Heat transfer

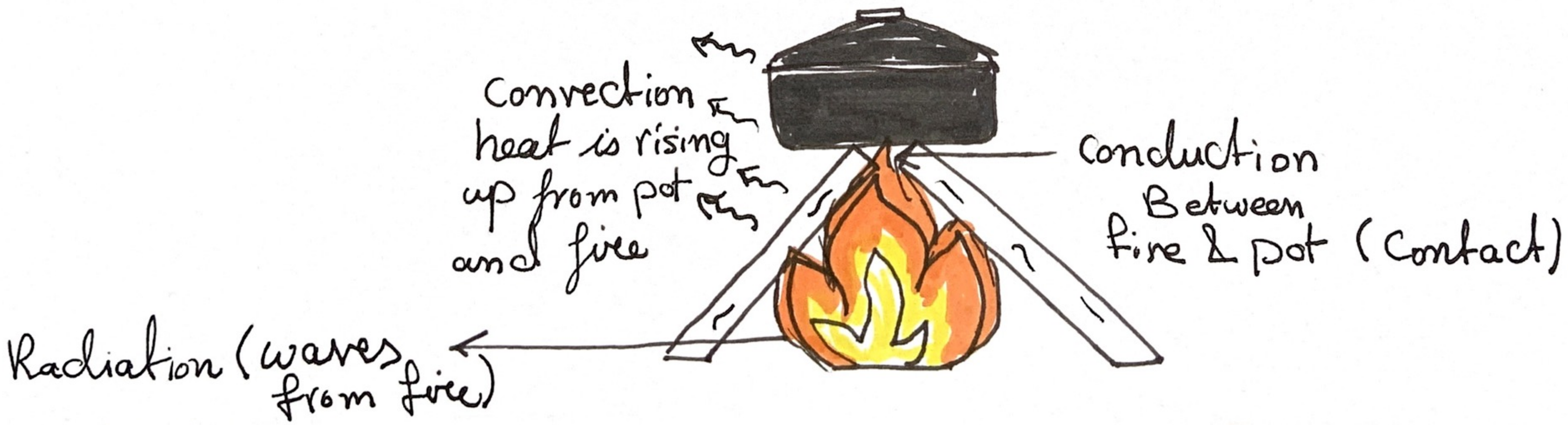
- Heat is transfered from higher temprelure to lower temprelure until they reach the same temprelure
-

Modes of H.t

Conduction
- Direct contact
- material required is Solids

Convection
- fluid movement (Density)
- material required is liquids and gases

Radiation
- wave motion
- No material required



1- Conduction occures ab direct contact of solids

The amount of energy transferred can be computed using rate equations

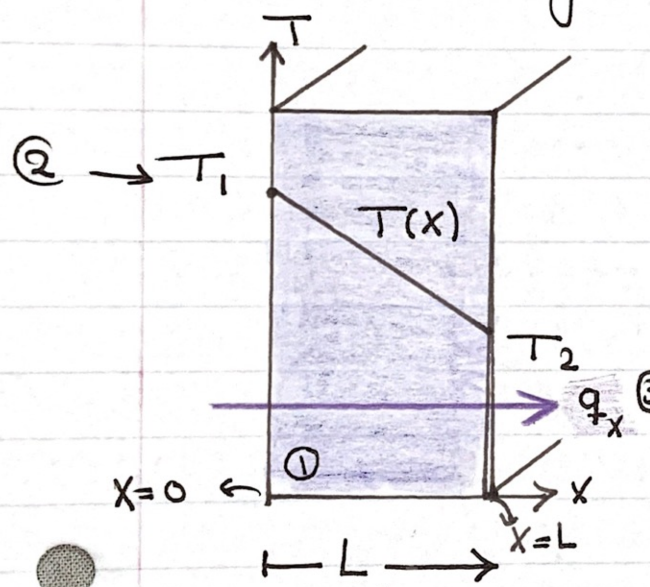
For Conduction, this rate equation is **Fourier's law**

Because heat goes from high to low.

General form :- $\boxed{q''_x = -K\frac{dT}{dx}}$ → In the x-direction

heat flux (W/m²)

Thermal conductivity (W/m.K) of the material we go through



- What does this graph mean?

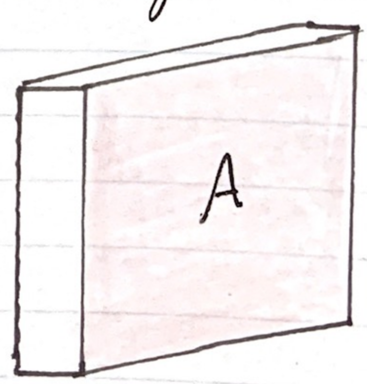
① - Solid (for example a wall)

② - measured temp at $x=0$ of the wall

③ - heat transfer q_x

- Note $q_x = q''.A$

area at which heat is transferred through

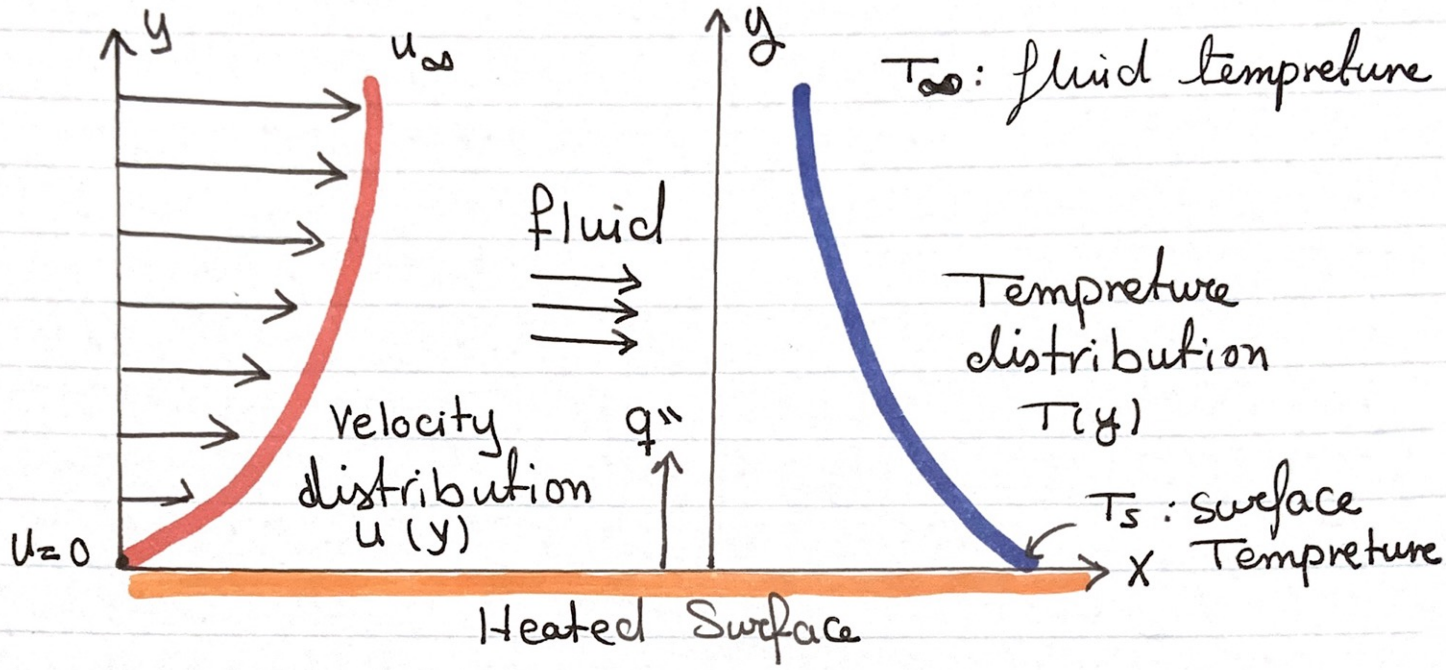


Going into the Law:-

$$\frac{dT}{dx} = \frac{T_2 - T_1}{L}$$

So $q_x = -K.A\left(\frac{T_2 - T_1}{L}\right)$

2- Convection occurs between a surface and a moving fluid / stationary



What does this Graph mean?

- At $y=0$

→ The fluid's velocity $(u) = 0$, this velocity keeps rising until reaching Max u_∞

→ T_s is the tempreture at $y=0$ and It is the higher tempreture $(T_s > T_\infty)$

- So Heat transfer (convection) will occur from surfac to outer flow

- The types of convection are : Forced or Natural

The rate equation used for convection is :-

Newton's law of cooling

$$\boxed{\begin{aligned} q'' &= h\,(T_s - T_\infty) \\ q &= A\,h\,(T_s - T_\infty) \end{aligned}}$$

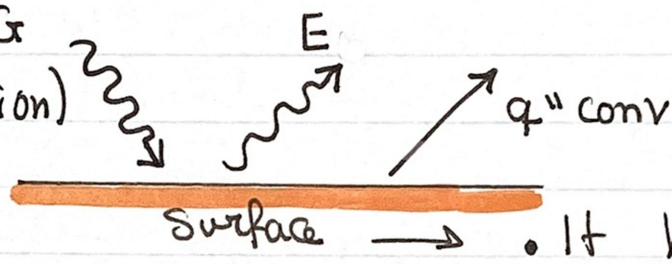
↳ convection heat transfer coefficient Depends on conditions in boundary layer

3- **Radiation** occurs as a result of electrons moving to lower energy levels

- We will focus on Radiation from Solid surfaces
- It needs no material to be transported
  It can be transported in Vacuum

Radiation at a Surface

irridiation (absorbed radiation) ← G



Surface →
- It has tempreture T_s
- emissivity ε, $0 \leq \varepsilon \leq 1$
- absorptivity α

E_b: surface emissive power
It is related to T_s

Stefan-Boltzmann law:-

It is equal to q''_{rad} ←

$$\boxed{E_b = \sigma T_s^4}$$

σ → Boltzmann constant $= 5.67 \times 10^{-8}\ W/m^2.K^4$

- Note: E_b is for Blackbody which is an ideal radiator

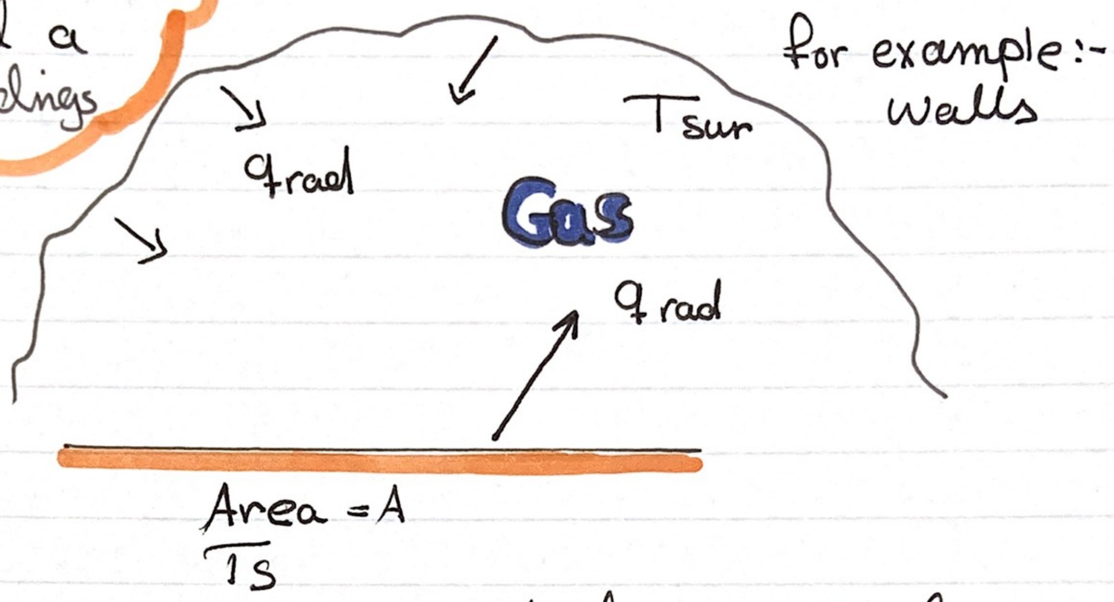
For a real surface:-

$$\boxed{q'' = E = \varepsilon \sigma T_s^4}$$

Absorbed radiation $G_{abs} = \alpha \underline{G}$ ← incident radiation (Irradiation)

energy coming to a surface

Radiation between a Surface and a large Surroundings



- There is an exchange between Surface & surroundings

$$\boxed{\begin{aligned} q &= \text{Emission} - \text{Irradiation} \\ q &= \varepsilon A \sigma T_s^4 - \alpha A \sigma T_{surr}^4 \end{aligned}}$$

- If we have a gray surface = $\varepsilon = \alpha$

$$q_{rad} = \varepsilon (A\sigma) [T_s^4 - T_{surr}^4]$$

- It can be simplified to

$$q_{rad} = \underline{\underline{h_r}} A (T_s - T_{surr})$$

$\downarrow$ radiation heat transfer coefficient

$$h_r = \varepsilon \sigma (T_s + T_{sur})(T_s^2 + T_{sur}^2)$$

If we have **Gas** then (convection between Gas & surface)

$$q = q_{conv} + q_{rad}$$
$$= hA(T_s - T_\infty) + \varepsilon A \sigma (T_s^4 - T_{sur}^4)$$

Conservation of energy for heat transfer

$$\boxed{\dot{E}_{in} + \dot{E}_g - \dot{E}_{out} = \dot{E}_{st}}$$

Stored energy in control volume

Heat transfer by one of the three modes

Heat generation (chemical, electrical, electromagnetic or nuclear) $\rightarrow$ Thermal or mechanical energy

If we assumed: $\dot{E}_g = 0$, steady state: $\dot{E}_{st} = 0$
Then
$$q = \dot{m}\, c_p \,(T_{out} - T_{in})$$

Note:
$\dot{E}_g$ can be electrical $= I^2 R_e' L$

Solved Examples

1.11 Wall

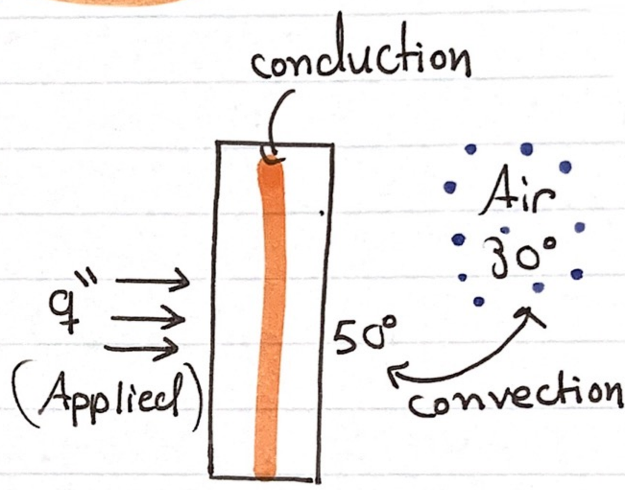
(Applied) ← $q'' = 20\ W/m^2$ → one face

$T = 30°$ for air → opposite face ($T = 50°$)

$h = 20\ W/m^2.K$

Answer : Steady state → $\dot{E}_{st} = 0$

$$\dot{E}_{in} + \cancel{\dot{E}_g}^{\,0} - \dot{E}_{out} = \dot{E}_{st}$$



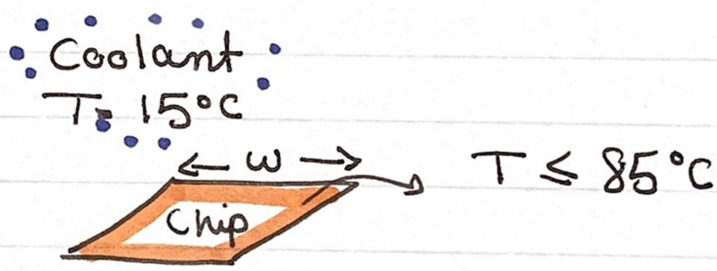
$$q'' A - hA(50-30) = ?$$

$$A[20 - \underset{20}{h}(20)] = ?$$

It does not exist

$\dot{E}_{st} < 0$ So:- Stored energy decreasing
So temp ↓

1.26



Coolant = air
↳ $h_1 = 200\ W/m^2.K$
Max Chip Power?

If coolant dielectric, $h_2 = 3000$ → Max P = ?

$$q_{conv} = h_1 A (T_s - T_\infty) = (200)(5 \times 5 \times 10^{-6})(85 - 15)$$

$$= 0.35\ W$$

for h_2 $\quad q_{conv} = (3000)(25 \times 10^{-6})(70) = 5.25\ W$

1.85

$G = 700\ W/m^2$

$A = 3m^2$

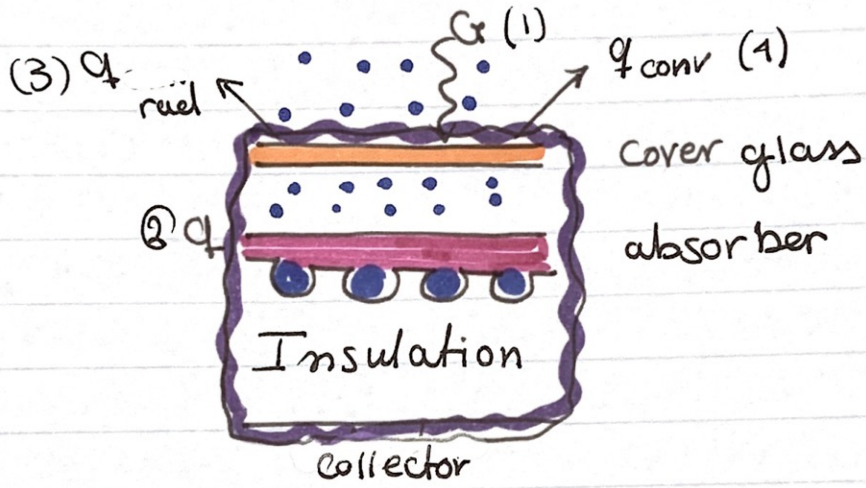
90% of solar radiation passes through glass

10% reflected

Water : $T_i \to T_o$

$T_{cover} = 30°c$, $\varepsilon = 0.94$, radiation with sky at $-10°c$

Convection between air & cover, $h = 10$, $T_{air} = 25°$



Heat transfer we have

① G from Sun (aborbed = 700 W/m2)

90% passes

10% reflects

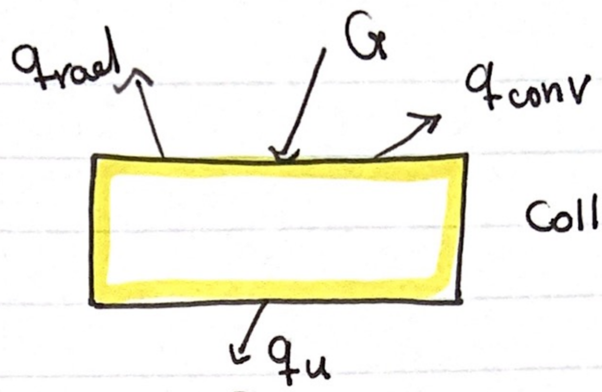
② Convection between water & Absorber

③ Radiation from Cover at $T = -10°$, $T_{cover} = 30°$

④ Convection between air & Cover

1.85

a)



collecter

$$\dot{E}_{in} - \dot{E}_{out} + \dot{E}_{gen} = 0$$

$$q_{solar} - q_{conv} - q_{rad} - q_u = 0$$

$$q_{solar} = 90\%\ q''(G)$$
$$q_{conv} = h(T_s - T_\infty) = 10(30-25)$$
$$q_{rad} = \varepsilon\sigma(T_{cover}^4 - T_{sky}^4) = (0.94)(\sigma)\left((30+273)^4 - (-10+273)^4\right)$$

$$= 90\%(700) - 50 - (0.94)(5.67 \times 10^{-8})(3644541920)$$

$$= 385.75$$

b) $T_o - T_i$?
$\dot{m} = 0.01$
$C_p = 4179$

- Water enters collector at T_i goes out at T_o heat transferred $= q_u$

$$q = A \cdot q''_u = \dot{m}\, c_p (T_o - T_i)$$

$$T_o - T_i = \frac{(386)(3)}{(0.01)(4179)} = 27.7\,°C$$

c) $$\eta = \frac{q_u}{q_{solar}} = \frac{386}{700} = 0.551 = 55\%$$