FLOW OF HEAT

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Classification of Heat–Flow Process

1. Conduction

Ex: Flow of heat through the brick wall of a furnace or the metal shell of a boiler takes place by conduction.

2. Convection

Ex: 1. Heating of a room by means of a steam radiator.
2. Heating of water by a hot surface.

3. Radiation

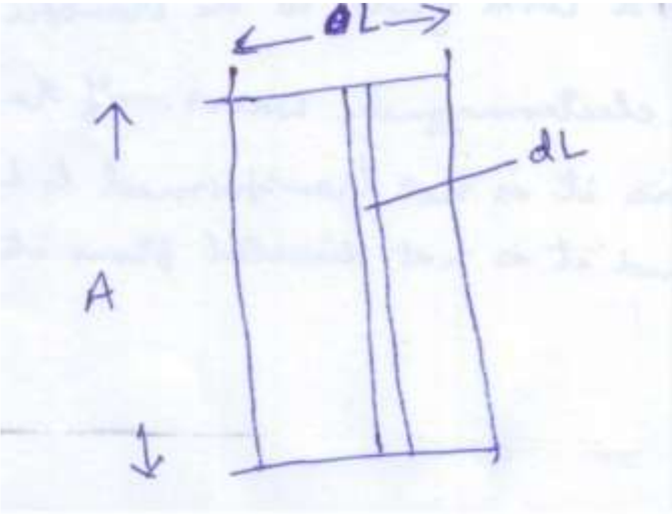
Ex: 1. Fused quartz transmits practically all the radiation that strikes it.
2. Mirror will reflect most of the radiation impinging on it.
3. Black or matty surface will absorb most of the radiation received by it and will transform such absorbed energy quantitatively into heat.

CONDUCTION

Rate = Driving force/ Resistance.

Fourier's Law

Through Single Wall:



$$dq / d\theta = - KA \, dt/dL \quad --- \quad (1)$$

$$dq / d\theta = constant = q = - KA \, dt/dL \quad --- \quad (2)$$

By rearranging the above equation (2)

$$qdL / A = - Kdt \quad --- \quad (3)$$

On integration , it t, is the higher temperature q

$$q \int_o^l dl/ A = - \int_{t_1}^{t_2} kdt = \int_{t_2}^{t_1} kdt \quad --- \quad (4)$$

$$q L/A = K_m (t_1 - t_2) = K_m \Delta t \quad --- \quad (5)$$

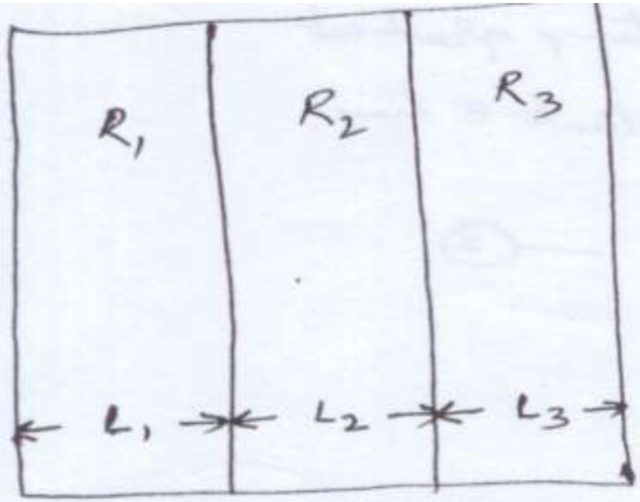
By rearranging the above equation (5)

$$q = K_m A \Delta t / L \quad --- \quad (6)$$

Where Δt is the driving force and

$L / K_m A$ is resistance.

Compound Resistance in Series
(Conduction Through Layers in Series)



Thermal resistance in Series.

$$\Delta t = \Delta t_1 + \Delta t_2 + \Delta t_3 \quad \text{--- (1)}$$

$\Delta t_1 = q_1. \; L_1/K_1 A$ --- (2)

$\Delta t_2 = q_2. \; L_2/K_2 A$ --- (3)

$\Delta t_3 = q_3 . L_3/K_3 A$ --- (4)

Adding Equation 2,3,4 results in the formation of Δt.

$\Delta t_1 + \Delta t_2 \;\; \Delta t_3 = q_1.L_1/AK_1 + q_2.L_2/A K_2 + q_3 .L_3/AK_3 = \Delta t$

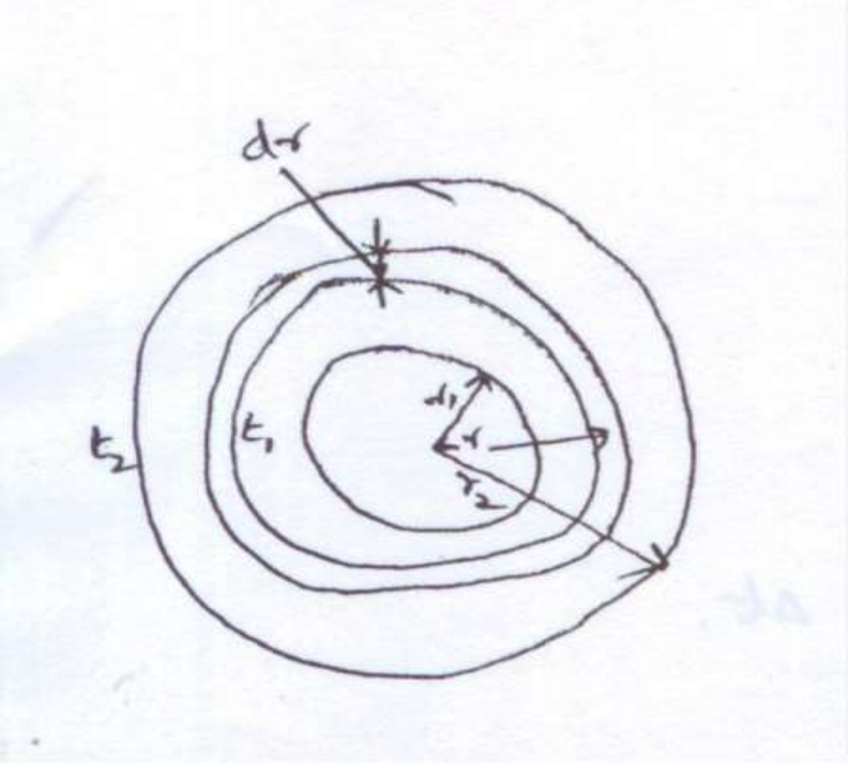
--- (5)

$q = \Delta t / L_1/K_1 A + L_2/ K_2 A + L_3/K_3 A$

$= \Delta t / R_1 + R_2 + R_3$ --- (6)

Where R_1, R_2 & R_3 are the resistances.

Heat Flow Through a Cylinder : (Conduction Through Cylinders)



$q = - K\, dt/dr\, (2\pi rN)$ --- (1)

Where area is equivalent to $2\pi rN$ & thickness is dr.

By differentiating the above equation (1)

$dr/r = - 2\pi NK/q.dt$ --- (2)

Equation (2) can be integrated as follows

$$\int_{r_1}^{r_2} dr/r = 2\,\Pi N/q \int_{t_2}^{t_1} k\,dt$$

$\ln r_2 - \ln r_1 = 2\pi NK_m / q.\ \ (t_1 - t_2)$

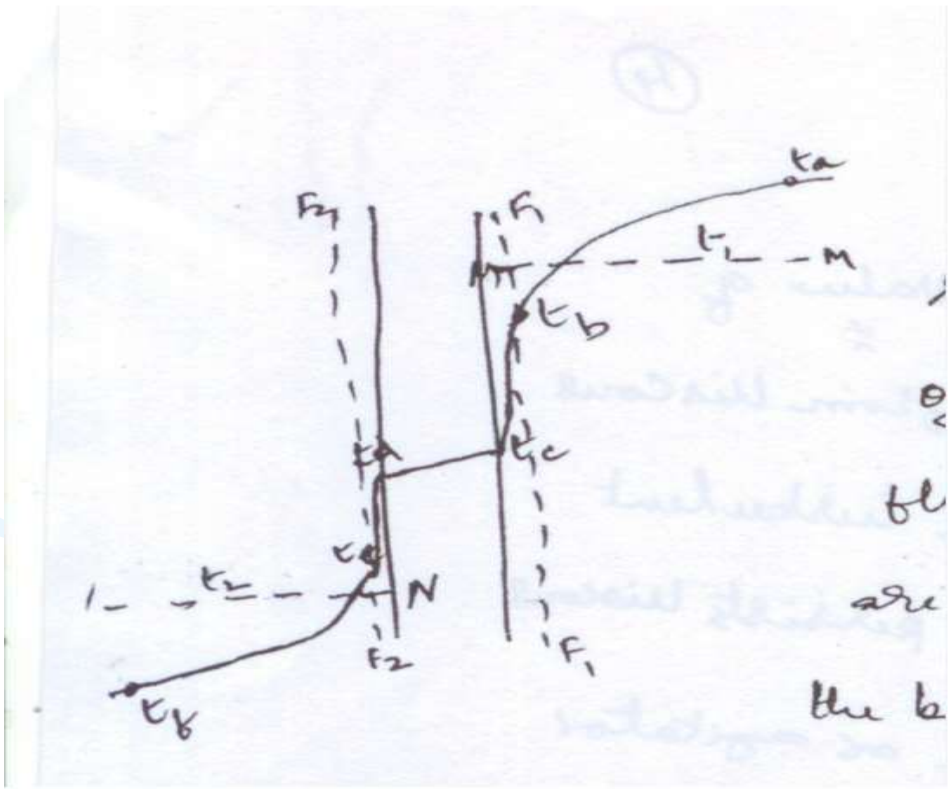
$q = K_m(2\pi N)\,(t_1-t_2) / \ln(r_2/r_1)$ ----(3)

(or)

$q = K_m A_m\, (t_1-t_2)/L$ ----(4)

CONVECTION

TEMPERATURE GRADIENTS IN FORCED CONVECTION



Surface Coefficients

$h_1 = q/\ A_1(t_1 - t_c)$ ---(1)

Hence the thermal resistance is $1/\ h_1 A_1$

Where $h_1 = K/L$

$h_2 = q/\ A_2(t_d - t_2)$ ---(2)

Hence the thermal resistance is $1/\ h_2 A_2$ is the thermal resistance of the wall is

$L/K.A_m$

$q = \Delta t \,/\, 1/\ h_1 A_1 + L/K.A_m + 1/\ h_2 A_2$ ---(3)

$U_1 = 1 \,/\, 1/\ h_1 + L/K + 1/\ h_2$ ---(4)

Dimensional Analysis

Name	Formula	Symbol
Nusselt	hD/K	Nu
Reynolds	$Du\ \rho\ /\mu$	Re
Prandtl	$C\ \mu\ /K$	Pr
Grashof	$gD^3\beta\Delta tP^2\ /\mu^2$	Gr
---	L/D	---

Where

h= Co-effecient of heat transfer
D= Diameter
K= Thermal Conductivity
U = Linear velocity
ρ = Density
μ = Viscosity
C= Specific heat at constant pressure

g = acceleration of gravity
R = Co-effecient of thermal expansion
Δ t = temperature difference
L = Length of path of flow.

$$Nu = f\ (Re, Pr, Gr, L/D)$$

$$Nu = K\ Re^a\ Pr^b\ , Gr^c (L/D)^d$$

Where K,a,b,c and d are constants.

Boiling of Liquids

Stages of Boiling:

1) Nucleate Boiling
2) Film Boiling
3) Surface Boiling

Types of Boiling:

1) Pool Boiling
2) Film type Boiling
3) Sub cooled Boiling

Condensing Vapours:

1. Film type Condensation.
2. Drop wise Condensation.

$$h = 0.725 \sqrt[4]{K^3 p^2 \lambda / D\mu\Delta t}$$

λ = latent heat of vapourization of vapour Btu /lb

P = density of condensate lb/co-efficient.

K = thermal conductivity of condensed vapour.

G = acceleration of gravity ft/hr2 (4.18 x 108)

μ = viscosity of condensate film ft-16-in

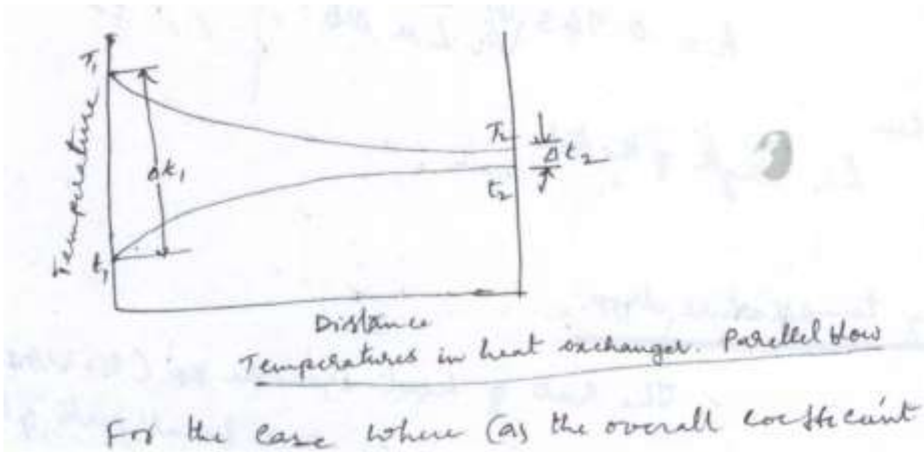
D= outside pipe diameter ft.

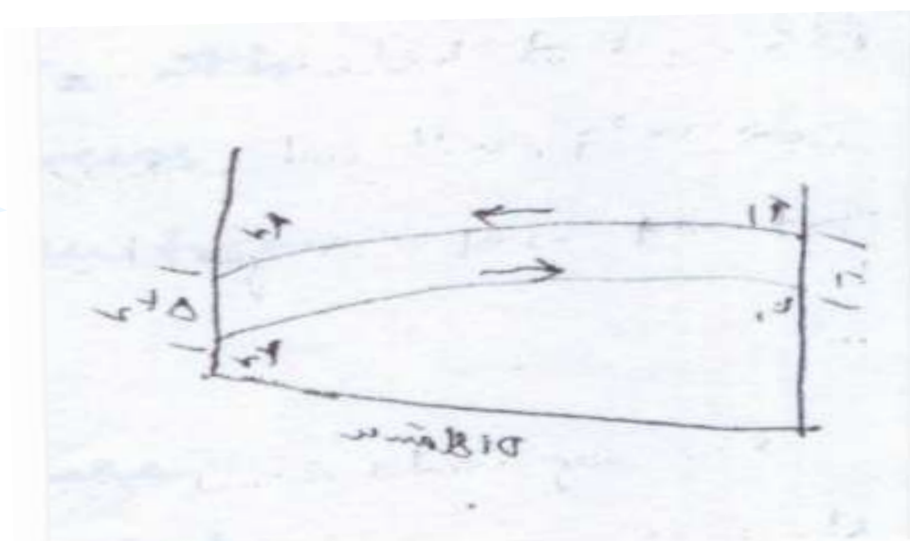
Δ = temperature difference b/n vapour and metal F0

$$h = 0.943 \sqrt[4]{K^3 p^2 g\lambda / L\mu\Delta t}$$

Where L = Length of the tube

Varying Temeparature Drop





$$q = UaL \cdot \Delta t_1 - \Delta t_2 / \ln(\Delta t_1 - \Delta t_2) \text{ ---(1)}$$

Let Δt_m be defined as

$$\Delta t_m = \Delta t_1 - \Delta t_2 / \ln(\Delta t_1 - \Delta t_2) \text{ --- (2)}$$

And note that the total heating surface A is

$$A = aL \text{ --- (3)}$$

Then substituting the equation (1)

$$q = UA\, \Delta t_m \text{ --- (4)}$$

Radiation

- The term” thermal radiation “ is used for radiation corresponding to wavelengths from 0.8 to 400 microns. Although for most cases of industrial interests the range can be narrowed down to wavelengths from 0.8 to 25 microns.

The Black Body:

- This is defined as that body which radiates the maximum possible amount of energy at a given temperature.

Rate of Radiation

Stefan-Boltzmann Law

$q = bAT^4$ --- (1)

When q = Energy radiated per hour.

A = Area of radiating surface.

T = absolute temperature of the radiating surface .R^0 (Rankine)

For black bodies the value of b is

0.174×10^{-8} Btu/ hr.sq.ft.^oF

$q = \epsilon bAT^4$ --- (2)

$\epsilon = \alpha$

Gray Body

The absorptivity of a gray body at a give temperature is constant for all wavelengths of radiation.

$q = bA\,(T_1^4 - T_2^4)$ ----(3)

Classification of Heat Exchangers /Interchanges

1). Heat Exchangers:

a) Tubular Heaters.

Ex:1)Single pass tubular heater.

2)Multi pass tubular heater.

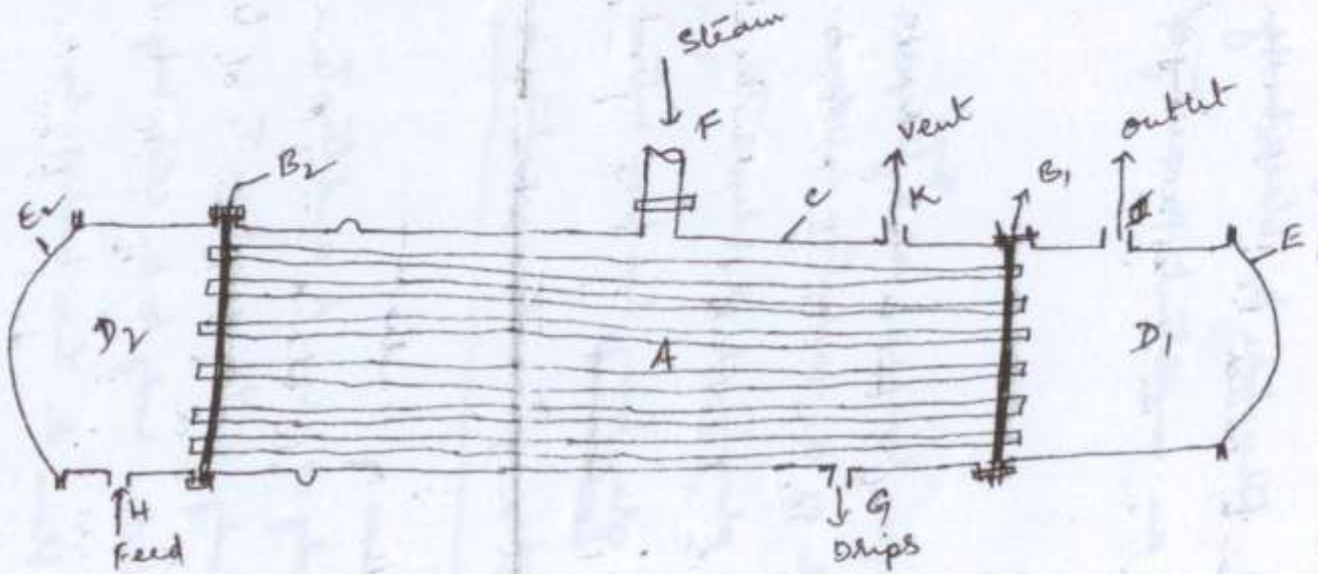
b)Expansion type heaters:

Ex: Floating Head two pass heater.

2)Heat Interchangers:

Ex: a)Liquid to Liquid heat interchangers.

b)Double pipe heat interchangers.



Single - Pass tubular heater

A - tubes

B1, B2 - tube sheets

C - Shell

D1, D2 - Liquor distribution chambers

E1, E2 - Covers

F - Steam inlet

G - Condensate outlet

H - Liquor inlet

J - Liquor outlet

K - Non condensate. Gas vent.

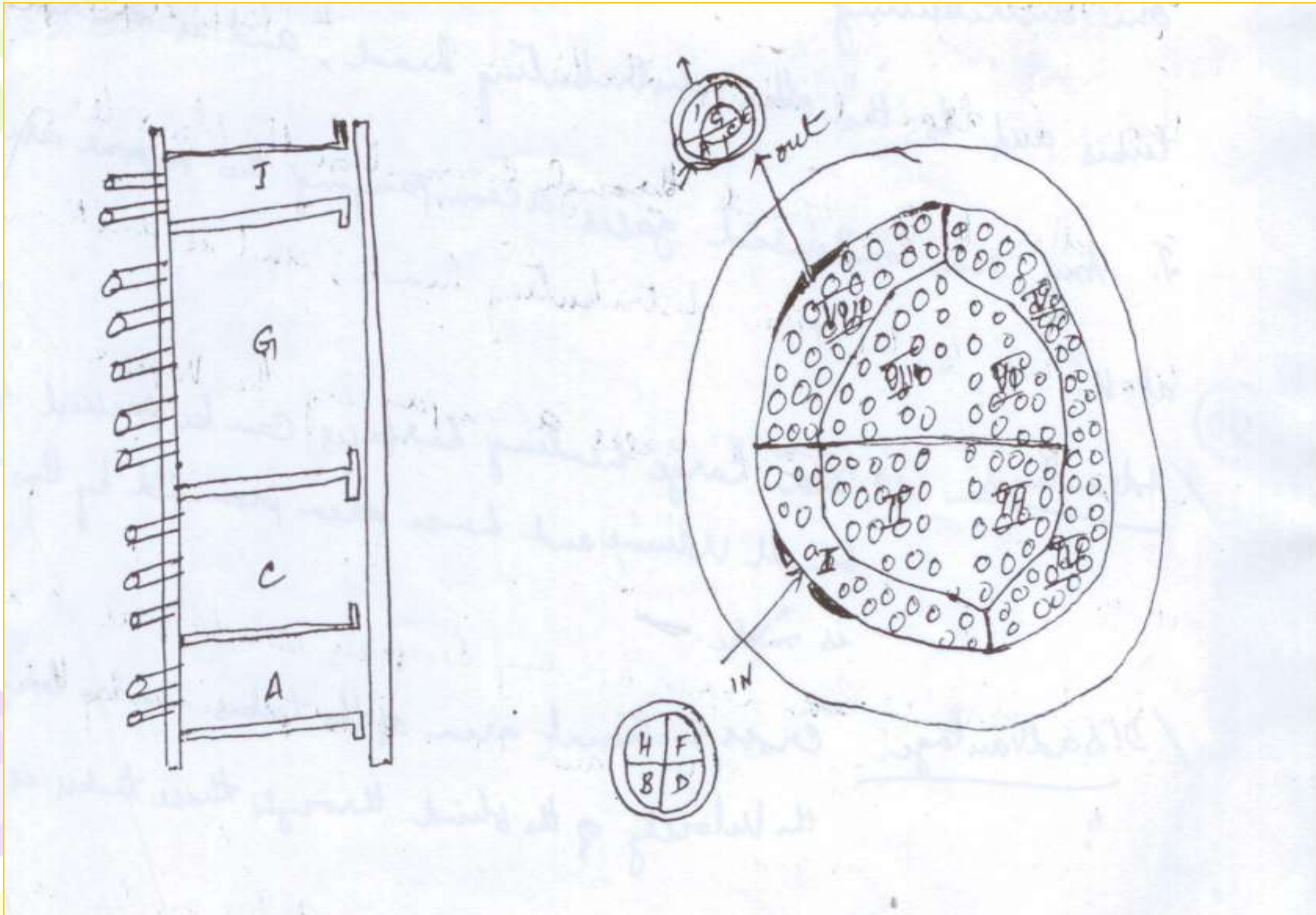
Advantages:

1) Large heating surfaces can be packed into a small volume and hence area provided by this water is more.

Disadvantages:

1) Cross sectional area of the tubes is also large & the velocity of the fluid through these tubes is low.

Multi Pass Tubular Heater



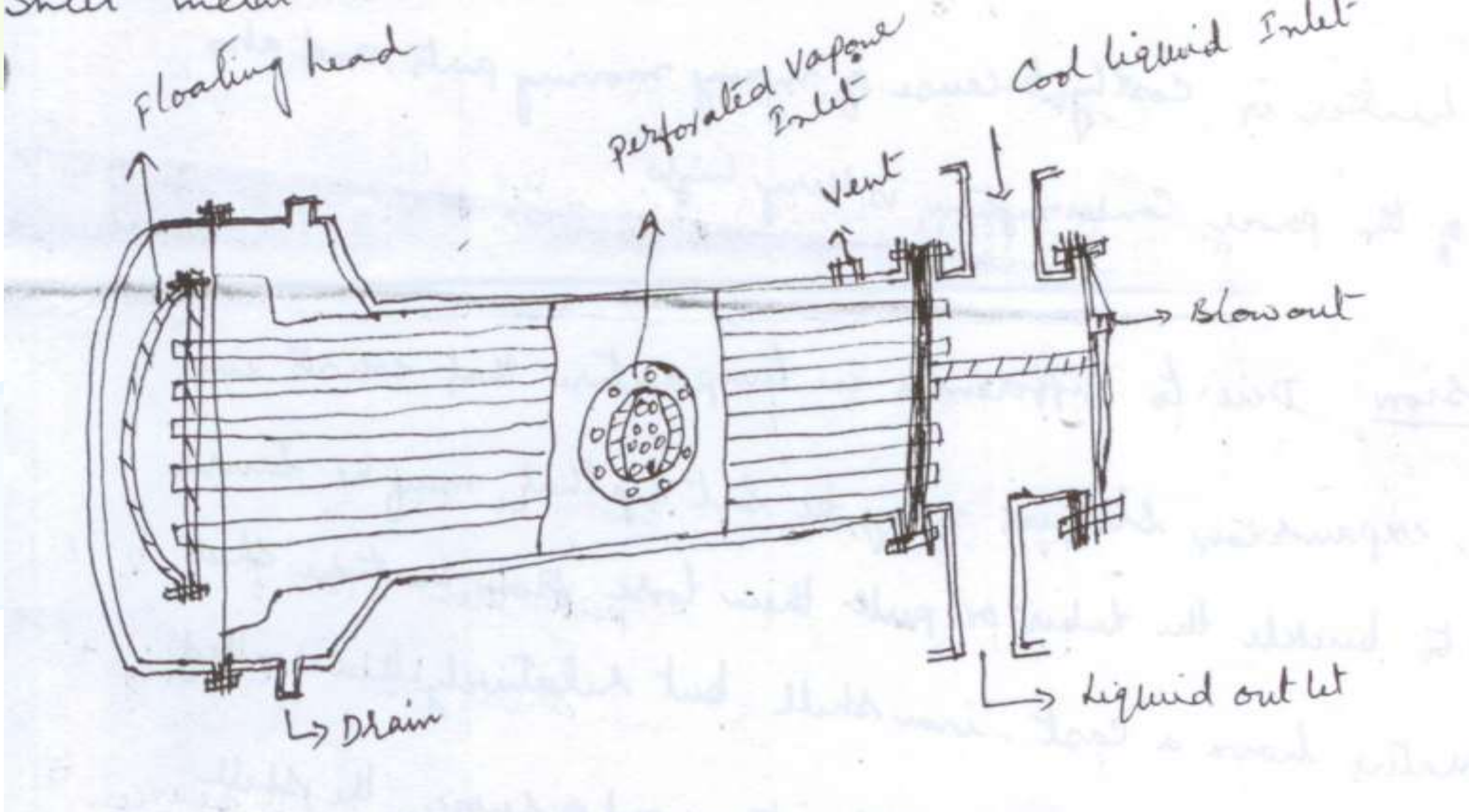
Advantages:

- Multi pass construction ↓ses the cross section of the fluid path and ↑ ses the fluid velocity with a corresponding increase in the heat transfer co-effecient.

Disadvantages:

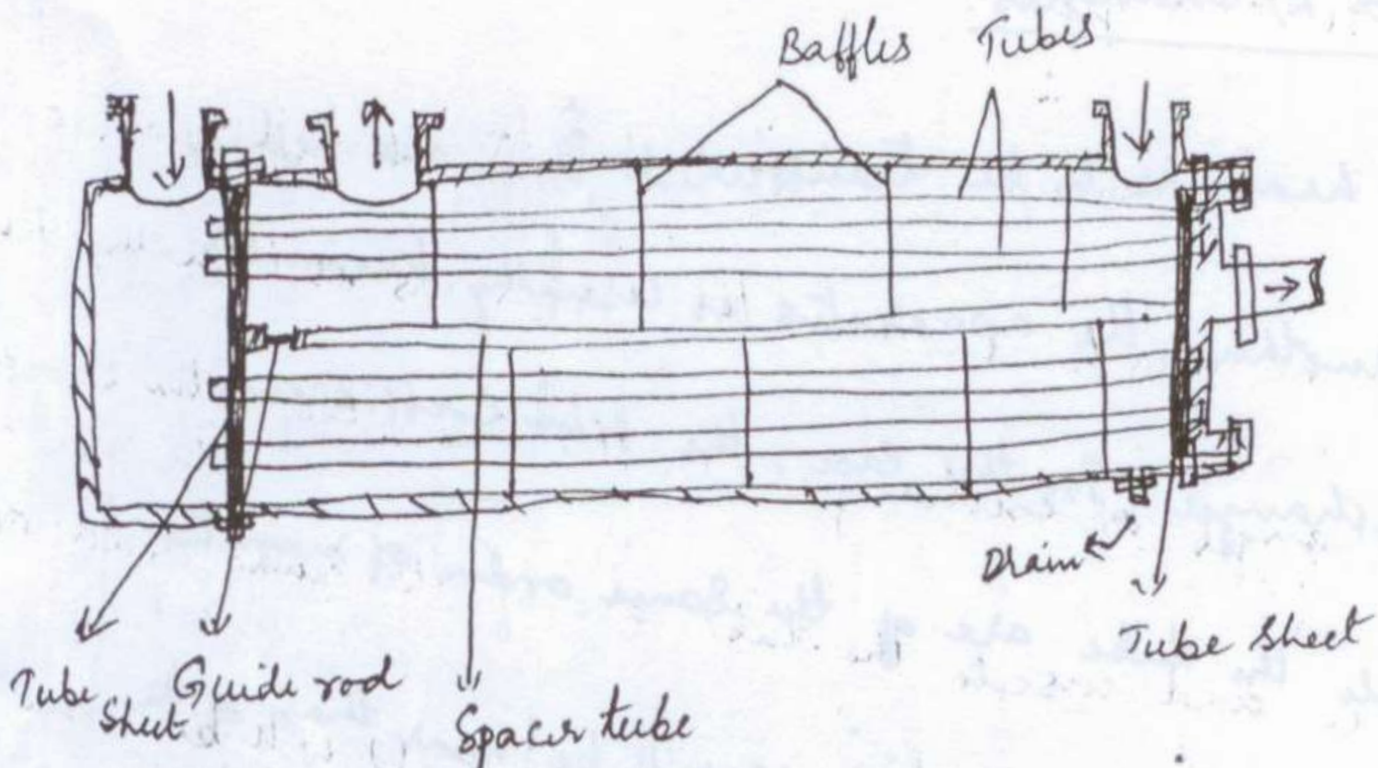
1) The heater is slightly more complicated.
2) Friction drop through the apparatus is increased because of the effect of velocity on friction drop and the miltiplication of exit and entrance losses.
3) The heater is costly because of many moving parts and also cost of the power consumption is very high.

Sheet metal is

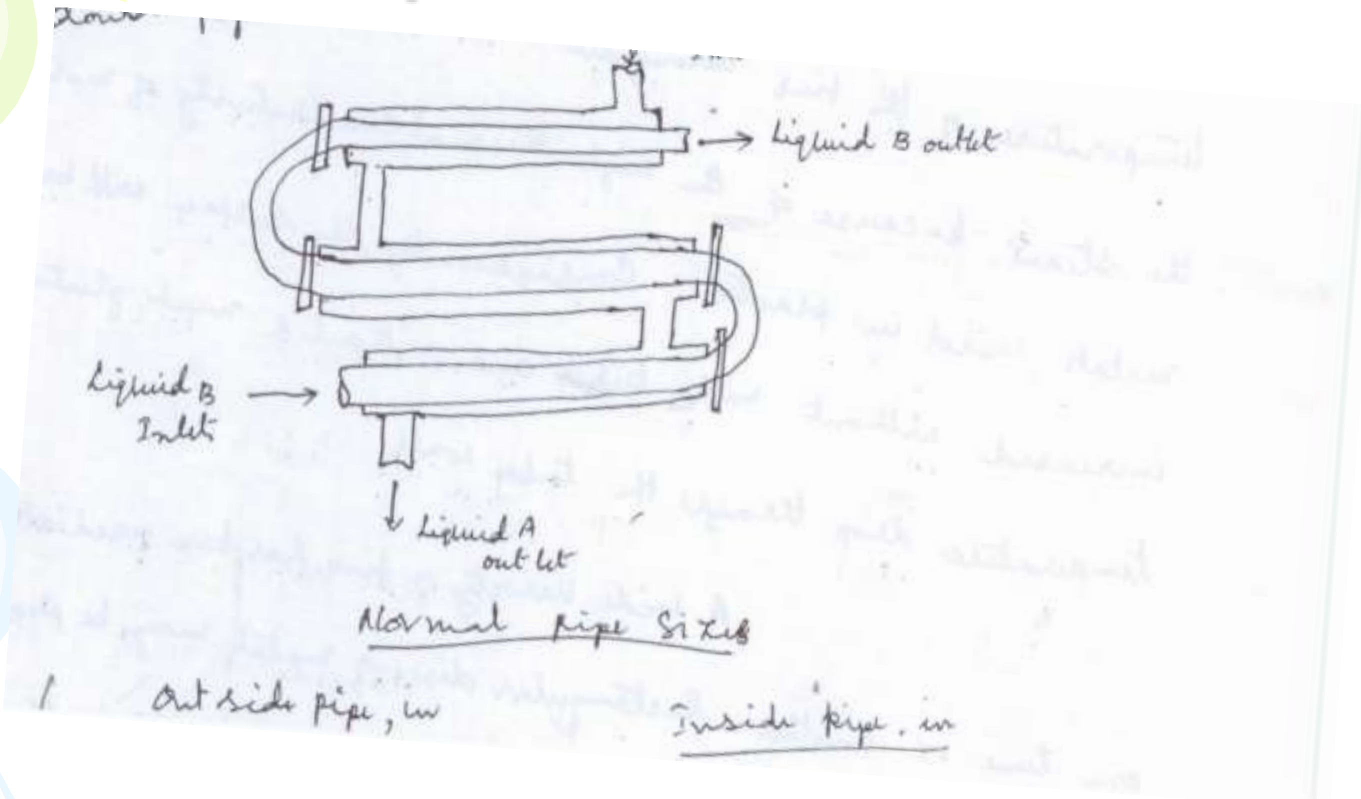


Two-pass Floating Head Heater

Liquid to Liquid Heat Interchanger:



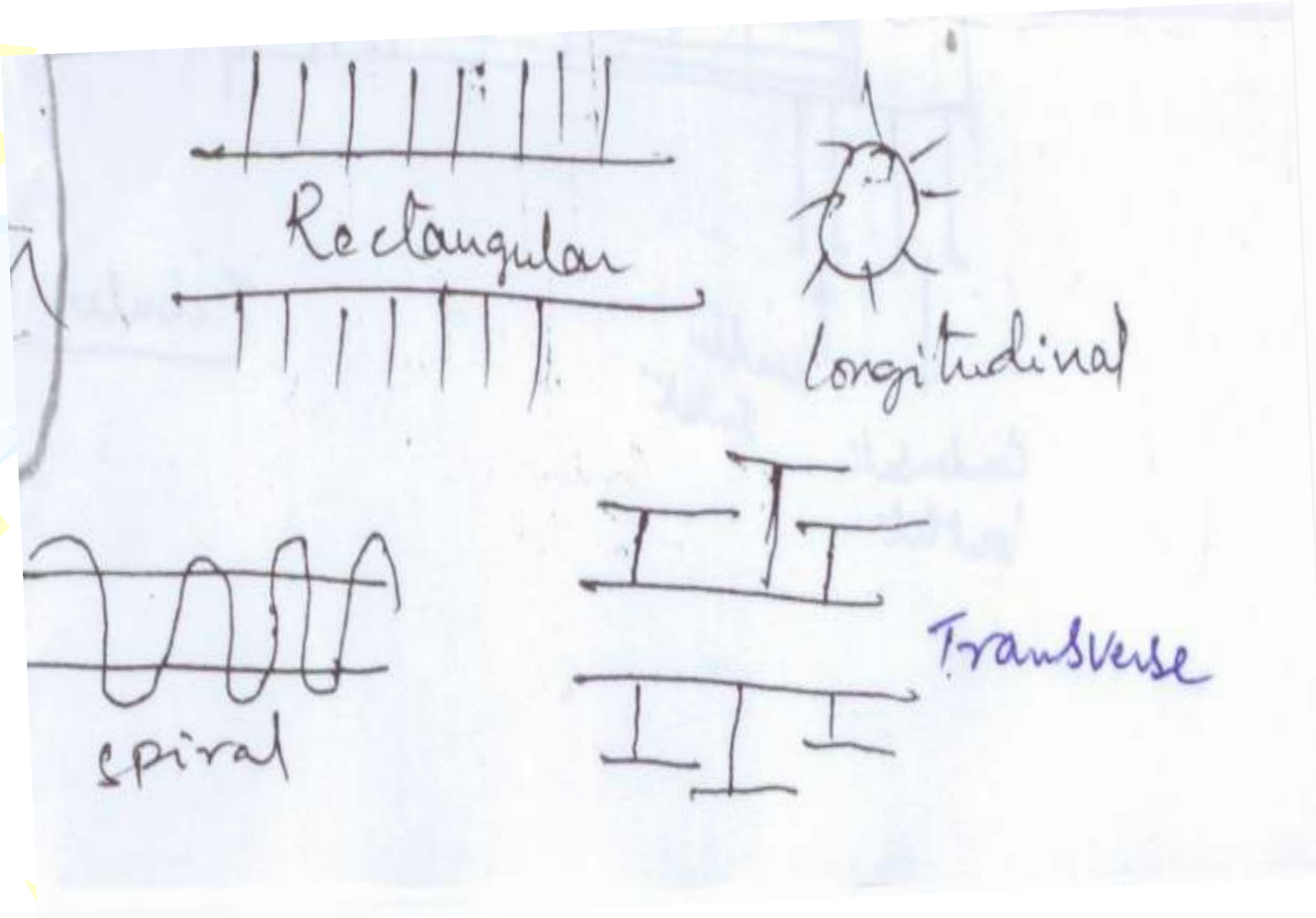
Double Pipe Heat Interchanger



Normal Pipe sizes

Out side pipe(inch)	Inside pipe(inch)
2	1 ¼
2 ½	1 ¼
3	2
4	3

Finned Tubes



Thank You