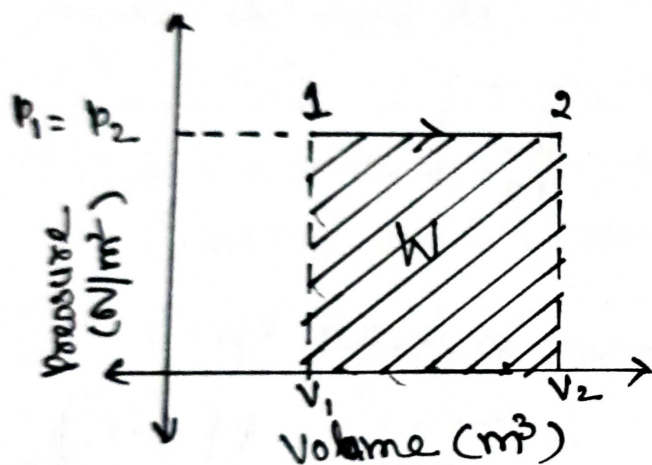
change in enthalpy (ΔH):

In this process no work is done the heat supplied is stored in the gas as internal energy.

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

Constant pressure process or Iso baric process.

When a gas is heated at constant pressure, both volume and temperature will increase. The gas expands in the cylinder and pushes the piston outwards, thus the work is done by the gas.



Relation between P , V and T

From characteristic gas equation

$$\frac{PV}{T} = C \Rightarrow \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

In this process $P_1 = P_2$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \Rightarrow \boxed{\frac{V_1}{V_2} = \frac{T_1}{T_2}}$$

Work done (W):

$$W = \int_{V_1}^{V_2} P dv = P \int_{V_1}^{V_2} dv = P(V_2 - V_1)$$

$$\boxed{W = P_2 V_2 - P_1 V_1} \quad \text{or} \quad \boxed{W = mR[T_2 - T_1]}$$

$$[\because PV = mRT]$$

change in internal energy (ΔU):

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

Heat transfer (Q):

From first law of thermodynamics

$$Q = \Delta U + W$$

$$Q = U_2 - U_1 + (P_2V_2 - P_1V_1)$$

$$Q = (U_2 + P_2V_2) - (U_1 + P_1V_1)$$

$$Q = h_2 - h_1$$

$$Q = mC_p(T_2 - T_1)$$

change in enthalpy (ΔH):

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

Constant temperature or Isothermal process.

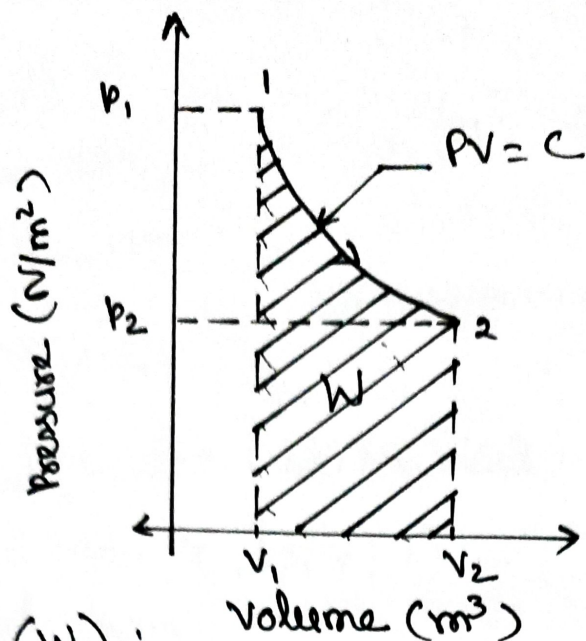
In this process, the temperature remains constant, the pressure and volume varies during the process. Hence there is no change in temperature, there is no change in internal energy and enthalpy because both are functions of temperature only. Isothermal process is very slow process so that the temperature is maintained constant during the process.

Relation between P , V and T

$$\frac{PV}{T} = C \Rightarrow PV = CT$$

$$T_1 = T_2 = T$$

$$P_1V_1 = P_2V_2 \Rightarrow \boxed{\frac{P_1}{P_2} = \frac{V_2}{V_1}}$$



Work done (W):

$$W = \int_{v_1}^{v_2} p \, dv$$

From gas equation $\frac{pV}{T} = c \Rightarrow p = \frac{c}{V}$

$$W = \int_{v_1}^{v_2} \frac{c}{V} \cdot dv \Rightarrow c \int_{v_1}^{v_2} \frac{dv}{V} \Rightarrow c \ln[V]_1^2$$

$$= c \ln[V_2 - V_1] = c \ln \left[\frac{V_2}{V_1} \right]$$

$$W = pV \ln \left[\frac{V_2}{V_1} \right] \Rightarrow W = p_1 V_1 \ln \left[\frac{V_2}{V_1} \right] \text{ or } W = p_2 V_2 \ln \left[\frac{V_2}{V_1} \right]$$

$$W = nRT \ln \left[\frac{V_2}{V_1} \right]$$

Change in internal energy (ΔU):

$$\Delta U = nC_v (T_2 - T_1) = 0$$

$$\therefore T_1 = T_2$$

Heat transfer (Q):

$$Q = \Delta U + W$$

$$Q = W = pV \ln \left[\frac{V_2}{V_1} \right] \text{ or } nRT \ln \left[\frac{V_2}{V_1} \right]$$

change in Enthalpy (ΔH):

$$\Delta H = nC_p (T_2 - T_1) = 0$$

Reversible Adiabatic or Isentropic process.

Governing law :-

In adiabatic process there is no heat transfer takes place across the boundary.

$$Q = 0.$$

According to First law of thermodynamics

$$Q = \Delta U + W$$

$$\therefore Q = 0$$

$$\Delta U = -W$$

$$m C_v dt = -p dv$$

$$\frac{dv}{dt} = -\frac{p dv}{m C_v} \quad \text{--- (1)}$$

The characteristic gas equation is

$$PV = mRT \quad \rightarrow \text{differentiate on both sides}$$

$$P \cdot dv + v \cdot dp = mR dt$$

$$\frac{dt}{dt} = \frac{P dv + v \cdot dp}{mR} \quad \text{--- (2)}$$

Comparing (1) and (2)

$$-\frac{p dv}{m C_v} = \frac{P dv + v dp}{mR}$$

$$\frac{R}{C_v} = -\left(\frac{P dv + v dp}{p dv}\right)$$

W.K.T

$$C_p - C_v = R$$

$$\frac{C_p - C_v}{C_v} = -\frac{P dv}{p dv} - \frac{v dp}{p dv}$$

$$\frac{C_p}{C_v} - \gamma = -\gamma - \frac{v}{dv} \cdot \frac{dp}{p}$$

$$\gamma = -\frac{v}{dv} \cdot \frac{dp}{p}$$

$$v \cdot \frac{dv}{v} = -\frac{dp}{p}$$

Integrating both sides

$$\int \gamma \cdot \frac{dv}{v} + \int \frac{dp}{p} = 0$$

$$\gamma \cdot \ln v + \ln p = C$$

$$\ln v^\gamma + \ln p = C$$

$$\ln(p \cdot v^\gamma) = C$$

Taking anti log on both sides.

$$\boxed{p v^\gamma = C}$$

→ Adiabatic process follows this law.

Where γ - adiabatic index

Adiabatic process is the process in which neither heat is received nor rejected. There are two ways, a process can be adiabatic. Either the system is well insulated so that only a negligible amount of heat can pass through the boundary, or both the system and surrounding are at same temperature and therefore there is no temperature difference for heat transfer. Even though there is no heat transfer during the adiabatic process, the temperature of the system can still be changed by means of work. Adiabatic process is a very rapid process.

Relation between P, V and T :

W.K.T

$$P V^\gamma = C$$

$$P_1 V_1^\gamma = P_2 V_2^\gamma \Rightarrow$$

$$\boxed{\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^\gamma} \text{ or}$$

$$\boxed{\left(\frac{V_2}{V_1}\right) = \left(\frac{P_1}{P_2}\right)^{1/\gamma}}$$

— (1)

For the relation between P and T

From gas equation

$$\frac{PV}{T} = C$$

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

From equ. (1) replace the $\frac{V_2}{V_1} = \left(\frac{P_1}{P_2}\right)^{1/\gamma}$

$$\frac{T_2}{T_1} = \frac{P_2}{P_1} \cdot \left(\frac{P_1}{P_2}\right)^{1/\gamma} = \left(\frac{P_2}{P_1}\right) \left(\frac{P_2}{P_1}\right)^{-1/\gamma}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{1 - \frac{1}{\gamma}} \Rightarrow \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\boxed{\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}}$$

For the relation between V and T

From gas equation

$$\frac{PV}{T} = C$$

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

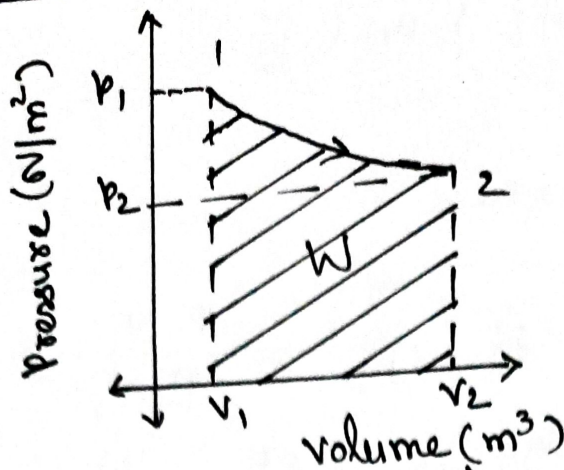
From equation (1) replace the $\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^\gamma$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^\gamma \cdot \frac{V_2}{V_1} \Rightarrow \left(\frac{V_1}{V_2}\right)^\gamma \cdot \left(\frac{V_1}{V_2}\right)^{-1}$$

$$\boxed{\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}}$$

Work done (W) :-

$$\text{Work done, } W = \int_1^2 p \, dv$$



For adiabatic process $PV^\gamma = C$

$$P = \frac{C}{V^\gamma}$$

$$W = \int_1^2 \frac{C}{V^\gamma} \cdot dV \Rightarrow C \int_1^2 V^{-\gamma} \cdot dV$$

$$W = C \left[\frac{V^{-\gamma+1}}{-\gamma+1} \right]_1^2 \Rightarrow \frac{C}{1-\gamma} \left[V_2^{-\gamma+1} - V_1^{-\gamma+1} \right]$$

$$W = \frac{PV^\gamma}{1-\gamma} \left[V_2^{-\gamma+1} - V_1^{-\gamma+1} \right]$$

$$W = \frac{1}{1-\gamma} \left[P_2 \cdot V_2 \cdot V_2^{-\gamma} - P_1 \cdot V_1 \cdot V_1^{-\gamma} \right]$$

$$W = \frac{1}{1-\gamma} \left[P_2 \cdot V_2 - P_1 \cdot V_1 \right]$$

$$W = \frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$$

$$\text{or } W = \frac{mR [T_1 - T_2]}{\gamma - 1}$$

Heat transfer Q :-

There is no heat transfer during adiabatic process

$$Q = 0$$

change in internal energy ΔU :

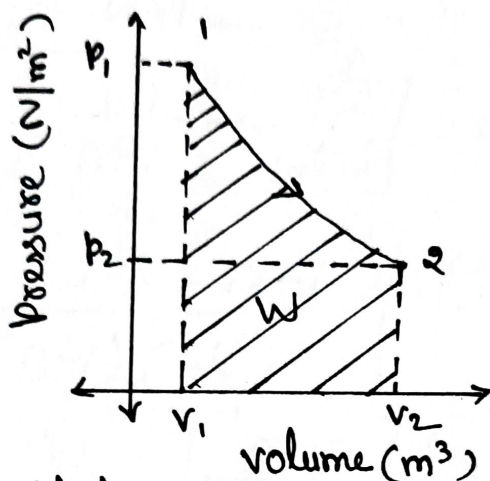
$$\Delta U = mC_v (T_2 - T_1)$$

change in Enthalpy (ΔH) :

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

Polytropic process :-

This process follows the law $PV^n = \text{constant}$, where n is polytropic index. It is also called as a general law of expansion and compression of gases.



P, V and T relation :-

The P, V and T relation can be derived in the same manner as in adiabatic process.

$$\frac{P_1}{P_2} = \left(\frac{V_2}{V_1} \right)^n$$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2} \right)^{n-1}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}}$$

Work done W :-

$$\text{Work done, } W = \frac{P_1 V_1 - P_2 V_2}{n-1} \quad \text{or} \quad \frac{mR(T_1 - T_2)}{n-1}$$

Change in Internal energy ΔU :

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

Change in Enthalpy (ΔH) :

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

Heat transfer Q :-

$$Q = \Delta U + W$$

$$Q = m C_v (T_2 - T_1) + \frac{m R (T_1 - T_2)}{n-1}$$

$$Q = \frac{m R (T_2 - T_1)}{\gamma-1} + \frac{m R (T_2 - T_1)}{1-n}$$

$$Q = m R (T_2 - T_1) \left[\frac{1}{\gamma-1} + \frac{1}{1-n} \right]$$

$$Q = m R (T_2 - T_1) \left[\frac{1-n + \gamma-1}{(\gamma-1)(1-n)} \right]$$

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

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

$$Q = W \left[\frac{\gamma-n}{\gamma-1} \right]$$

where $W = \frac{m R (T_1 - T_2)}{n-1}$

$$C_p - C_v = R$$

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

$$C_p = \gamma \cdot C_v$$

$$C_p = \frac{\gamma \cdot R}{(\gamma-1)}$$

W.K.T

$$C_p - C_v = R$$

$$\left(\frac{C_p}{C_v} - 1 \right) C_v = R$$

$$(\gamma-1) C_v = R$$

$$C_v = \frac{R}{(\gamma-1)}$$

Process	P, V and T relations	Change in Internal Energy kJ	Change in Enthalpy kJ	Work done kJ	Heat transfer kJ
Constant Volume process	$\frac{P_1}{P_2} = \frac{T_1}{T_2}$	$m C_V (T_2 - T_1)$	$m C_V (T_2 - T_1)$	0	$m C_V (T_2 - T_1)$
Constant pressure process	$\frac{V_1}{V_2} = \frac{T_1}{T_2}$	$m C_V (T_2 - T_1)$	$m C_P (T_2 - T_1)$	$P(V_2 - V_1)$ or $m R (T_2 - T_1)$	$m C_P (T_2 - T_1)$
Constant temperature process	$\frac{P_1}{P_2} = \frac{V_2}{V_1}$	0	0	$P_1 V_1 \ln \left(\frac{V_2}{V_1} \right)$ or $m R T_1 \ln \left(\frac{V_2}{V_1} \right)$	$P_1 V_1 \ln \left(\frac{V_2}{V_1} \right)$ or $m R T_1 \ln \left(\frac{V_2}{V_1} \right)$
Reversible Adiabatic process	$\frac{P_1}{P_2} = \left(\frac{V_2}{V_1} \right)^\gamma$ $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2} \right)^{\gamma-1}$ $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}}$	$m C_V (T_2 - T_1)$	$m C_P (T_2 - T_1)$	$\frac{P_1 V_1 - P_2 V_2}{\gamma - 1}$ or $\frac{m R (T_1 - T_2)}{\gamma - 1}$	0
Polytropic process	$\frac{P_1}{P_2} = \left(\frac{V_2}{V_1} \right)^n$ $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2} \right)^{n-1}$ $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1} \right)^{\frac{n-1}{n}}$	$m C_V (T_2 - T_1)$	$m C_P (T_2 - T_1)$	$\frac{P_1 V_1 - P_2 V_2}{n - 1}$ or $\frac{m R (T_1 - T_2)}{n - 1}$	$\frac{m R (T_1 - T_2)}{n - 1} \left[\frac{\gamma - n}{\gamma - 1} \right]$ or $W \left[\frac{\gamma - n}{\gamma - 1} \right]$