UNIT- 1

BASIC CONCEPTS AND FIRST LAW.

INTRODUCTION:

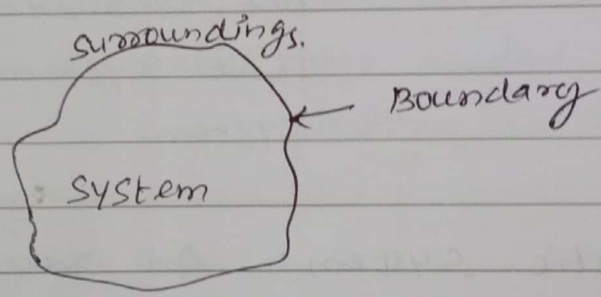
Thermodynamics is the science that deals with the interaction between energy and material system.
(or) mass of

(or)

Thermodynamics is an axiomatic science which deals with the relations among heat, work and properties of system which are in equilibrium.

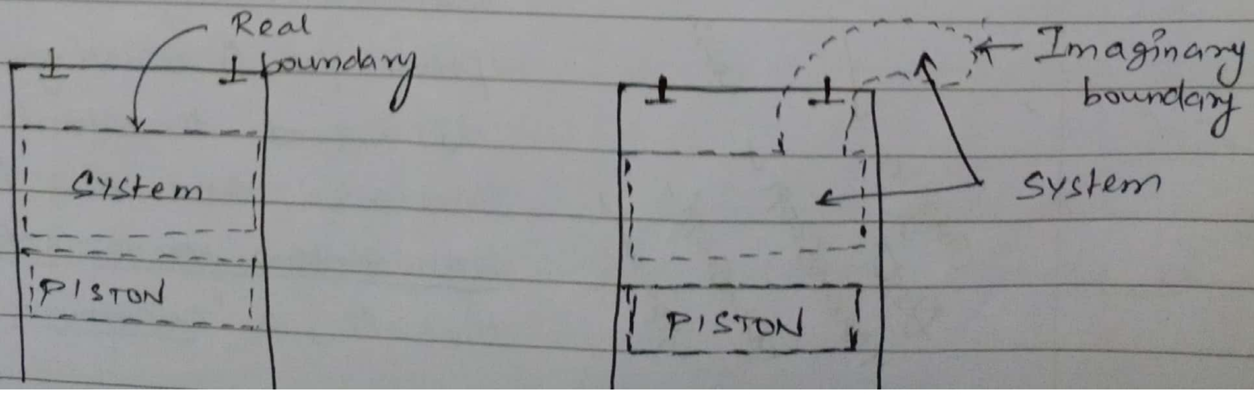
Thermodynamic systems:

System: A system is a finite quantity of matter or a prescribed region of space.



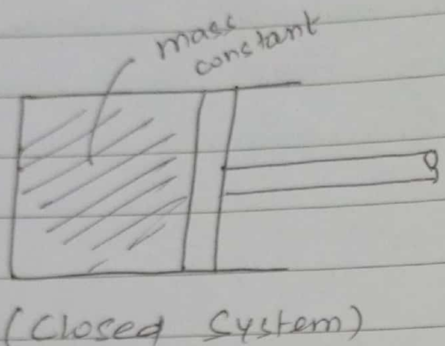
Boundary: → The actual or hypothetical envelope enclosing the system is the boundary of the system. The boundary may be fixed or it may move, as and when a system containing a gas is compressed (or) expanded.

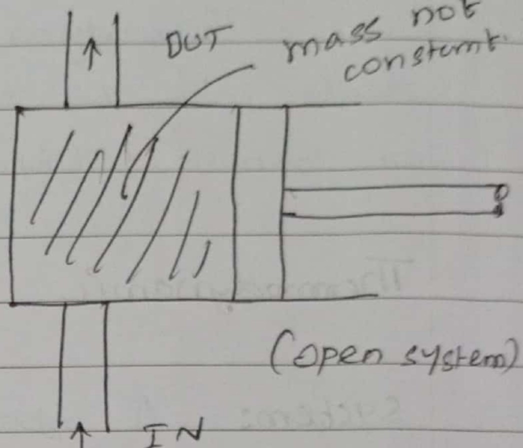
→ The boundary may be real (or) imaginary.



Closed system: If the boundary of the system is have constant mass is called as closed system. (Only Energy Transfer)

Open system: If the boundary of the system have mass transfer into it is called as open system. (BOTH) (mass & energy)





Isolated system: If the system, even energy is not allowed to cross the boundary that system is called an Isolated system.

Adiabatic system: An adiabatic system is one which is thermally insulated from its surroundings. It can exchange work with its surroundings. If it is not done, it becomes an isolated system.

Concept of continuum: Matter is made up of atoms that are widely spaced in the gas phase. Yet it is very convenient to disregard the atomic nature of a substance and view it as continuous homogeneous matter with no holes, that is, a "continuum" of space.

Only in Macroscopic not in Microscopic approach

Macroscopic approach	Microscopic approach
* This approach is concerned with gross or overall behaviour. This is known as classical thermodynamics.	This approach is concerned with molecules behaviour. This is known as statistical thermodynamics.
* To analysis of macroscopic system requires simple mathematical formulae.	* It requires advanced statistical and mathematical methods are needed to explain the changes in the system.
* pressure, temperature can be easily measured.	Such as velocities, momentum etc cannot be easily measured.
* In order to describe a system only a few properties are needed.	* Large number of variables are needed to describe a system. so it is complicated.

Thermodynamic properties, processes and cycles:

Every system has certain characteristics by which its physical condition may be described, eg volume, temperature, pressure etc. Such characteristics are called properties of the system.

→ When all the properties of a system have definite values, the system is said to exist at a definite "state".

→ Any operation in which one or more of the properties of a system changes is called "change of state".

→ The change of state is called as "path"

→ When the path is completely specified, the change of state is called a "process".
Eg. P=C, V=C, T=C ... etc.

→ A series of state of changes such that the final state is identical with the initial state is called as "cycle".

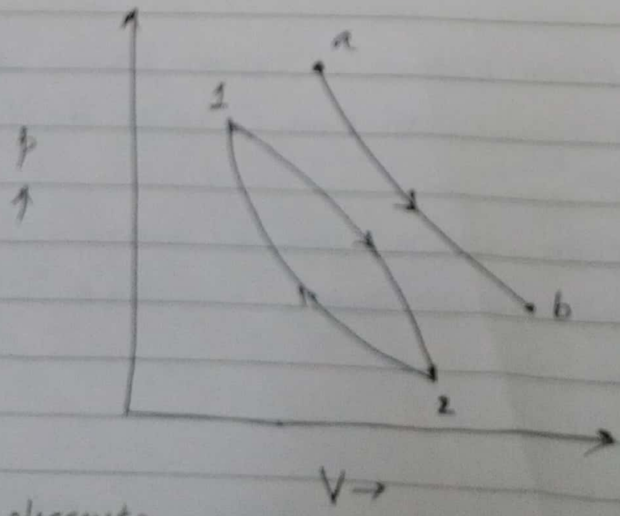
Properties are classified into two types,

* Intensive property.
* Extensive property.

Intensive property : It is independent of the mass in the system. Eg., pressure, temp.etc

Extensive Property : It is dependent of the mass (or) related to mass of the system.
Eg: Volume, energy etc.

NOTE : Specific extensive properties, i.e., extensive properties per unit mass are intensive properties
Eg: specific volume, specific energy, & density etc.



a and b are state.
a-b → Process.
1-2-1 → Cycle.

Thermodynamic Equilibrium:

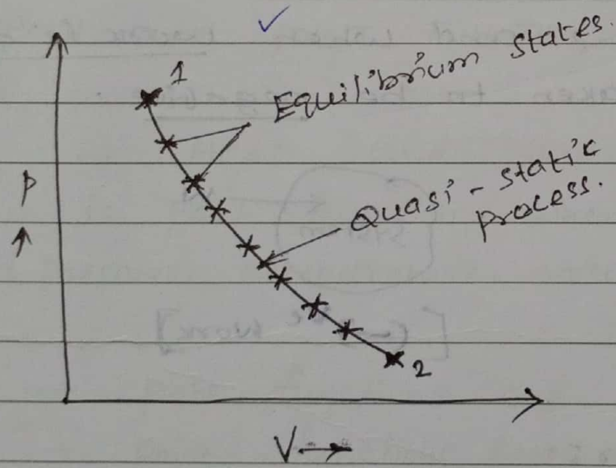
A system is said to exist in a state of thermodynamic equilibrium when no change in any macroscopic property of the system. Three types of equilibrium are;

→ Mechanical Equilibrium: Force is balanced within the system.

→ Chemical Equilibrium: No chemical reaction takes place within the system.

→ Thermal Equilibrium: Temperature is constant throughout of the system.

Quasi Static Process:



Quasi means 'almost'. So every state passed through by the system will be an equilibrium state, is known as Quasi-static Process. It is also called as "reversible Process".

Work and Heat transfer:

A closed system and its surroundings can interact in two ways. a) by work transfer and b) by heat transfer. These may be called energy interactions and these bring about changes in the properties of the system.

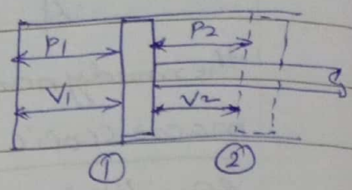
Work Transfer: (W)

→ Workdone = Force × distance

= Pressure × area × dl

= $p \times a \times dl$

= $p \times dv$.



Where, dv = displacement volume.

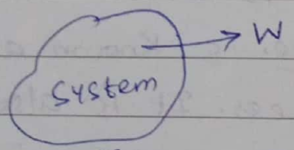
∴ When piston moves out from position 1 to position 2 with the change of volume from V_1 to V_2 by the system will be the amount of work (W) done

$$\boxed{W_{1-2} = \int_{V_1}^{V_2} p\,dv}$$

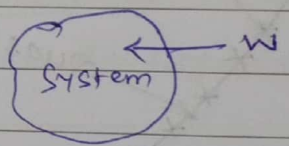
→ The unit of work is N.m (or) Joule (J).

NOTE : (Sign convention of work)

When work is done by a system, it is taken to be positive, and when work is done on a system, it is taken to be negative.



[+ve Work]



[(−)ve Work]

Types of Work transfer:

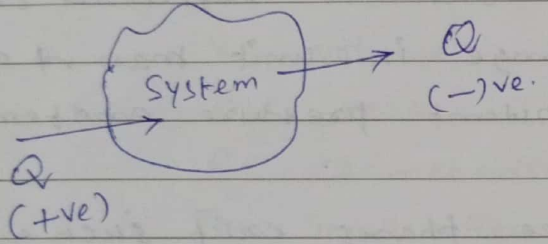
1. Electrical Work.
2. Shaft work.
3. Paddle-wheel work (or) Stirring work.
4. flow work etc.

Heat Transfer: (Q)

→ Whenever there is a difference in temperature, there will be heat flow. The temperature difference, is the cause and heat transfer is the effect.

→ The unit of heat is Joule in S.I units.

NOTE:
→ Sign convension of heat transfer is, heat flow into a system is taken to be positive, and heat flow out of a system is taken as negative.



PATH and POINT FUNCTION:

→ Heat and work transfer is path traced, so it is path function, where as thermodynamic properties (pressure, temperature, volume etc) are point function.

→ Path functions are inexact differentials.
→ Point functions are exact differentials.

$$\int_1^2 dQ = Q_{1-2} \quad \text{(or)} \quad \int_1^2 dW = W_{1-2} = \int_1^2 p\,dV.$$

NOTE:

* Area under the P-V diagram is Work transfer
* Area under the T-S diagram is Heat transfer.

It is valid for Quasi-static process only.

Specific heat: (C)

It is defined as the amount of heat required to raise a unit mass of the substance through a unit rise in temperature.

$$C = \frac{Q}{m \cdot \Delta t} \quad J/kg\text{-}K.$$

Latent heat :

(Phase change)

Amount of heat transfer required to cause a phase change in unit mass of a substance at a constant pressure and temperature.

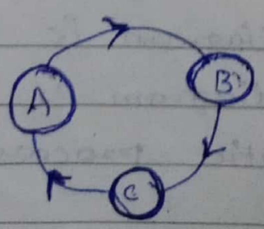
→ There are three phases exist such as solid, liquid and gas.

→ Solid to liquid (or) liquid to solid is called as Latent heat of fusion.

→ liquid to vapour (or) vapour to liquid is called as Latent heat of vapourization.

Zeroth Law of Thermodynamics:

When a body 'A' is in thermal ~~eqlb~~ equilibrium with a body 'B', and also separately with a body 'C', then B and C will be in thermal equilibrium with each other. This is known as "Zeroth Law of Thermodynamics".



Ideal gas equation:

It has been established from experimental observations that the P-v-T behaviour of gases at a low pressure is closed closly given by the following relation

$$pv = RT$$ v = specific volume (m^3/kg)

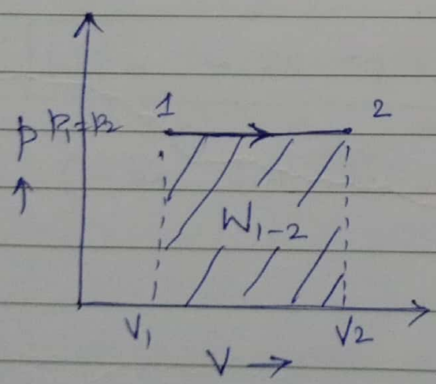
$$\therefore \boxed{PV = mRT}$$

Where,

P = Pressure in (kPa)
V = volume in (m^3)
m = mass in (kg)
R = Characteristic gas constant $= \frac{\bar{R}}{\mu}$ in KJ/KgK.
T = Temperature in (K)

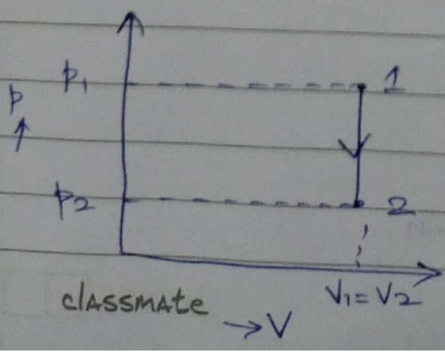
P-dv work in various processes:

(a) Constant pressure process (or) Isobaric process:



$$W_{12} = \int_{V_1}^{V_2} p\,dv = P(V_2 - V_1)$$

(b) constant volume process: (or) Isochoric process:



$$W_{1-2} = \int p\,dv = 0$$

(c) Constant temperature process : $(pv = c)$

$$pv = p_1 V_1 = c$$

$$p = \frac{p_1 V_1}{V}$$

$$W_{1-2} = \int_{V_1}^{V_2} p\,dv$$

$$= \int_{V_1}^{V_2} \frac{p_1 V_1}{V}\,dv$$

$$= p_1 V_1 \int_{V_1}^{V_2} \frac{dv}{V} \Rightarrow p_1 V_1 \ln\left(\frac{V_2}{V_1}\right)$$

$$\boxed{W_{1-2} = p_1 V_1 \ln\left(\frac{V_2}{V_1}\right)}$$

$$\because pV = p_1 V_1 = p_2 V_2$$

$$\frac{V_2}{V_1} = \frac{p_1}{p_2}$$

$$\boxed{W_{1-2} = mRT_1 \ln\left(\frac{p_1}{p_2}\right)}$$

$$\because (p_1 V_1 = mRT_1)$$

(d) Polytropic process $(pv^n = c)$:

$$pv^n = C \Rightarrow p_1 v_1^n = p_2 v_2^n$$

$$p = \frac{p_1 v_1^n}{v^n}$$

$$W_{1-2} = \int_{V_1}^{V_2} p\,dv$$

$$= \int_{V_1}^{V_2} \frac{p_1 V_1^n}{V^n}\,dv$$

$$= p_1 V_1^n \left[\frac{V^{-n+1}}{-n+1}\right]_{V_1}^{V_2}$$

$$= \frac{p_1 V_1^n}{1-n}\left[V_2^{1-n} - V_1^{1-n}\right]$$

$$= \frac{p_2 V_2^n \cdot V_2^{1-n} - p_1 V_1^n \cdot V_1^{1-n}}{1-n}$$

$$= \frac{P_2V_2 - P_1V_1}{1-n}$$

$$\boxed{W_{1-2} = \frac{P_1V_1 - P_2V_2}{n-1}}$$

Problem:

① A mass of 1.5 kg of air is compressed in a quasi-static process from 0.1 MPa to 0.7 MPa for which PV = const. The initial density of air is 1.16 kg/m². Find the workdone by the piston to compress the air.

Solution.

PV = constant.
(Temp is const).

$$W = P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$$

(or)

$$W = mRT_1 \ln\left(\frac{P_1}{P_2}\right)$$

$$= 1.5 \times 0.287 \times 300.34 \ln\left(\frac{100}{700}\right)$$

$$\boxed{W = -251.59 \text{ kJ}}$$

(−Ve indicates that compression)

Given data:

$m = 1.5$ kg

$P_1 = 0.1$ MPa $= 0.1 \times 10^3$ kPa

$P_2 = 0.7$ MPa $= 0.7 \times 10^3$ kPa

$\rho_1 = 1.16$ kg/m³.

$$\rho_1 = \frac{m}{V_1}$$

$$V_1 = \frac{m}{\rho_1} = \frac{1.5}{1.16}$$

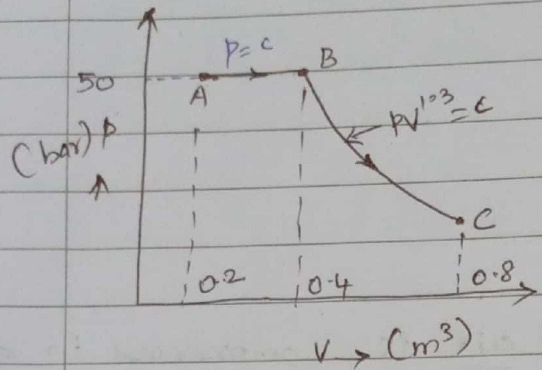
$$\boxed{V_1 = 1.293 \text{ m}^3}$$

$$P_1V_1 = mRT_1$$

$$T_1 = \frac{P_1V_1}{mR} = \frac{0.1 \times 10^3 \times 1.293}{1.5 \times 0.287}$$

$$\boxed{T_1 = 300.34 \text{ K}}$$

② Determine the total work done by a gas system following an expansion process as shown in fig.



Given data:

$P_A = P_B = 50$ bar

$= 5000$ KPa.

$V_A = 0.2\ m^3$

$V_B = 0.4\ m^3$

$V_C = 0.8\ m^3$.

Total workdone (W) = $W_{A-B} + W_{B-C}$

$W_{A-B} = P(V_B - V_A)$

$= 5000(0.4 - 0.2)$

$\boxed{W_{A-B} = 10{,}00\ KJ}$

$W_{B-C} = \dfrac{P_B V_B - P_C V_C}{n-1}$

$= \dfrac{(5000 \times 0.4) - (2030.63 \times 0.8)}{1.3 - 1}$

$PV^{1.3} = c$

$P_B V_B^{1.3} = P_C V_C^{1.3}$

$P_B \cdot \left(\dfrac{V_B}{V_C}\right)^{1.3} = P_C$

$5000 \cdot \left(\dfrac{0.4}{0.8}\right)^{1.3} = P_C$

$\therefore \boxed{P_C = \cancel{20{,}30.63}\ KPa}$

Calculate by Calculator

$\boxed{W_{B-C} = \cancel{5415.01}\ KJ}$

Total workdone = 1000 + ~~5415.01~~

= ~~6415.01~~ KJ

= ~~6.415~~ MJ.

Book Ans: 2952 KJ.

First Law of Thermodynamics:

The transfer of heat and the performance of work may both cause the same effect in a system. Heat and work are different forms of the same entity, called energy, which is conserved. Energy which enters a system as heat may leave the system as work, (or) energy which enters the system as work may leave as heat. Therefore, its intrinsic energy (or) internal energy is unchanged for an cyclic process. Therefore, the first law of thermodynamic states that,

"When a system undergoes a thermodynamic cycle then the net heat supplied to the system from the surroundings is equal to net workdone by the system on its surroundings."

$$\boxed{\oint dQ = \oint dW}$$

Where $\oint$ represents the sum of complete cycle.

Application of First Law to a process:

" When a process is executed by a system, the change in stored energy of the system is numerically equal to the net heat interactions minus the net work interaction during the process.

$$E_2 - E_1 = Q - W$$

$$\Delta E = Q - W \quad \text{(or)} \quad \boxed{Q = \Delta E + W}$$

Where, E - Represents the total internal energy.

If the electric, magnetic and chemical energies are absent, and changes in potential and kinetic energy for a closed system are neglected, the above equation can be written as

$$Q - W = \Delta U = U_2 - U_1$$

$$\boxed{Q = W + \Delta U}$$

NOTE:

The Joule's law states that,

The internal energy of a perfect gas is a function of the absolute temperature only.

$$u = f(T)$$

Specific heat at constant volume, (C_v) is rate of change of internal energy with respect to temp at const. volume,

$$C_v = \left(\frac{\partial u}{\partial T}\right)_v$$

for constant volume process, (1-2)

$$(\Delta u)_v = \int_{T_1}^{T_2} C_v \, dT$$

$$u_2 - u_1 = C_v (T_2 - T_1)$$

$$u_{1-2} = C_v (T_2 - T_1) \qquad \because u = \frac{U}{m}$$

$$\Rightarrow \frac{U_{1-2}}{m} = C_v (T_2 - T_1)$$

$$\boxed{U_{1-2} = m C_v (T_2 - T_1)}$$

Enthalpy:

$$h = u + pv$$

Total enthalpy of mass (m) of a fluid can be,

$$H = U + PV$$

from equation $h = u + pv$ $\quad \because pv = RT$

$= C_v T + RT$

$= (C_v + R) T$ $\quad \because$ ~~CpAld+RT~~

$h = C_p . T$

$\boxed{H = mC_p T}$ $\quad \because [C_p - C_v = R]$

$[\gamma = C_p / C_v]$

PERPETUAL MOTION MACHINE OF FIRST KIND (PMM1):

The first law states that principle of the conservation of energy. ~~Either is~~ Energy is neither created nor destoryed, but only gets transformed from one form to another. There can be no machine which would continuously supply mechanical work without some other form of energy disappearing simultaneously. Such a fictitious machine is called PMM-1. A PMM-1 is thus impossible.

(3) A stationary mass of gas is compressed without friction from an initial state of $0.3 \ m^3$ and 0.105 MPa to a final state of $0.15 \ m^3$ and 0.105 MPa, the pressure remaining constant during the process. There is a transfer of 37.6 kJ of heat from the gas during the process. How much does the internal energy of the gas change?

Given data:

$V_1 = 0.3 m^3$, $V_2 = 0.15 m^3$, $P = C \Rightarrow 0.105 MPa = 105 kPa$.

Solution:

For a process, First law given.

$$Q = W + \Delta u \quad \text{——} \quad ①$$

$$Q_{1-2} = W_{1-2} + (u_2 - u_1)$$

$$W_{1-2} = \int_1^2 p\,dV \Rightarrow \left[105 \times (V_2 - V_1)\right]$$

$$\Rightarrow \left[105 \times (0.15 - 0.3)\right]$$

$$\boxed{W_{1-2} = -15.75 \text{ KJ}}$$

$$Q_{1-2} = -37.6 \text{ KJ.}$$

Sub in equ ①

$$-37.6 = -15.75 + (u_2 - u_1)$$

$$\therefore u_2 - u_1 = \Delta u = -21.85 \text{ KJ.}$$

$\therefore$ The internal energy of the gas decreases by 21.85 KJ in the process.

④ A piston and cylinder machine contains a fluid system which passes through a complete cycle of four processes. During a cycle, the sum of all heat transfer is −170 KJ. The system completes 100 cycles per min. Complete the following table showing the method for each item, and compute the net rate of work output in KW.

Process	Q (KJ/min)	W (KJ/min)	ΔE (KJ/min)
a-b	0	2170	–
b-c	21,000	0	–
c-d	-2,100	–	–
d-a	–	–	-36,600

Solution:

Process a-b:

$$Q = \Delta E + W$$
$$0 = \Delta E + 2170$$
$$\Delta E = -2,170 \text{ kJ/min}$$

Process b-c:

$$Q = \Delta E + W$$
$$21,000 = \Delta E + 0$$
$$\Delta E = 21,000 \text{ kJ/min}$$

Process c-d:

$$Q = \Delta E + W$$
$$-2,100 = -36,000 + W$$
$$W = 34,500 \text{ kJ/min.}$$

Process (d-a):

$$\Sigma_{cycle} Q = -170 \text{ kJ.}$$

The ~~cycle~~ system complete one cycle is 100 cycle/min

$$\therefore Q_{a-b} + Q_{b-c} + Q_{cd} + Q_{da} = -17000 \text{ kJ/min}$$
$$0 + 21,000 - 2100 + Q_{da} = -17,000$$
$$\boxed{Q_{da} = -35,900 \text{ kJ/min.}}$$

Now $\oint \Delta E = 0$, Since cyclic integral of any property is zero.

$$\Delta E_{a-b} + \Delta E_{b-c} + \Delta E_{c-d} + \Delta E_{d-a} = 0$$

$$-2170 + 21000 - 36600 + \Delta E_{d-a} = 0$$
$$\boxed{\Delta E_{d-a} = 17770 \text{ kJ/min}}$$

$Q_{d-a} = W_{d-a} + \Delta E_{d-a}$

$W_{d-a} = Q_{d-a} - \Delta E_{d-a}$

$= -35900 - 17770$

$\boxed{W_{d-a} = -53670 \ kJ/min}$

$\because \quad \Sigma Q = \Sigma W$ for cycle's process.

$-17000 \ kJ/min = \Sigma W$.

$\Sigma W = \frac{-17000}{60} = \underline{-283.3 \ kW}$

(5). A fluid is confined in a cylinder by a spring-loaded, frictionless piston so that the pressure in the fluid is a linear function of the volume ($p = a + bv$). The internal energy of the fluid is given by the following equation

$u = 34 + 3.15 \, pv$

Where u is in kJ, p in kPa, V in m3. If the fluid changes from an initial state of 170 kPa, 0.03 m3 to a final state of 400 kPa, 0.06 m3, with no work other than that done on the piston, find the direction and magnitude of the work and heat transfer.

Solution:

$u = 34 + 3.15 \, pv$

Given data:

$P_1 = 170$ kPa

$V_1 = 0.03 \ m^3$

$P_2 = 400$ kPa

$V_2 = 0.06 \ m^3$

$(P = a + bv)$

The change in internal energy

$u_2 - u_1 = \cancel{34}^{0} + 3.15 (P_2V_2 - P_1V_1)$

$$u_2 - u_1 = 3.15\,(400 \times 0.06 - 170 \times 0.03)$$

$$= 59.5 \text{ KJ.}$$

W.K.T $\quad p = a + bv.$

$$170 = a + b \times 0.03$$
$$400 = a + b \times 0.06$$

from these two equations, $\quad kN/m^2 = a + b \times m^3$

$$a = -60$$
$$b = 7667$$

Work transfer involved during the process,

$$W_{1-2} = \int_1^2 p\,dV = \int_1^2 (a + bv)\,dv \qquad a^2 - b^2 = (a+b)(a-b)$$

$$= a(V_2 - V_1) + b\left(\frac{V_2^2 - V_1^2}{2}\right)$$

$$= (V_2 - V_1)\left[a + \frac{b}{2}(V_1 + V_2)\right]$$

$$= 0.03\left[-60 + \frac{7667}{2} \times 0.09\right]$$

$$= 8.55 \text{ KJ.}$$

Work is done by the system, the magnitude being 8.55 kJ.

Heat transfer involved is given by.

$$Q_{1-2} = u_2 - u_1 + W_{1-2}$$

$$= 59.5 + 8.55$$

$$= 68.05 \text{ KJ}$$

$\therefore$ 68.05 kJ of heat flow into the system during the process.

⑥ A gas undergoes a thermodynamic cycle consisting of the following processes. (i) Process 1-2: Constant pressure $p = 1.4$ bar, $V_1 = 0.028\ m^3$, $W_{1-2} = 10.5$ KJ (ii) process 2-3: Compression with $pv =$ Constant, $U_3 = U_2$, (iii) Process 3-1: constant volume, $U_1 - U_3 = -26.4$ KJ. There are no significant changes in KE and PE. (a) Sketch the cycle on a p-V diagram. (b) Calculate the net work for the cycle in KJ. (c) Calculate the heat transfer for process 1-2 (d) Show that $\sum_{cycle} Q = \sum_{cycle} W$.

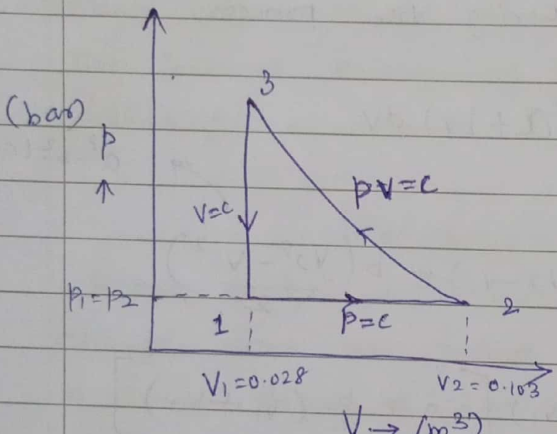
Solution:

Given data:

Process 1-2: $p = C$

Process 2-3: $pv = C$

Process 3-1: $V = C$



To find:

(i) Net work for a cycle in KJ

(ii) Q_{1-2}

(iii) $\sum Q = \sum W$ prove.

$p = p_1 = p_2 = 1.4$ bar $= 140$ kPa

$V_1 = 0.028\ m^3$

$W_{1-2} = 10.5$ KJ.

$U_1 - U_3 = -26.4$ KJ.

Process 1-2 $(p=C)$:

$\boxed{W_{1-2} = 10.5\ KJ}$

$W_{1-2} = p[(V_2 - V_1)]$

$10.5 = 140(V_2 - 0.028)$

$0.075 = V_2 - 0.028$

$\boxed{V_2 = 0.103\ m^3}$

$\therefore V_1 = V_3 = 0.028\ m^3$

Process 2-3: $(pv = c)$

$W_{2-3} = P_2 V_2 \ln\left(\frac{V_3}{V_2}\right)$

$= 140 \times 0.103 \ln\left(\frac{0.028}{0.103}\right)$

$\boxed{W_{2-3} = -18.78\ KJ}$

Process 3-1 : ($V=c$)

$$\boxed{W_{3-1} = 0}$$

$\therefore$ Net Work Transfer = $W_{1-2} + W_{2-3} + W_{3-1}$

$= 10.5 - 18.78$

$= -8.28$ KJ. Ans

(ii) $Q_{1-2} = ?$

$P_1V_1 = mRT_1$

$$Q_{1-2} = W_{1-2} + (U_2 - U_1)$$

Process 3-1: ($V=C$)

$U_1 - U_3 = -26.4$ KJ.

$= 10.5 + 26.4$ KJ

✓ $= 36.9$ KJ

$Q_{3-1} = W_{3-1} + \Delta U_{3-1}$

$Q_{3-1} = 0 + 26.4 = 26.4$ KJ

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

$Q_{2-3} = 0$

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

$-8.28 = Q_{1-2} + 0 + 26.4$

$Q_{1-2} =$

$= 36.9 + \cancel{0}\ (-18.78) + (-26.4)$

$\Sigma Q = -8.28$ KJ.

$\therefore$ Hence proved $\Sigma Q = \Sigma W$

✓ $U_1 - U_3 = (U_1 - U_2) + (U_2 - U_3)$

$$Q_{3-1} = W_{3-1} + (U_1 - U_3)$$

$-26.4 = (U_1 - U_2) + 0$

$Q_{3-1} = 0 - 26.4$ KJ

$U_1 - U_2 = -26.4$ KJ

$$\therefore \boxed{Q_{3-1} = -26.4 \text{ KJ}}$$

$$Q_{2-3} = W_{2-3} + (U_3 - U_2)$$

$= -18.78 + 0$

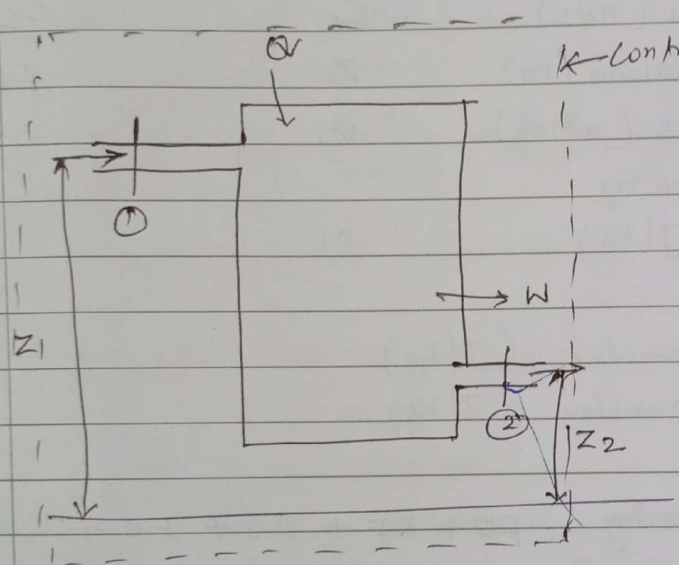
$Q_{2-3} = -18.78$ KJ

Steady flow system:

In a thermodynamic system the working fluid may enter the system and leave the system. If there is a steady rate ($\dot{m}$) of flow through the system, then the system is known as Steady flow system.

Ex: steam boiler, turbine, compressor, IC engine, pump
Heat Exchanger etc.

Steady flow energy equation (SFEE):



Consider a thermodynamic System in which a fluid is flowing at a Steady rate. Fluid enters the system at point 1 and leaves the system point 2. The space under consideration between entry and exit is known as control volume.

Assumptions made in the system analysis:

1. The mass flow rate through the control volume is constant.

2. Only PE, KE, IE, and flow energies are considered. Other forms of energy (Electrical, magnetic

chemical etc) are not considered.

3. The interaction b/w the system and the surroundings are only work and heat.

4. The state of fluid at any point remains constant at all times.

Let,	① at entry	② at exit
pressure (N/m^2)	p_1	p_2
Internal energy (J/kg)	u_1	u_2
velocity of flow (m/s)	C_1	C_2
Height above datum (m)	Z_1	Z_2
Specific volume (m^3/kg)	v_1	v_2
Enthalpy of working fluid (J/kg)	h_1	h_2

Also let,

Q - Heat transfer (J/kg)

W - Work transfer (J/kg).

Total energy entering the system $= P.E + K.E + I.E + F.E + Q$

$$= gZ_1 + \frac{C_1^2}{2} + u_1 + p_1 v_1 + Q$$

Total energy leaving the system $= P.E + K.E + I.E + F.E + W$

$$= gZ_2 + \frac{C_2^2}{2} + u_2 + p_2 v_2 + W$$

By law of conservation of energy,

Energy entering the system = Energy leaving the system.

$$gZ_1 + \frac{C_1^2}{2} + u_1 + p_1 v_1 + Q = gZ_2 + \frac{C_2^2}{2} + u_2 + p_2 v_2 + W$$

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$\therefore [u + pv = h]$

$$gz_1 + \frac{C_1^2}{2} + h_1 + Q = gz_2 + \frac{C_2^2}{2} + h_2 + W$$

If $(\dot{m})$ is mass flow rate of the fluid, the SFEE may be written as,

$$\dot{m}\left[gz_1 + \frac{C_1^2}{2} + h_1\right] + Q = \dot{m}\left[gz_2 + \frac{C_2^2}{2} + h_2\right] + W$$

If h, Q, and W are expressed in KJ/kg then SFEE may be written as,

$$\boxed{\dot{m}\left[\frac{gz_1}{1000} + \frac{C_1^2}{2\times1000} + h_1\right] + Q = \dot{m}\left[\frac{gz_2}{1000} + \frac{C_2^2}{2\times1000} + h_2\right] + W}$$

Applications of SFEE :

a) Steam boiler.
b) Steam Condensor.
c) Steam nozzle.
d) Air compressor
e) Steam (or) gas turbines. etc.

Steam boiler:

a) No mechanical work $(W=0)$
b) Fluid velocity at the inlet and exit is small. there is no change in K.E $\therefore (C_1 = C_2)$
c) $Z_1 = Z_2$

Applying in SFEE

$$h_1 + Q = h_2$$

$$\therefore \boxed{Q = h_2 - h_1}$$

Steam Nozzle :

Nozzle is a device used for increasing the velocity of flowing fluid at the cost of pressure drop.

In a nozzle,

a) No Work is done ($W=0$)
b) No heat is transferred ($Q=0$)
c) No Change in P.E ($Z_1=Z_2$)

applying in SFEE

$$\frac{C_1^2}{2} + h_1 = \frac{C_2^2}{2} + h_2$$

$$\frac{C_2^2}{2} - \frac{C_1^2}{2} = h_1 - h_2$$

$$C_2^2 = C_1^2 + (h_1 - h_2) \times 2$$

$$\boxed{C_2 = \sqrt{2(h_1-h_2) + C_1^2}}\ , \text{ m/s}$$

if h_1 and h_2 are given in kJ/kg, $\boxed{C_2 = \sqrt{2 \times 1000 (h_1-h_2) + C_1^2}}$

initial velocity is so small than final velocity

$\therefore$ Neglible. ($C_1 = 0$)

$$\boxed{C_2 = \sqrt{2(h_1-h_2)}}$$

for a perfect gas $h = C_p.T$

$$C_2 = \sqrt{2 C_p (T_1 - T_2) + C_1^2}$$

The expansion of a fluid in the nozzle is treated as frictionless adiabatic (Isentropic)

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

$$\therefore C_2 = \sqrt{2 \times C_p \times \left[T_1 - T_1\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right] + C_1^2}$$

$$C_2 = \sqrt{2 \times C_p \times T_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right] + C_1^2} \quad m/s$$

If specific heat capacity at const. pressure (C_p) is taken in KJ/kg K, then,

$$\boxed{C_2 = \sqrt{2 \times 1000 \times C_p \times T_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right] + C_1^2}} \quad m/s.$$

ZA

Q. In a gas turbine unit, the gases flow through the turbine is 15 kg/s and the power developed by the turbine is 12000 kW. The enthalpies of gases at the inlet and outlet are 1260 kJ/kg and 400 kJ/kg respectively, and the velocity of gases at the inlet and outlet are 50 m/s and 110 m/s resp. Calculate:

(i) The rate at which heat is rejected to the turbine, and

(ii) The area of the inlet pipe given that the specific volume of the gases at the inlet is 0.45 m^3/kg.

Solution:

$\dot{m} = 15$ kg/s.

$P = 12000 kW = \cancel{12000}$ kJ/s

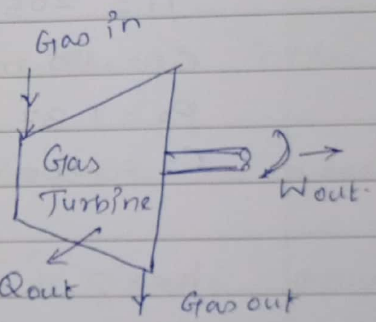
$= \frac{12000}{15} = 800$ kJ/kg.

$h_1 = 1260$ kJ/kg $= 1260 \times 15 = 18900$ kW

$h_2 = 400$ kJ/kg. $= 400 \times 15 = 6000$ kW

$C_1 = 50$ m/s

$C_2 = 110$ m/s.



Using SFEE,

$$h_1 + \frac{C_1^2}{2} + Q = h_2 + \frac{C_2^2}{2} + W$$

$$\dot{m}\left[h_1 + \frac{C_1^2}{2000}\right] + Q = \dot{m}\left[h_2 + \frac{C_2^2}{2000}\right] + W$$

$$(15 \times 1260) + \frac{15 \times (50)^2}{2 \times 1000} + Q = (15 \times 400) + \frac{(110)^2 \times 15}{2 \times 1000} + 12000$$

$$\therefore Q = 6000 + 90.75 + 12000 - 18900 - 18.75$$

$$\boxed{Q = -828 \text{ kW}}$$

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$-$ Ve indicates Heat is rejected.

(ii) $\dot{m} = \dfrac{C_1 A_1}{\vartheta_1}$

$$A_1 = \frac{0.45 \times 15}{50}$$

$$\boxed{A_1 = 0.135\ m^2}$$

(8) Steam at a 6.87 bar, 205°C, enters in an insulated nozzle with a velocity of 50 m/s. It leaves at a pressure of 1.37 bar and a velocity of 500 m/s. Determine final enthalpy of steam.

Solution:

$P_1 = 6.87$ bar $= 687$ kpa.

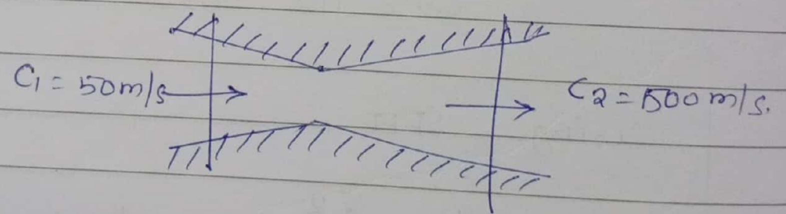
$T_1 = 205°C + 273 = 478$ K

$C_1 = 50$ m/s

$P_2 = 1.37$ bar $= 137$ kpa.

$C_2 = 500$ m/s.

$h_2 = ?$



$$h_1 + \frac{C_1^2}{2} = h_2 + \frac{C_2^2}{2}$$

if h_1 and h_2 are in kJ/kg.

$$C_2 = \sqrt{2 \times 1000 (h_1 - h_2) + C_1^2}$$

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$$500 = \sqrt{2 \times 1000\,(2850 - h_2) + (50)^2}$$

$h_1 = 2850$ KJ/kg. from steam table. @ 6.87 bar $T_1 = 205°C$

$$(500)^2 = 2000\,(2850 - h_2) + (50)^2$$

$$\boxed{h_2 = 2726.25 \text{ KJ/kg}}$$

356.64 KJ/kg.

Q. Air at a temperature of 20°c passes through a heat exchanger at a velocity of 40 m/s where its temperature is raised to 820°c. It then enters a turbine with same velocity of 40 m/s and expands till the temp. falls to 620°c. On leaving the turbine, the air is taken at a velocity of 55 m/s to a nozzle where it expands until the temperature has fallen to 510°C. If the air flow rate is 2.5 kg/s, calculate:

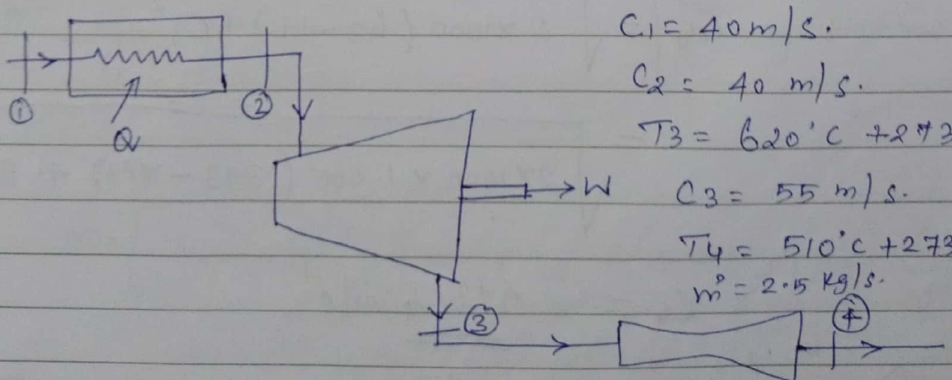
(i) Rate of heat ~~flea~~ transfer to the air in the heat exchanger.

(ii) The power o/p from the turbine assuming no heat loss;

(iii) The velocity at exit from the nozzle, assuming no heat loss.

Take the enthalpy of air as $h = C_pT$ where, C_p - specific heat equal to 1.005 KJ/kg K, ~~and~~

Solution:



$T_1 = 20°C + 273 = 293$ K

$T_2 = 820° + 273 = 1093$ K

$C_1 = 40$ m/s.

$C_2 = 40$ m/s.

$T_3 = 620°C + 273 = 893$ K

$C_3 = 55$ m/s.

$T_4 = 510°C + 273 = 783$ K.

$\dot{m} = 2.5$ kg/s.

$$Q_{1-2} = \dot{m}(h_2 - h_1) \qquad \because [h = c_p \cdot T]$$

$$= \frac{kg}{s} \cdot \frac{kJ}{kg} = kW$$

$$= 2.5 \times 1.005 (1093 - 293)$$

$$\boxed{Q_{1-2} = 2010 \ kJ/s}$$

(ii) Turbine:

Power o/p of the turbine: $\qquad \because Q_{2-3} = 0, \ (Z_2 = Z_3)$

$$\dot{m}\left[h_2 + \frac{C_2^2}{2\times1000}\right] = \dot{m}\left[h_3 + \frac{C_3^2}{2\times1000}\right] + W_{2-3}$$

$$2.5\left[(1.005\times1093) + \frac{(40)^2}{2\times1000}\right] = 2.5\left[(1.005\times 893) + \frac{(55)^2}{2\times1000}\right] + W_{2-3}$$

$$\therefore \boxed{W_{2-3} = 504.3 \ kW.}$$

(iii) Nozzle:

$W_{3-4} = 0, \ Z_1 = Z_2, \ Q_{3-4} = 0$

$$h_3 + \frac{C_3^2}{2\times1000} = h_4 + \frac{C_4^2}{2\times1000}$$

$$C_4 = \sqrt{2\times1000(h_3 - h_4) + C_3^2}$$

$$= \sqrt{2\times1000 \times 1.005 (893 - 783) + (55)^2}$$

$$C_4 = \underline{\underline{473.4 \ m/s}}$$

1) During flight, the air speed of a turbojet engine is 250 m/s. Ambient air temperature is −14 °C. Gas temperature at outlet of nozzle is 610 °C. Corresponding enthalpy values for air and gas are resp. 250 and 900 KJ/kg. Fuel air ratio is 0.018. Chemical energy of fuel is 45 MJ/kg. owing to incomplete combustion 6% of chemical energy is not released in the reaction. Heat loss from the engine is 21 KJ/kg of air. Calculate the velocity of the exhaust jet.

Solution:

Air speed of turbojet engine, $C_a = 250$ m/s.

Ambient air temp $= -14\,°C$

Gas temp at outlet of nozzle $= 610\,°C$

Enthalpy of air $(h_a) = 250$ KJ/kg.

Enthalpy of gas $(h_g) = 900$ KJ/kg

$$\frac{m_f}{m_a} = 0.018 \qquad \text{if } (m_a = 1\text{ kg})$$

$$m_f = 0.018\text{ kg}$$

$$m_g = m_a + m_f$$

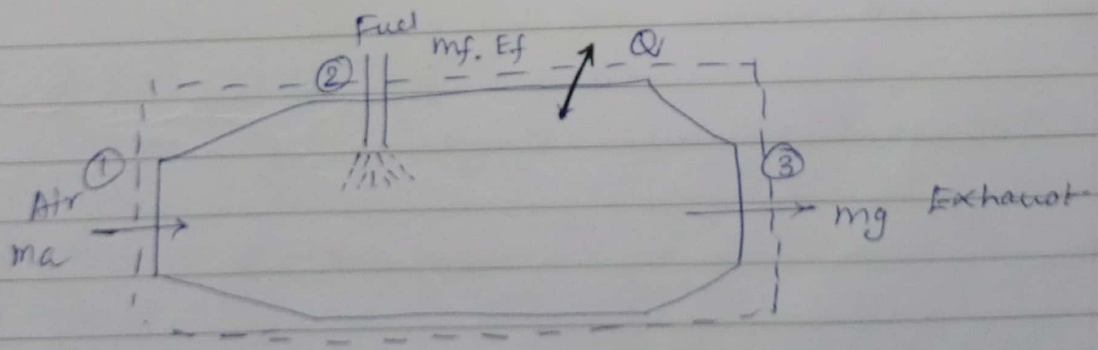
$$= 1 + 0.018$$

$$m_g = 1.018\text{ kg}$$

Chemical energy of fuel $= 45$ MJ/kg

$= 45000$ KJ/kg

Heat loss from the engine $= -21$ KJ/kg of air



$$m_a\left[h_a + \frac{C_a^2}{2\times1000}\right] + m_f \cdot E_f + Q = m_g\left[h_g + \frac{C_g^2}{2000}\right] + E_g$$

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$$1\left[250 + \frac{(250)^2}{2000}\right] + 0.018 \times 45 \times 10^3 - 21 =$$

$$1.018\left[900 + \frac{C_g^2}{2000} + 0.06 \times \frac{0.018}{1.018} \times 45 \times 10^3\right]$$

$$281.25 + 810 - 21 = 1.018\left[900 + \frac{C_g^2}{2000} + 47.74\right]$$

$$\boxed{C_g = 455.16 \ m/s}$$

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