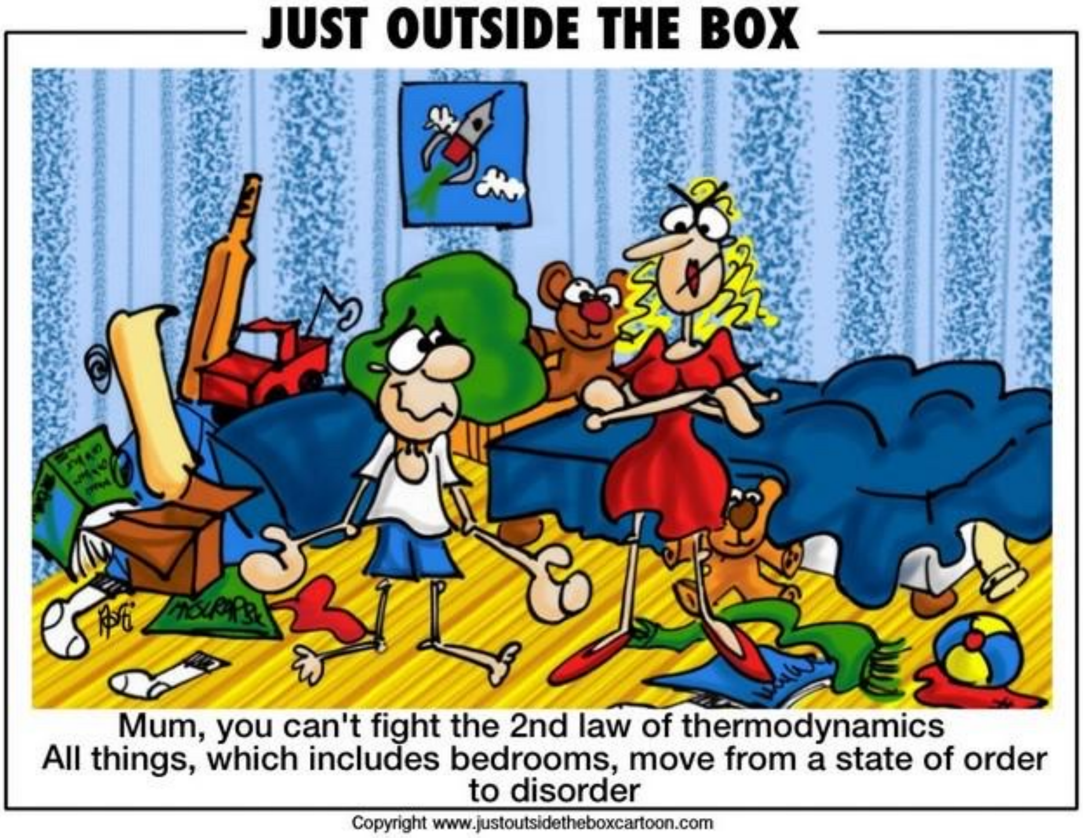
Lecture 3 :-



Thermally perfect gas Vs. Calorically perfect gas

$\Downarrow$ $E = E(T) \Rightarrow C_v(T), C_p(T)$

$\Downarrow$ C_v, C_p $E = \text{Const.}\, T$

→ Kinetic theory of gases tells us that the internal energy (E) of a gas is the sum of

1. Translational kinetic energy
2. Rotational " "
3. Vibrational " "

For calorically perfect gases, the % energy distribution between these types of motion is independent of temperature.

Air is compressed in a cylinder from a value of 1 atm & 300K to 10% of its initial volume. The heat transfer is given by

$$dq = -h_f R\, d(T - T_w)$$

$h_f = 2$, $T_w = 300k$.

Determine the final pressure & Temperature.

→ Assumptions. — ① Air is a perfect gas

② Process is reversible.

1st law gives

$$de = dq - p\,dv$$

$$c_v\, dT = -h_f R\, dT - \frac{RT}{v}.dv$$

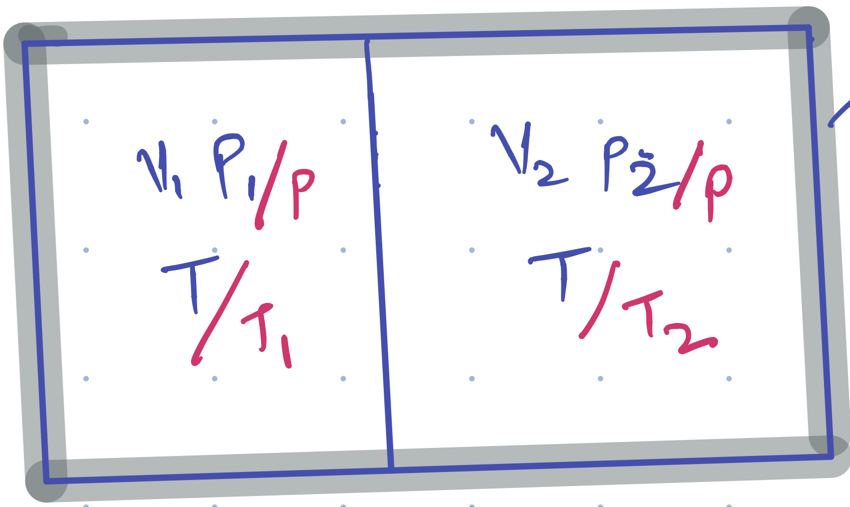
$$\therefore \left(\frac{R}{\gamma-1} + 2R\right) dT = \frac{-RT}{v}.dv$$

$$\therefore \left(\frac{2\gamma-1}{\gamma-1}\right) \frac{dT}{T} = -\frac{dv}{v}$$

$$\therefore T_2 = T_1 \left(\frac{v_1}{v_2}\right)^{\frac{(\gamma-1)}{(2\gamma-1)}} = 500.4\ K$$

$$\frac{P_2}{P_1} = \frac{T_2}{T_1} \cdot \frac{v_1}{v_2} = 16.68\ atm$$

First law applied to adiabatic irreversible process



Thermally insulated

$\Downarrow$

Adiabatic process

1^{st} scenario – Thermal equilibrium

2^{nd} scenario – Mechanical equilibrium

Q: What is the T & p & V while the system transitions from

① $\longrightarrow$ ② ?

Throttling process (section 1·8 Roshko)

$W_{in} = P_1 \cdot V_1$

$t_B - t_A \rightarrow$ unit mass passes thro. resistance

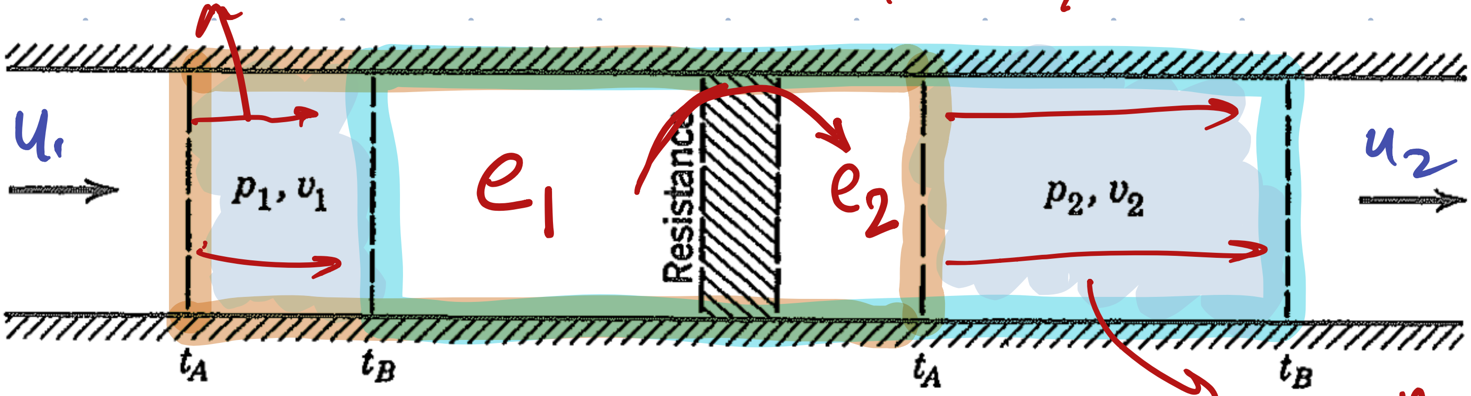


FIG. 1·4 Throttling process.

$W_{out} = -P_2 \cdot V_2$

Moving fluid under stationary conditions

Assuming u_1, u_2 to be small.

Hence $e \gg \frac{1}{2}u^2$

$$\Delta E = e_2 - e_1$$

$$W = W_1 + W_2 = \int_{(1)} p\, dv + \int_{(2)} p\, dv$$

$$= P_1 V_1 - P_2 V_2$$

Since, $\Delta E = W \Rightarrow h_1 = h_2$

Enthalpy is conserved in adiabatic flow.

For perfect gas, this means $T_1 = T_2$

Non-adiabatic irreversible process

$$\rightarrow \quad de = dq + dw$$

Very difficult to analyse.

This course does not address these systems.

So for a general gas,

$$E = E(V, T)$$

Now $$dE = \left.\frac{\partial E}{\partial V}\right|_T dV + \left.\frac{\partial E}{\partial T}\right|_V dT \quad \text{— (1)}$$

Adiabatic expansion.

If the process is also reversible then

$$dE = dQ - p\,dV \quad \text{— (2)}$$

From (1) & (2) $\Rightarrow$ $-p = \left.\frac{\partial E}{\partial V}\right|_T$

E acts like potential energy.

I want to create a state variable that acts similar to this for T.

Let me define $E = E(S, V)$ such that

$$-p = \left.\frac{\partial E}{\partial V}\right|_S \ , \quad T = \left.\frac{\partial E}{\partial S}\right|_V$$

Then $$dE = \left.\frac{\partial E}{\partial V}\right|_S dV + \left.\frac{\partial E}{\partial S}\right|_V dS$$

$$\therefore \ dE = -p\,dV + T\,dS$$

Now, as $dE = -p\,dV + dQ_{rev}$

we have

$$dQ_{rev} = T\,dS$$

$$\therefore \; S_B - S_A = \int_A^B \frac{dQ_{rev}}{T}$$

2nd law

→ Helps us to understand which processes will happen naturally/spontaneously

$$dS \geq \frac{dQ}{T}$$

We will stop our review of thermodynamics here. Any additional concepts will be introduced as required.

Ref: Liepmann-Roshko sec. 1.1 – 1.10

One dimensional Gasdynamics

→ Streamlines

→ Streamtubes

→ Quasi-1D flows.

→ Control Mass Vs Control volume approach

→ Reynold's Transport theorem