Properties of Gases
* Numericals *

3.14 3 kg of ethane gas is compressed according to the law '$pv^{1.3}$ = constant' from 1.013 bar, 27°c to 8 bar pressure. Determine (i) heat transferred (ii) work done, (iii) Change in Internal energy. Molecular weight of ethane is 30 kg/kg.mol & $C_p = 1.75$ kJ/kg K for ethane. Assume ethane is a perfect gas. [$R_0 = 8314.4$ J/kg.mol K].

sol^n.:- Given data:

$m = 3$ kg   polytropic index $n = 1.3$

$P_1 = 1.013 \times 10^5$ N/m², $P_2 = 8 \times 10^5$ N/m²

$T_1 = 27°c \rightarrow 273 + 27 = 300$ K

M (molecular weight) = 30 kg/kg.mol, $C_p = 1.75$ kJ/kg.K &

$R_0 = 8314.4$ J/kg.mol K.

& $Q = ?$, $W = ?$, $\Delta U = ?$

* Work done for polytropic process:-

$$W = \frac{P_1V_1 - P_2V_2}{n-1} \quad \text{or} \quad W = \frac{mR(T_1 - T_2)}{n-1}$$

→ For T_2,

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

$$\therefore \frac{T_2}{300} = \left(\frac{8 \times 10^5}{1.013 \times 10^5}\right)^{\frac{1.3-1}{1.3}}$$

$$\therefore T_2 = 300(7.897)^{0.231}$$

$$\therefore T_2 = 300 \times 1.6118$$

$$\therefore T_2 = 483.54 \text{ K}$$

R = Ro / M

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Ro =

→ for Characteristic gas Constant;

$$R = \frac{R_0}{M} = \frac{8314.4}{30} = 277.14 \text{ J/kg.K}$$
$$= 0.277 \text{ kJ/kg.K}$$

$\therefore W = \frac{mR(T_1 - T_2)}{n-1}$

$\therefore W = \frac{3 \times 0.277(300 - 483.54)}{1.3-1}$

$= \frac{0.831(-183.54)}{0.3}$

$= -508.40 kJ$

• Also, change in Internal energy;

$\Delta U = mC_v \Delta T$

$= mC_v(T_2 - T_1)$

$= 3 C_v (483.54 - 300)$

$= 550.62 \, C_v$

→ For C_v :- we have $C_p - C_v = R$

$\therefore C_v = C_p - R$

$= 1.75 - 0.277 = 1.473 \; kJ/kg \cdot K$

$\therefore \Delta U = 550.62 \times 1.473$

$= 811.06 \; kJ$

+ Heat transferred : $Q = \Delta U + W$

$= 811.06 - 508.40$

$= 302.66 \; kJ$

Q3.15 One cubic metre of air at pressure 1 bar & 60°C is compressed final pressure 6 bar & volume $0.25 m^3$. Determine (i) mass of (ii) index 'n' for compression, (iii) Change in internal energy, (iv) heat transferred. (Take $\gamma = 1.4$ & $R = 287 \; J/kg$

Solⁿ.

$V_1 = 1 m^3$, $V_2 = 0.25 m^3$

$P_1 = 1 \times 10^5 \; N/m^2$, $P_2 = 6 \times 10^5 \; N/m^2$, $T_1 = 60 + 273 = 333 K$

& $m = ?$, $n = ?$, $\Delta U = ?$, $Q = ?$

* For 'm'; we have eqⁿ. $P_1V_1 = mRT_1$

$\therefore m = P_1V_1/RT_1$

$= 10^5/95571$

$\therefore m = 1.046\ kg$

* Index 'n';

$P_1V_1^n = P_2V_2^n$

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

$\therefore 0.166 = (0.25)^n$

$\therefore \log(0.166) = n\log(0.25)$

$-0.779 = n(-0.602)$ $\therefore n = 1.29$

* For Δu; $\Delta U = mC_v(T_2 - T_1)$

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

$= \frac{287}{0.4} = 717\ J/kg\,K$

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

$\therefore T_2 = T_1 \cdot (1/0.25)^{0.29}$

$\therefore T_2 = 496.17\ K.$

$\therefore \Delta u = m\,C_v(T_2 - T_1)$

$= 1.046(0.717)(163.17)$

$= 122.37\ kJ$

* Workdone; $W = \frac{mR(T_1 - T_2)}{n-1}$

$= \frac{1.046(287)(-163.17)}{0.29} \rightarrow W = -168910\ J$

$= -168.91\ kJ$

* Heat transferred;

$Q = \Delta u + W$ (Accⁿ to first law of Thermodynamics)

$\therefore Q = 122.37 + (-168.91)$

$= -46.54\ kJ$

Q. 3.28 A steel cylinder contains O_2 at a pressure of 25 bar & temprature 27°C. After using some quantity of gas, the pressure was found to be 5 bar at 20°C. 700 litres of O_2 was

4 ~~originally put into cylinder at N.T.P.~~

Density of O_2 at NTP is 1.43 gm/litre. Find mass of O_2 used.

Solⁿ: Given data:-

$p_1 = 25$ bar , $p_2 = 5$ bar

$T_1 = 27+273 = 300K$, $T_2 = 20+273 = 293$ K

Initial volume of O_2 = 700 litres = 0.7 m^3

Pressure at NTP: $p = 101.325$ kPa

Temprature at NTP, $T = 0°C = 273$ K

We have, $pV = mRT$

$\therefore p\frac{V}{m} = RT$, as $\frac{m}{V} = \rho$

$\therefore \frac{p}{\rho} = RT$

$\therefore R = \frac{p}{\rho \cdot T} = \frac{101.325}{1.43 \times 273} = 0.26$ kJ/kg.K

$\therefore m_1 = \frac{pV}{RT} = \frac{101.325 \times 0.7}{0.26 \times 273} = 0.999 \simeq 1$ kg.

→ Volume of tank, $V_1 = \frac{m_1 R T_1}{p_1} = \frac{1 \times 0.26 \times 300}{2500}$

$= 0.0312\ m^3$.

→ Final mass, $m_2 = \frac{p_2 V_1}{R T_2} = \frac{500 \times 0.0312}{0.26 \times 293}$

$\therefore m_2 = 0.205$ kg.

$\therefore$ Mass of O_2 which is used $= m_1 - m_2$

$= 1 - 0.205$

$= 0.795$ kg

Jenish Patel

THERMODYNAMIC PROCESSES.

— Jenish Patel

	Types of process	Governing equations	Heat interaction Q	Work done during state change from 1 to 2. $\therefore W = \int_1^2 p\,dV$	Change in Internal energy ΔU	Change in Enthalpy ΔH
1)	Isobaric process $P =$ constant	$\frac{T_2}{T_1} = \frac{V_2}{V_1}$ index $n = 0$	$m C_p (T_2 - T_1)$	$W = p(V_2 - V_1)$	$\Delta U = m C_v (T_2 - T_1)$	$\Delta H = m C_p (T_2 - T_1)$
2)	Isochoric process. (Constant volume process)	$\frac{T_1}{T_2} = \frac{P_1}{P_2}$ index $n = \infty$	$m C_v (T_2 - T_1)$	$W = 0$	$\Delta U = m C_v (T_2 - T_1)$	$\Delta H = m C_p (T_2 - T_1)$
3)	Isothermal process (Constant tempreture process)	$P_1 V_1 = P_2 V_2$ index $n = 1$	$= P_1 V_1 \log_e \left(\frac{V_2}{V_1}\right)$ $= P_1 V_1 \log_e \left(\frac{P_1}{P_2}\right)$	$W = P_1 V_1 \log_e \left(\frac{V_2}{V_1}\right)$ $= P_1 V_1 \log_e \left(\frac{P_1}{P_2}\right)$	$\Delta U = 0$	$\Delta H = 0$

	Types of process	Governing equations	Heat interaction 'Q'	Work done during state change from 1 to 2 $W = \int_1^2 p\,dV$	Change in Internal energy ΔU	change in Enthalpy ΔH
4)	ADIABATIC PROCESS	• $P_1V_1^{\gamma} = P_2V_2^{\gamma}$ • $\left(\frac{T_1}{T_2}\right) = \left(\frac{V_2}{V_1}\right)^{\gamma-1}$ • $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$ • index $n = \gamma$	0	$W = \frac{P_1V_1 - P_2V_2}{\gamma - 1}$ also, $W = \frac{mR(T_1 - T_2)}{\gamma - 1}$	$\Delta U = mC_v(T_2 - T_1)$	$\Delta H = mC_p(T_2 - T_1)$
5)	POLYTROPIC PROCESS	• $P_1V_1^{n} = P_2V_2^{n}$ • $\left(\frac{T_1}{T_2}\right) = \left(\frac{V_2}{V_1}\right)^{n-1}$ • $\left(\frac{T_2}{T_1}\right) = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$	$\left(\frac{\gamma - n}{\gamma - 1}\right) \times$ work	$W = \frac{P_1V_1 - P_2V_2}{n - 1}$	$\Delta U = mC_v(T_2 - T_1)$	$\Delta H = mC_p(T_2 - T_1)$