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IIT(BHU) VARANASI

STUDENTS' NOTES

UNDERGROUND MINE ENVIRONMENT

FIFTH SEMESTER

TOPIC-PSYCHOMETRIC PROPERTIES

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Atmospheric pressure ≅ 10 km of air column ≅ 76 cm Hg
≡ 10m of water head.

Dry barometer (Aneroid barometer).
Atmospheric pressure = 100 kPa = 0.1 MPa.

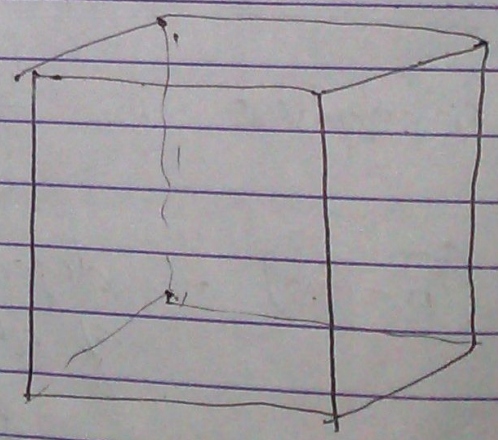
Vapour Pressure – Pressure exerted by vapour in air is vapour pressure.

Saturation vapour pressure – The pressure exerted by saturated vapour.

Mixing ratio / moisture content – It a mass of water vapour per ~~unit~~ kg of dry air.

$$(x \text{ or } r) = \frac{\text{Mass of water vapour}}{\text{Mass of dry air.}}$$

Total mass of air = 1.02 kg.
Dry air = 1.00 kg
~~mass~~ water vapour = 0.02 kg.
Compartment volume = 0.95 m^3.



Specific volume (v) – Volume per unit mass.

∴ v of dry air = 0.95 m^3/kg.

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Apparent density :- Mass of dry air in 1 m^3
(Dry air density) ÷

True density - $\frac{\text{Mass of total air}}{\text{Total volume}}$

Enthalpy - The heat content of air per kg of air. Unit: kJ/kg-air.

* Heat content = 0 at 273.15 K 0°C.

Heat content = mass * sp. heat * ΔT.

Enthalpy consists of 3 contribution terms:

Sensible heat of dry air + sensible heat of water vapour + latent heat of vaporiza

Sensible heat - A heat that can change the temperature of the body.

$$H = H_a + r(1.8t_{db} + 2501) \text{ kJ/kg}$$

$$H_a = 1.005\, t_{db} \text{ kJ/kg}$$

1.883 ≡ 1.8 - Specific heat at constant pressure kJ/kg·°C of water vapour.

l - latent heat of vaporization = 2501 kJ/kg
2450

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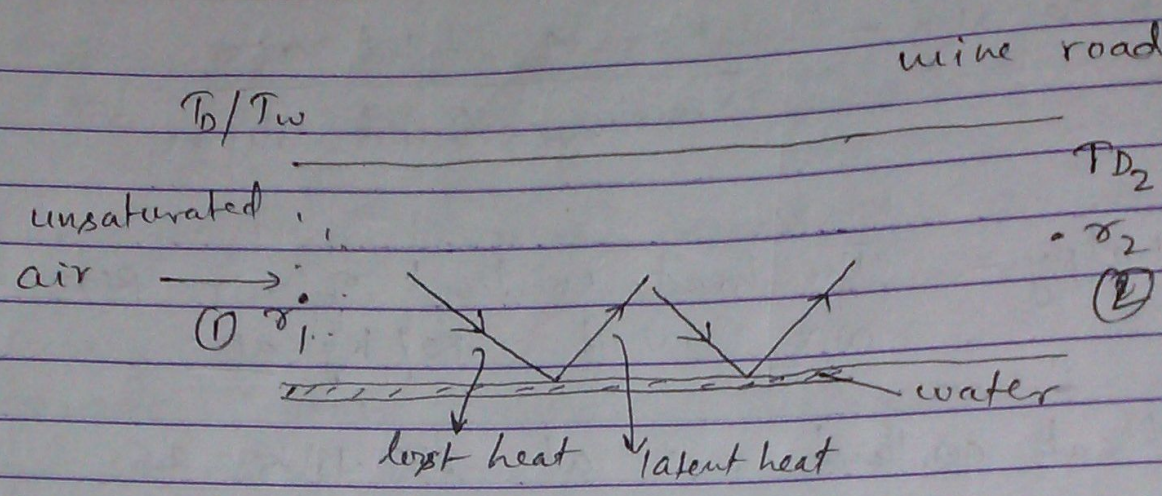
Sigma Heat



~~dry air mass flow rate~~ mass flow rate = 1 kg/sec.

r_1, h_1 } at ~~sta~~ inlet

r_2, h_2 } at outlet.

at the outlet, $h_2 > h_1$

$$h_2 - h_1 = C_{pw}(r_2 - r_1) \cdot T_W$$

C_{pw} – heat capacity at constant pressure.

$$h_2 - C_{pw} r_2 T_W = h_1 - C_{pw} r_1 T_W$$

= sigma heat.

So, $S_1 = S_2$ but the enthalpy relation is not similar.

$C_{pw} = 4.18$ kJ/kg·°C.

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$$S = H - r H'_{wt}$$

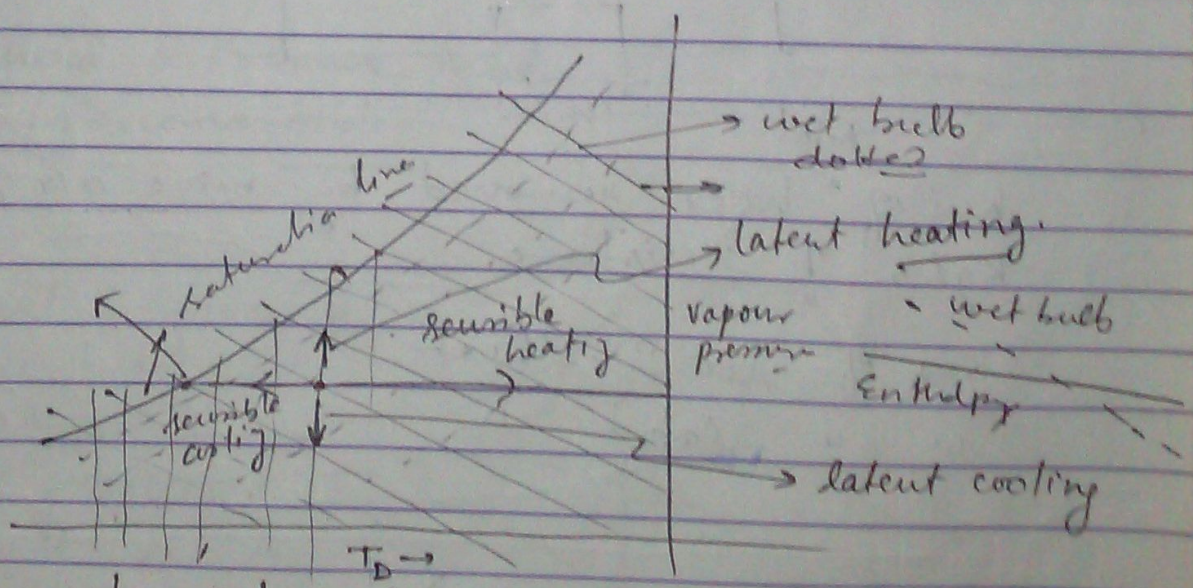
$H'_{wt} = 4.18\, t_{wb}$ 4.18 kJ/kg°C.

h-s ~ 4%.

Sigma heat is a function of Tw and pressure.
Enthalpy is a function of Tw, TD, B.

$$\text{Relative Humidity} = \frac{\text{Vap. Pressure}}{\text{sat. vap pressure at TD}} \times 100\ (\%)$$

Dew point temp = The temp. at which condensation starts for a particular moisture content of air is called Dew Point temperature.



State point - intersection of given TD & Tw. It gives the state of atmosph.

on the saturation line TD & Tw are same.

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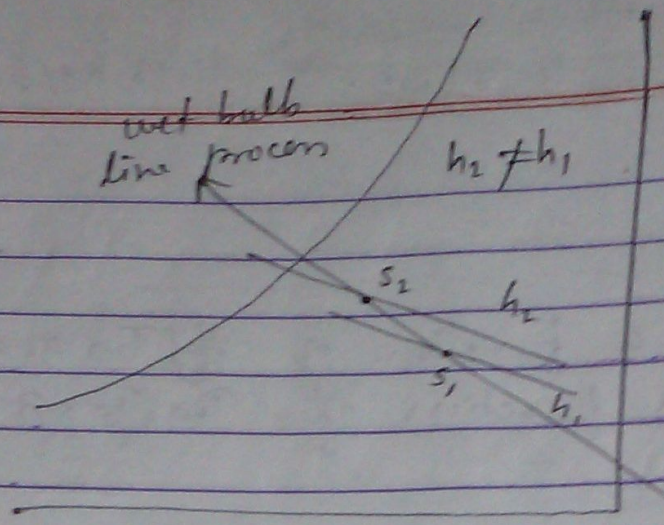
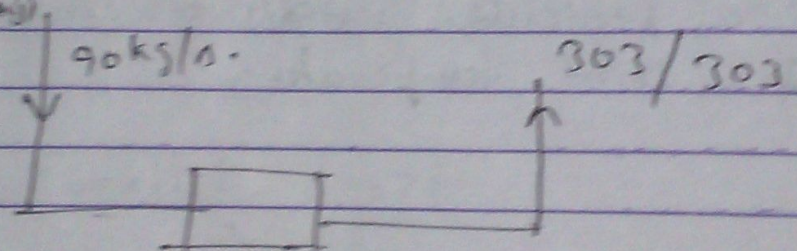


In wet bulb line process, the wet bulb temp remains constant but T_{DB} changes.

T_{DB} T_{WB}
305/300 101.3 kPa.

$\dot{m}_a = 90$ kg/s



Total
Kw of heat removed by mine air?
kg/s of moisture ?

Kw of sensible heat ?
" " latent " ?

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Losses in Air flow

Head Losses :

Mine static head loss $H_l = H_f + H_x$

H_f → frictional loss (80-90%)

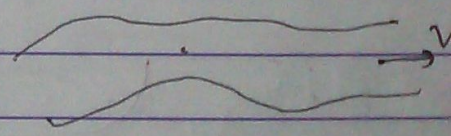
H_x → shock loss. (10-20%)

Mine velocity head = h_v

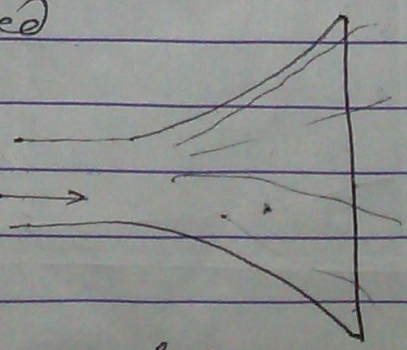
Mine total head ≡ $h_t = h_s + h_v$. ($H_s \doteq H_s$)

h_v is measured by the ~~max~~ discharge velocity.

velocity head & Pressure head are interconvertible.



velocity head is converted into static head due to the change in crossection. So, some energy is recovered.



Outgoing air will drain out the velocity head.

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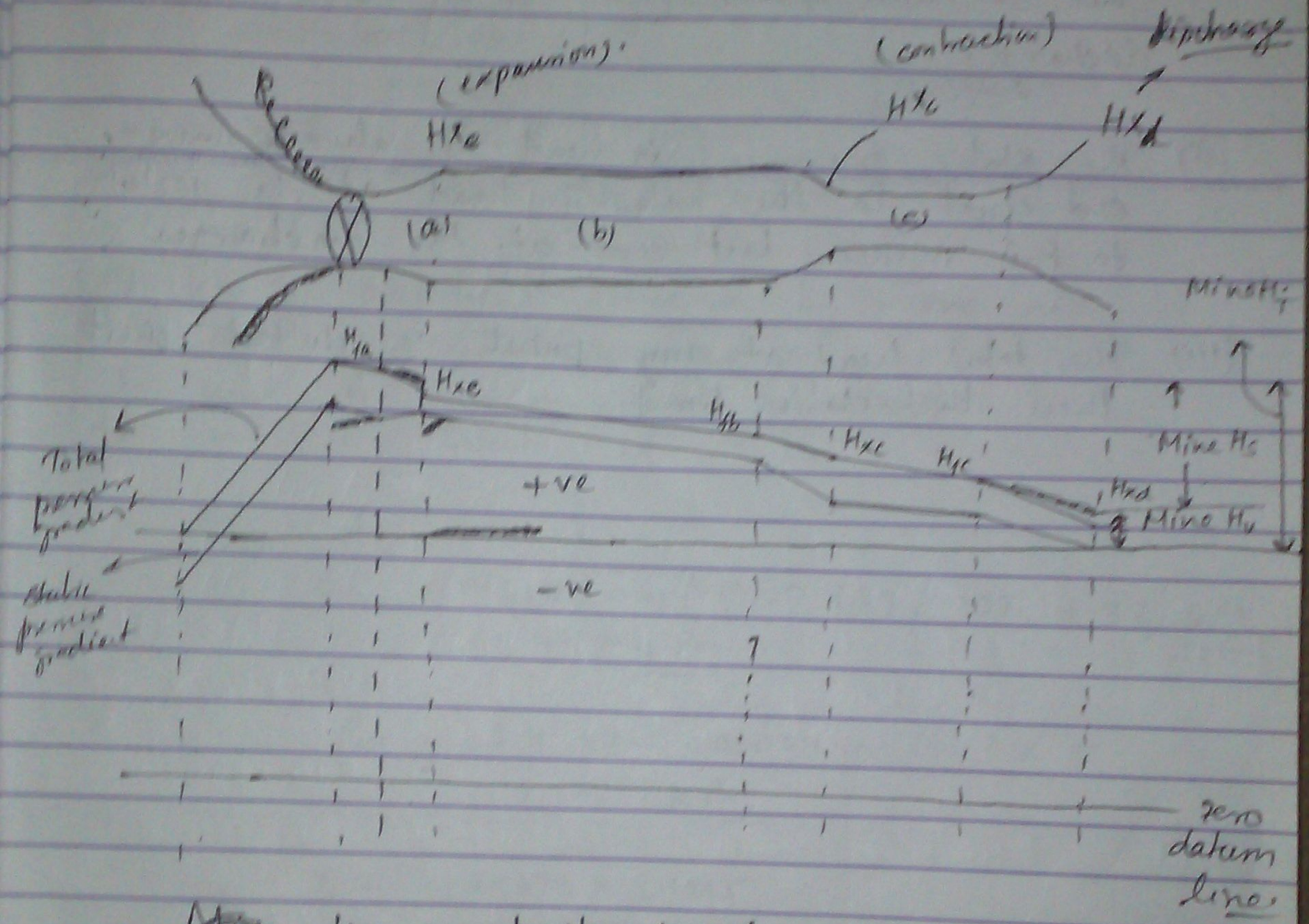
Forcing System:



Hv - velocity head.

* The inlet velocity head drops below the datum. This occur because a 'suction condition' must exist in order for air to flow into the system.

* The discharge velocity head lies above datum because air is in motion when it leaves the system and so is discharged with that amount of K.E remains.

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Rules for plotting a Pressure gradient:

(i) Total pressure head is always zero at the inlet but +ve and equal to velocity head at the discharge.

(ii) The static pressure head is always -ve and equal to the velocity head at the inlet to the system but zero at the discharge.

(iii) The total head at any point is plotted first then the static head.

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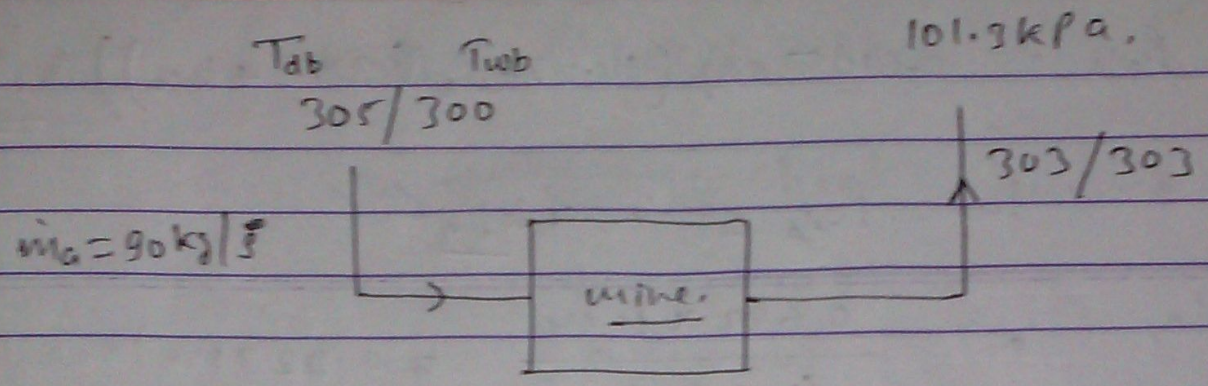
Psychrometry



(a) kW of total heat removed by mine air?
(b) kg/s of moisture removed " " " ?
(c) kW " sensible heat removed?
(d) " " latent " " ?

At inlet:

$$P_{ws} = 0.6105 \exp(17.27 \times 27 / 237.3 + 32) \text{ kPa}$$
$$= 3.4487 \text{ kPa}$$

$$P_w = 3.4487 - 0.000644 \times 101.3 \times 5$$
$$= 3.1225 \text{ kPa}$$

$$r_i = \frac{0.622 \times 3.1225}{101.3 - 3.1225} = 0.0197$$

$$H_{sh} = [1.005 \times 32 + 0.0197 \times (1.8 \times 32 + 2501)] \text{ kJ/kg}$$
$$(32.16 + 50.40) \text{ kJ/kg}$$
$$= 82.56 \text{ kJ/kg}$$

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At outlet:

$$P_w = P_{ws} - AP(t_{db} - t_{wb}) \text{ kPa.}$$

$$P_{ws} = 0.6105 \exp(17.27 t_{wb}/(237.3 + t_{wb})) \text{ kPa}$$

$$P_w = P_{ws} = 4.24 \text{ kPa}$$

So, $$r_o = \frac{0.622 \times 4.24}{(101.3 - 4.24)} = 0.0271$$

$$H_{out} = 1.005 \times 30 + 0.0271(1.8 \times 30 + 2501)$$

$$(30.15 + 69.24) \text{ kJ/kg.}$$

$$= 99.39 \text{ kJ/kg}$$

(a) Total heat removed from mine = 16.83 kJ/kg.

kW of air removed = $16.83 \text{ kJ/kg} \times \frac{50 \text{ kg}}{s}$

= 1514.7 kW.

(b) Moisture removed per kg dry air =

$(r_o - r_i) = (0.0271 - 0.0197) = 0.0074$

kg/s of moisture removed = $90 \times 7.4 \times 10^{-3}$

= 6.66 kg/sec

(c) Sensible heat at inlet = $H_{in} - r_{in} \times 2501$

" " " outlet = $H_{out} - r_{out} \times 2501$

Total sensible heat removed =

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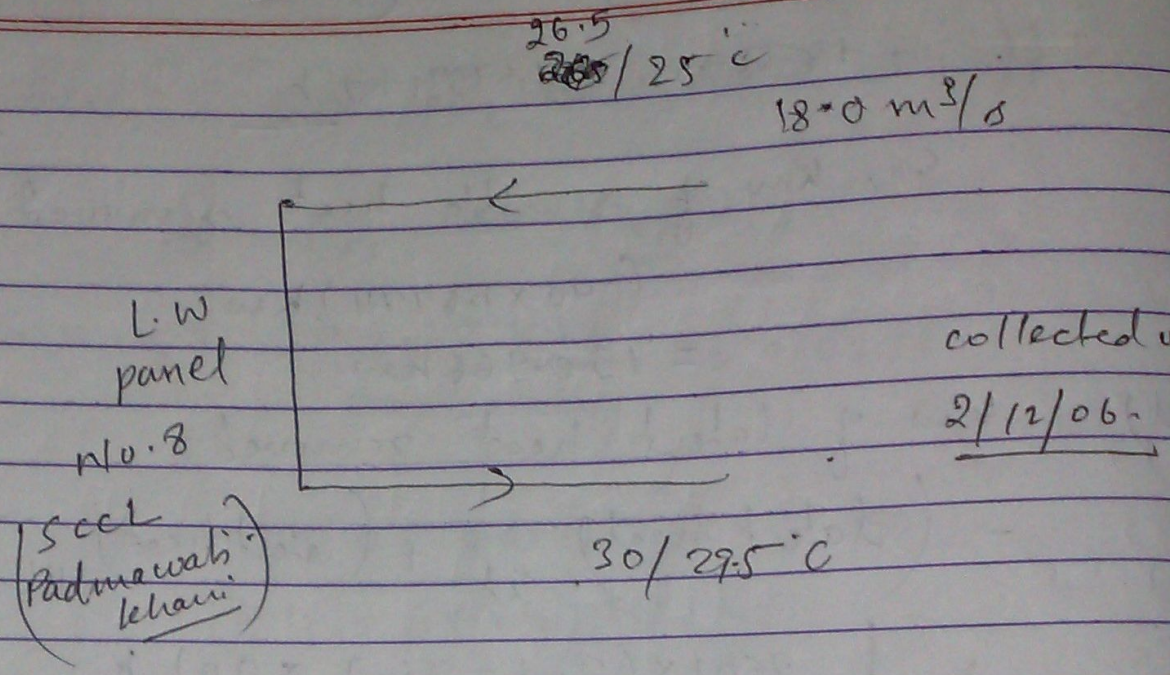
Psychrometry



$$Z = 67.4 * T \log\left(\frac{B_2}{B_1}\right)$$

Surface pressure: 99.85 kPa (B on surface).

Panel = 300 m.

T - mean T_D. between 2 locations.

$$\frac{Z}{67.4 \times T_D} = \log_{10}\left(\frac{B_2}{B_1}\right)$$

$$\left(\frac{B_2}{B_1}\right) = 10^{\frac{Z}{67.4 \times T_D}} \text{ or } e^{\frac{Z}{67.4 \times T_D}}$$

103.32 kPa 101.34

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Total heat $= \frac{Q_1}{v_1}(h_2 - h_1)$

$= \frac{18}{0.825} \times (98-25) = 473\,kW.$

latent heat $= \frac{Q_1}{v_1}(r_2 - r_1)$

$= \frac{18}{0.825} \times (0.027 - 0.019)\ 2400$

$= 403\,kW.$

Sensible heat = Total − latent heat

$= (473 - 403)\,kW = 70\,kW.$

Total − lat heat = Sensible heat

$= \dot{m}\, C_{pm} (T_{D_2} - T_{D_1})$

where C_{pm} − mean specific heat of mixture.

~~mixture~~ $C_{pm} = \frac{C_{pa} + r C_{pv}}{1+r}$

where $r = \frac{r_1 + r_2}{2}$

$r = \frac{0.027 + 0.019}{2}$

$= 0.023.$

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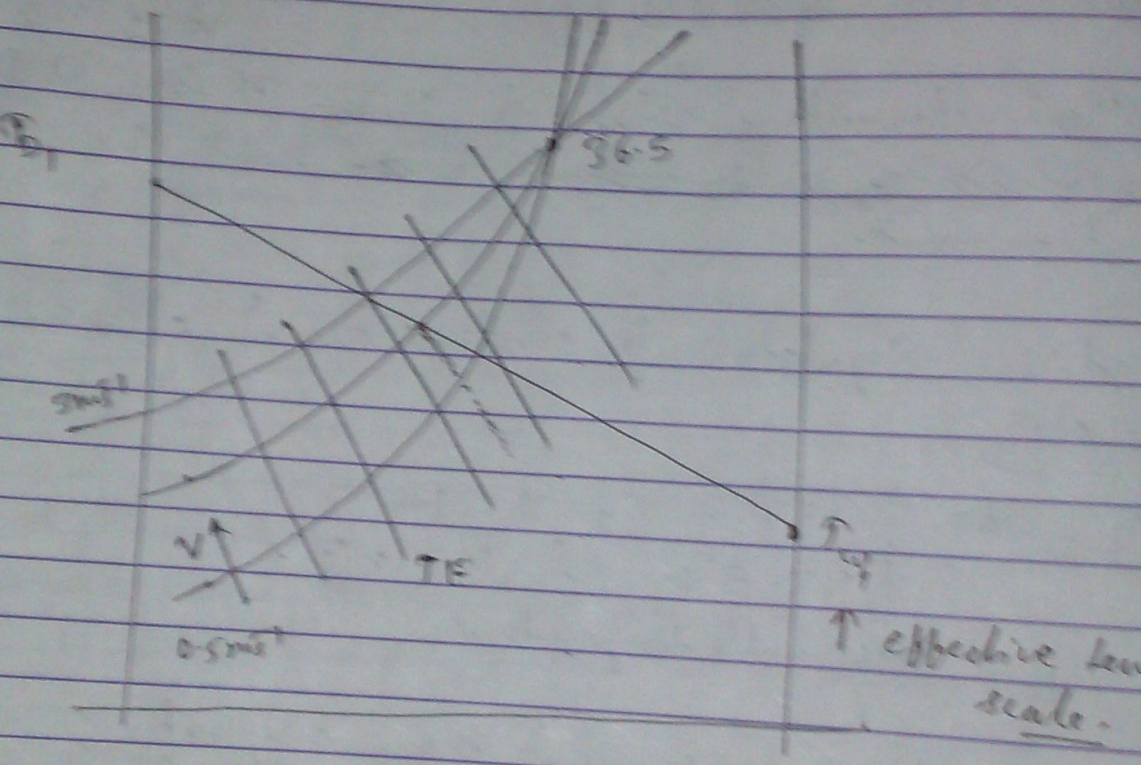
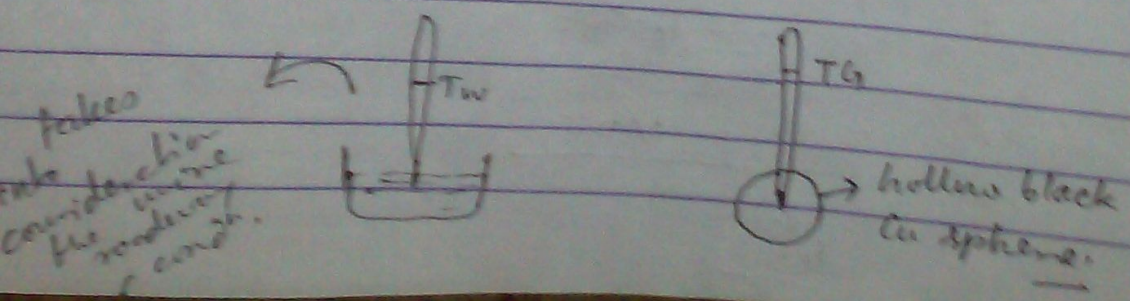
Effective temperature scale:

The human comfort level should be same in 2 environments, then the temperature of a saturated environment.



wet bulb globe temperature:

- Tw
- TE
- WBGT = 0.7Tw + 0.3TG.



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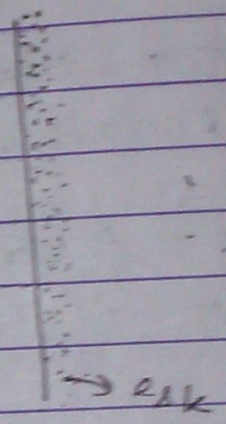
$$E = w \cdot \frac{965\, p^{1.6}\, v^{0.6}}{(p-e)^2}\,(e_{sk} - e) \quad W/m^2$$

T_s – skin temperature 32–36°C.
T_R – radiant temperature $\simeq T_G \simeq T_D + 0.2°C$.

e_{sk} – Saturation vapour pressure at skin temperature
e – partial vapour pressure of surrounding atmosphere.

fraction of body surface area which is wet.



at $T_w \geq 30°C$ hard work $\Rightarrow w \geq 0.9$.

P – Barometric Pressure (in kPa).

and by specific cooling power concept:

$$R + C + E \geq M$$

$M = 270\, W/m^2$ for hard work.

Steps to manage heat stress:

- light cotton clothing.
- increased velocities.
- cool water to be provided for drinking
- vitamin / salt supplements.
- work with periodic rests cycles.
- acclimatisation.

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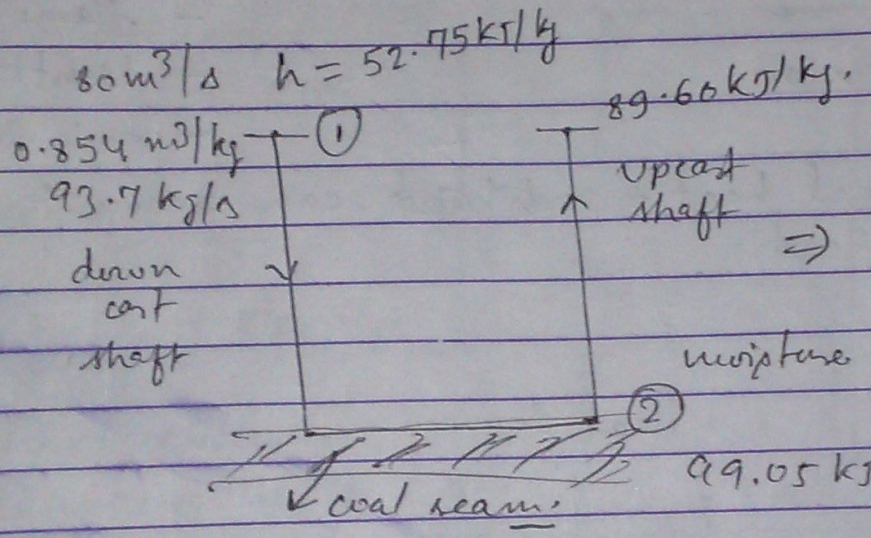
Mine velocities cannot be increased infinitely as they create dust problems in mine gallery.

Contribution factor of heat in mines:

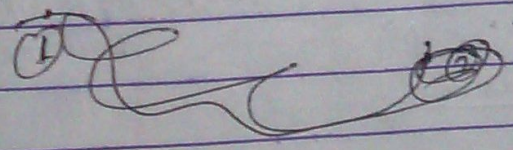
Chinakuri colliery, ECL.



⇒ Heat added = 4.43 MW.

moisture removed = 4.385 m³ eq. of water/hr.

Heat load = Sum of all heat transfer processes that take place in a ventilating air path.



$= \dot{m}(h_2 - h_1)$.

$= \frac{Q}{v}(h_2 - h_1)$

$= 93.7(99.05 - 52.75) = 4.43$

Contributing factors to heat in a mine:

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Total heat.

Major sources

- Geothermal heat (rock heat). + ground water.
- machinery.
- Oxidation.
- Auto compression.

Minor sources.

- blasting
- metabolic heat
- flame safety lamp
- lighting
- rock fall.

Geothermal heat ~~rock heat~~ can account to 95% of total heat.

Heat Sources.

Natural sources

500W – an individual who is doing hard work. (hard work)

Artificial sources.

(machinery biggest artifical source)

Blasting:

Explosive energy – 50% released instantaneously
50% released slowly because the ~~rock di~~ broken muck discharges slowly in 2 hrs roughly.

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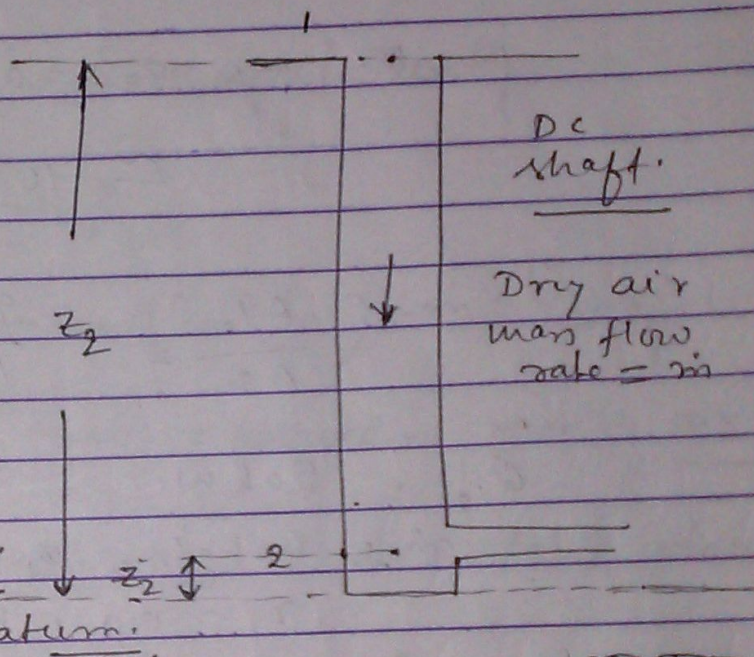
ANFO - 3700 kJ/kg.

NG - 5800 kJ/kg.

Blasting is not taken as major source because it doesn't contribute to heat content continuously but causes just a spike in the value for a very small time.

$$\boxed{\dot{m}gz_1 + \frac{\dot{m}V_1^2}{2} + \dot{m}h_1 = \dot{m}gz_2 + \frac{\dot{m}V_2^2}{2} + \dot{m}h_2 + Q_{12}}$$



Q_2 - heat exchange between shaft & air.

when $Q_2 = 0$, then adiabatic compression of air occurs.

neglecting K.E change:

$$\dot{m}gz_1 + \dot{m}h_1 = \dot{m}gz_2 + \dot{m}h_2$$

$$(h_2 - h_1) = g(z_1 - z_2).$$

assuming $\gamma_1 = \gamma_2$.

$$C_{pm}(T_{D_2} - T_{D_1}) = g(z_1 - z_2).$$

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So, $\frac{\Delta T_D}{\Delta z}$ = adiabatic lapse rate = $\frac{g}{C_{pm}}$.

$$C_{pm} = \frac{C_{pa} + r C_{pv}}{1+r}$$

$$= \frac{1005 + r(1883)}{1+r}$$

say $r = 0.02 - 0.03$

$\simeq 1020$.

$$\frac{\Delta T_D}{\Delta z} = \frac{9.81}{1020} \simeq 1°C/100m$$

$Q_{12} = 50 kW$.

$\dot{m} = 60 kg/s$, $r_1 = 0.02 kg/kg$.

$r_2 = 0.025 kg/kg$.

$z_1 - z_2 = 700 m$.

$T_{D_1} = 35°C$, $T_{D_2} = ?$

$r_2 = \frac{0.045}{2}$

$$C_{pm} = \frac{1005 + 0.0225 \times 1883}{1.0225}$$

$$\dot{m} g \Delta z - Q_{12} = \dot{m}(h_2 - h_1)$$

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Heat Load Sources

Major Sources:

- Auto Compression.
- Machinery.
- Oxidation.
- Wall rock. (Geothermal heat).

In DC shaft:

$$mg\Delta z - Q_{12} = m(h_2 - h_1)$$

$$= m c_{pm}(T_{D_2} - T_{D_1}) + m(r_2 - r_1) L$$

Q_{12} - External heat transfer between rock & air

In UC shaft: Autoexpansion of air takes pla

~~$mg\Delta z + Q_{12} =$~~

Mining Machinery:

3 types of energy sources:

→ Electricity.
→ Pneumatic (compressed air)
→ Diesel.

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i.e depletion of 1 kg of O_2 due to oxidation

carbon ⇒ $\frac{30 \times 12}{17}$ = $\frac{51}{4}$ = 12.67

Solution:

$O_2 = 20.97\%$

$O_2 = 20.77\%$ v/v

$90 m^3/s$

Density of O

1.3 kg/

coal mine.

→ All oxygen is utilized in oxidation.

$(0.002 \times 60 \times 12.675)$

$(0.002 \times 90 \times 1.3 \times 12.675)$

2.306 MJ/m

* 1 kg of S oxidation gives :- 9.3 MJ of h

So, depletion of 1 kg of O_2 due to oxidation of Sulphur gives out 9.3 MJ of heat.

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Minor Sources:

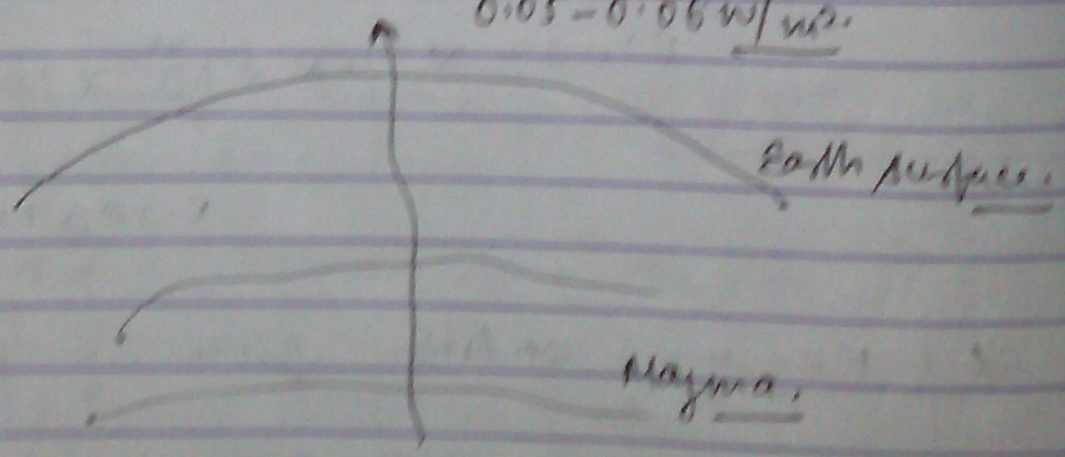
- Fall of rock. $mg(\Delta z)$.
- Lighting.
- Flame Safety lamp.
- Metabolism.
- Explosives.

Lighting:
10% of ~~energy~~ e-m wave emitted from filament bulbs is in IR region. So, roughly all energy is converted into heat.

* **Metabolism** – A hard working miner is a source of 500 W power.

Geothermal Heat

(Heat emitted by the earth).
0.05 – 0.06 W/m².



The transfer of heat can be assumed to be one dimensional as the crust thickness is very negligible w.r.t ~~magma~~ radius of earth.

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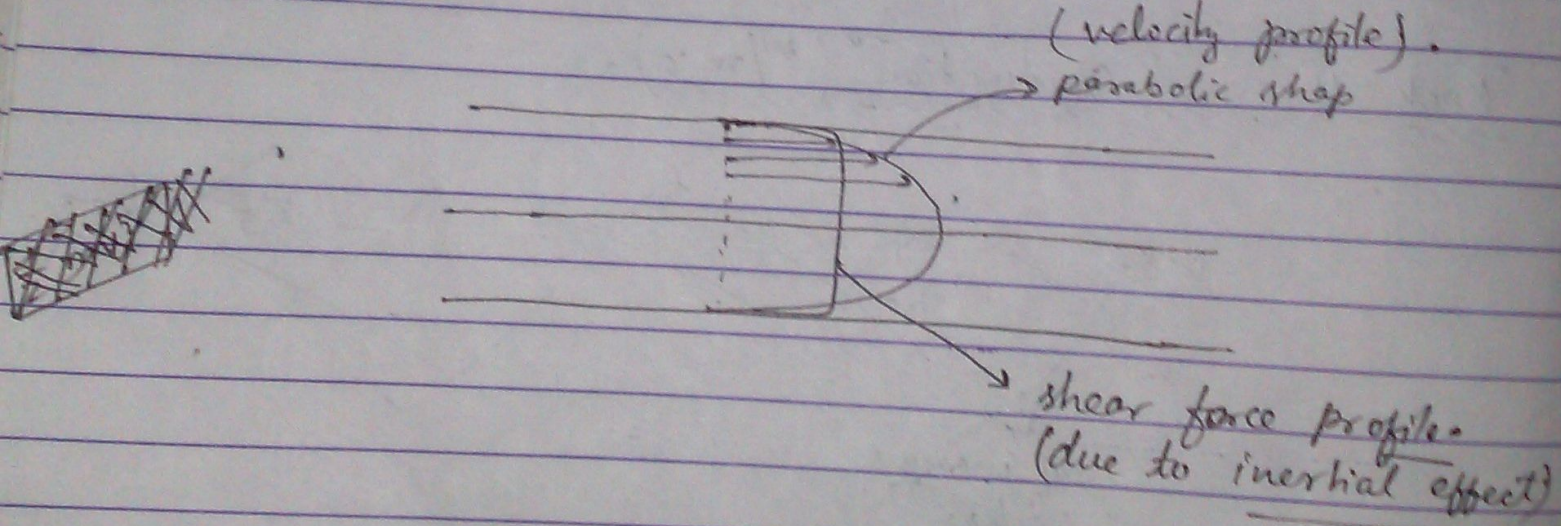
Friction loss calculations:

Reynold no: $= \dfrac{\text{Inertial force}}{\text{Viscous force}} = Re.$

$= \dfrac{\frac{1}{2}\rho u^2}{\text{Viscous force}}.$

Laminar flow:



Viscous force dominates in Laminar flow.
Inertial " " " Turbulent flow.

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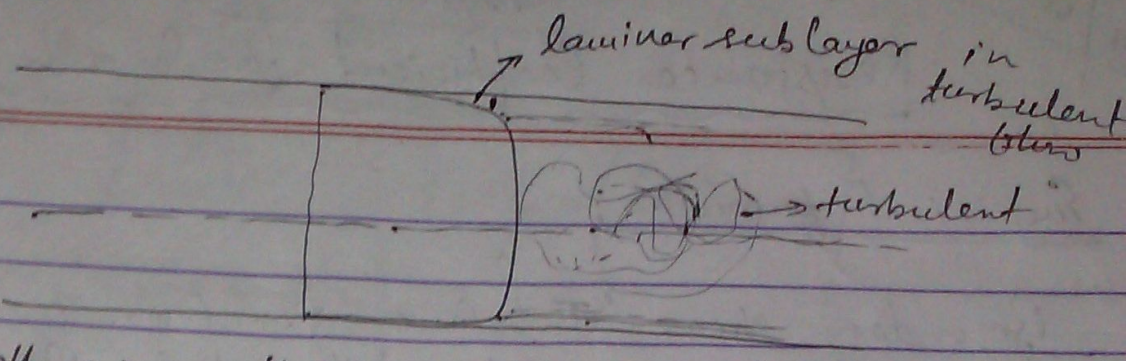
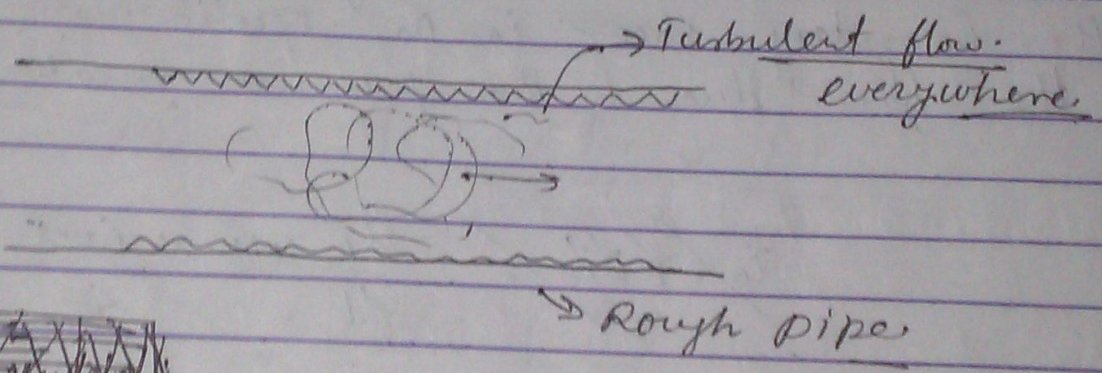


In smooth pipe, the near boundary laminar flow region will be there. → smooth pipe

Rough pipe:



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$$\Delta P_f = \frac{f \rho u^2 \times L}{2D}$$

$$\boxed{\Delta P_f = f \cdot \frac{L}{D} \cdot \left(\frac{\rho u^2}{2}\right).}$$

Equivalent diameter: of a rectangular airway:

$$\boxed{D = \frac{4A}{P}}$$

$$\Delta P_f = f \cdot \frac{L \times Per}{4A} \times \frac{\rho u^2}{2}$$

$$= f \cdot \frac{S \cdot \rho u^2}{8A}$$

S - surface area.

$$k = f\rho/8$$

$$\Delta P_f = \frac{k \times S u^2}{A}$$

K - frictional coefficient.

For values of Re, Reynold no greater than 2000 ~~due to~~ Blasius given by

$$2000 \le Re \le 10{,}000$$

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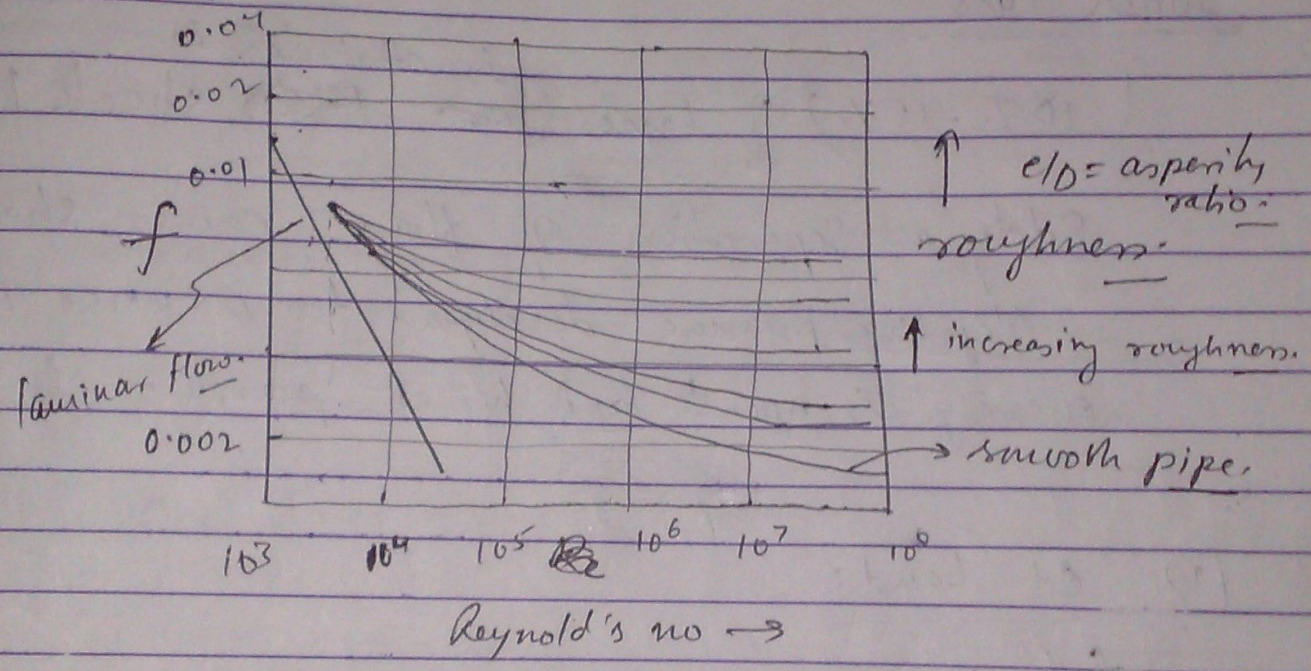
25/08/08 f depends upon:

Re, surface roughness of airway.

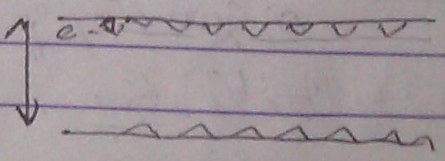
Moody diagram:

Function of 2 parameters:

Log & log scale: diagram.



e/D ratio more – roughness more.



e/D – Asperity ratio.

Departure from smooth curve line is faster as roughness increases.

In rough pipe ~~as low~~ low Re too, there will be turbulent flow.

After certain Re, the value of f becomes constant.

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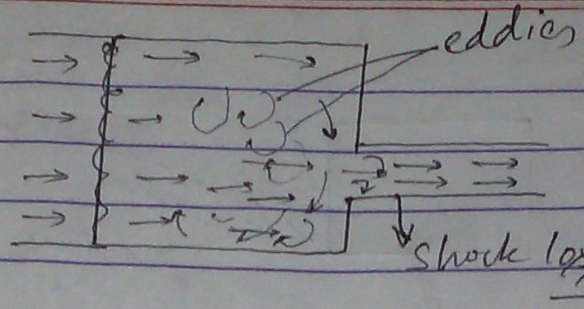
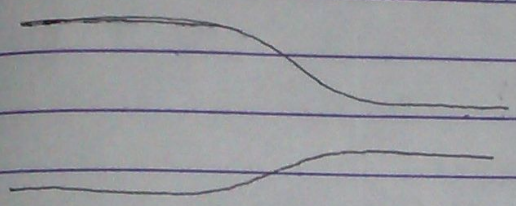
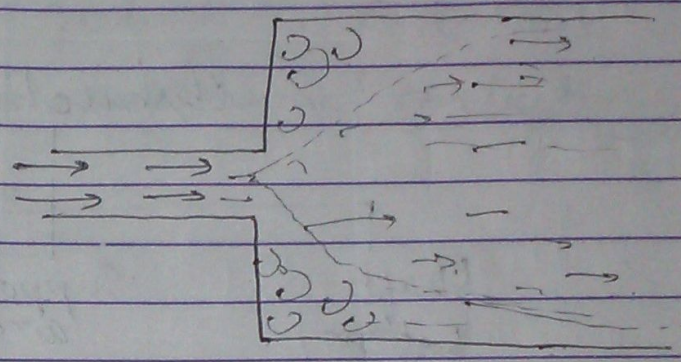
(ii) Area of crossection changes:



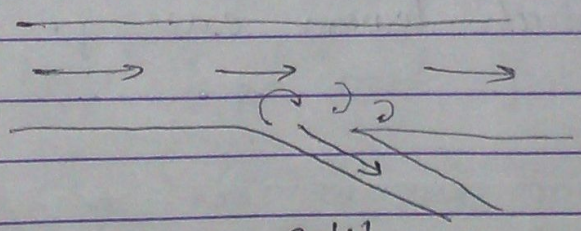


Continuous variation of A.

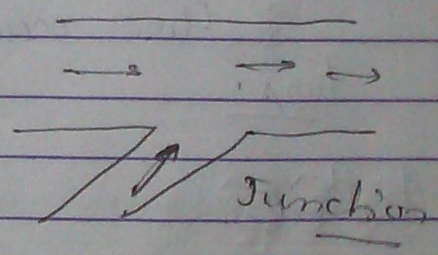


Expansion.

(iii) Split and Junction:



Split



Junction

$$\boxed{\text{Shock loss in split} > \text{shock loss in junction}}$$

Here also, shock loss depends upon the split / junction geometry.

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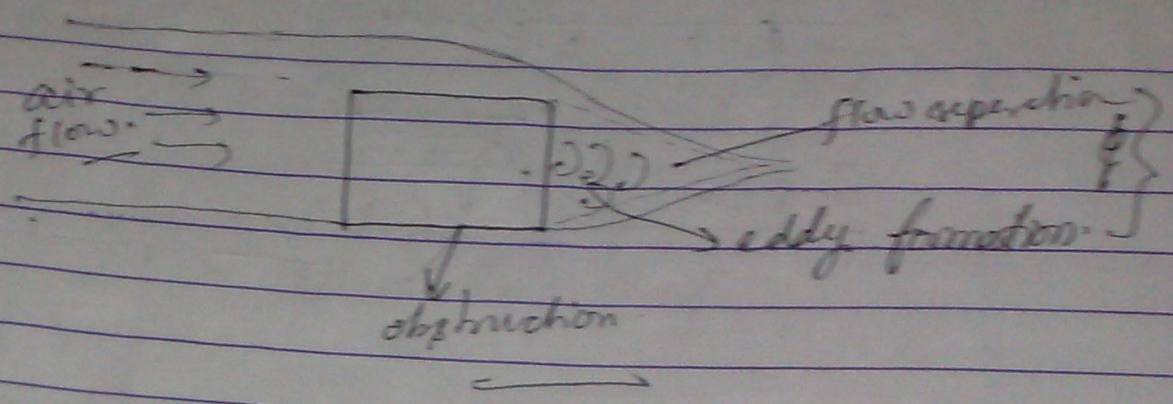
(iv) Obstructions:



Obstructions:

- Shaft (~~[illegible]~~ batten)
- Supported airways (props, bars, cog)
- (mine cars, machinery, tubs.)
- Conveyor b

Obstructions reduces the flow area.
So, for maintaining a flow, acceleration of flow occurs which lowers energy and causes loss.

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Geothermal Gradient

Rock to Air Heat Transfer

Heat flux

0.05 – 0.06 W/m²

Surface of earth

Temp gradient depends on:

the rock thermal conductivity,

magma.

$$Q = \text{Heat flux} \propto \left(\frac{dT}{dx}\right)$$

$$Q = k\left(\frac{dT}{dx}\right).$$

* Quartzite hot rock for Gold.
*
* In case of coal measure rocks the temperature increases more with depth as k is low. In other words Geothermal grad. is high.

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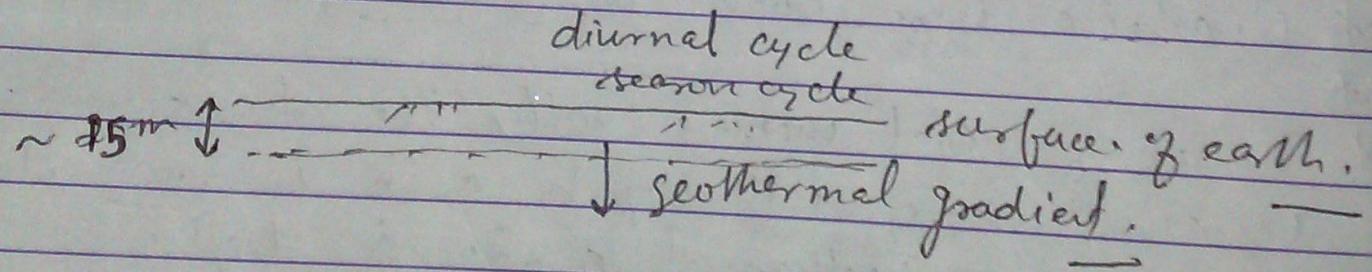
Formation	Geothermal gradient °C/m.
Indian Coal mines	1°C / 38.4 m.
UK " "	1°C / 34 m.
~~Broken Hill, Australia~~ Mount Isa	1°C / 50 m.
Balaria, HZL, sterlite	1°C / 50 m.
Musaboni, HCL	1°C / 47 m.
Kolar gold fields	1°C / 91 m.
1km deep mines: Witwatersrand, SA	1°C / 110 m.



At a depth of 15m, the temperature stabilizes and hence from here it will increase by geothermal gradient.

Approx. Temp at a depth 15m in India = 21°C.

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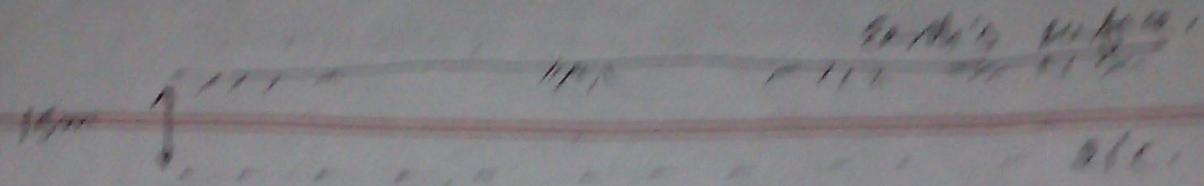


$$\frac{214 \times 1500}{50} = 5850C$$

at 1500m ..... 58°C

Virgin Rock Temp.

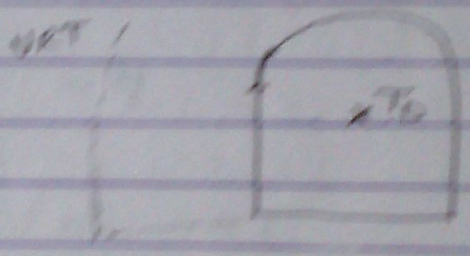
Driving force of Heat flow: $(VRT - T_0)$

VRT = Virgin Rock Temperature.

T_0 = Dry Bulb Temperature.

$(VRT - T_0) \propto Q$

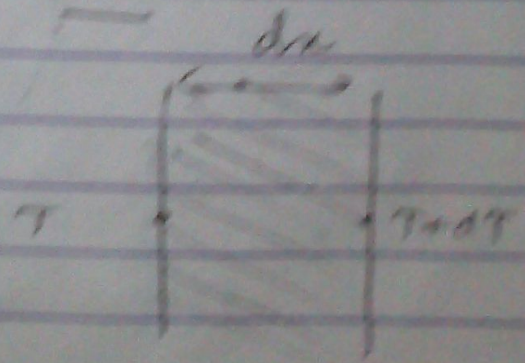
$= RQ$



Q = heat flux (or) of heat flow.

R = Resistance of for heat flow.

$$Q = k \frac{dT}{dx}$$



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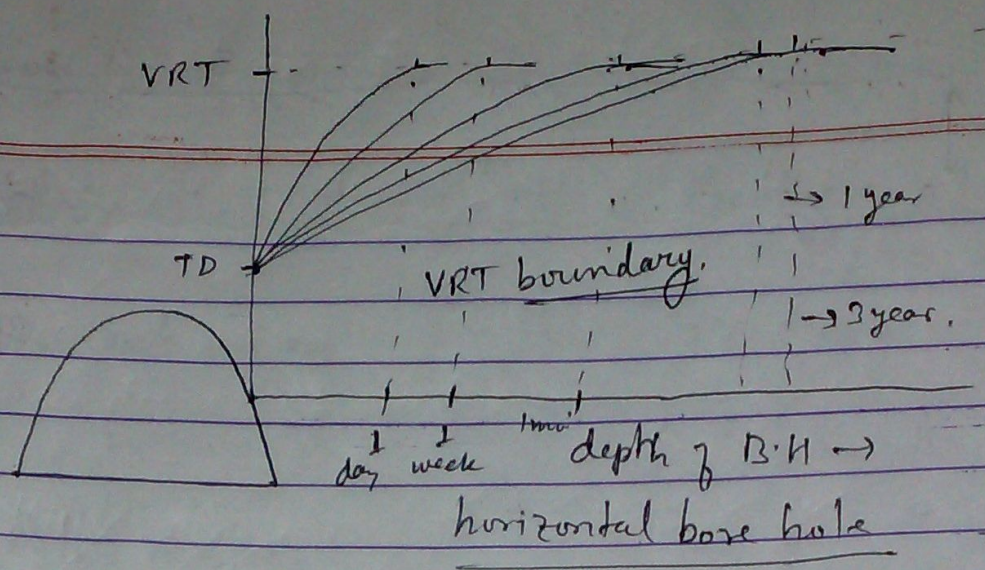
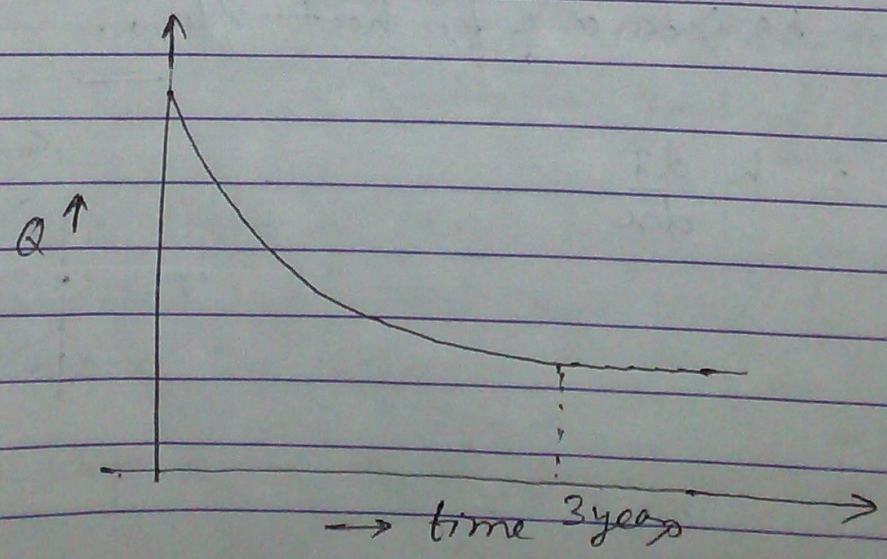


After 3 years the surrounding rock temperature stabilizes. So, the VRT boundary doesn't shift after that appreciably.

VRT boundary is at typical 8ϕ of the ~~ex~~ tunnel where

ϕ – hydrulic diameter $(4A/P)$.
(for fluid flow).

Depending upon the age of the opening, the VRT boundary shifts unbill the age is 3 years.



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(b) One Dimensional Heat flow in stopes:

$$Q \text{ (in watts)} = \frac{A(k\rho c)^{0.5}(VRT - T_0)}{t^{0.5}}$$

A = X sec. area in m^2. (of all faces).
k, ρ, c = rock T.C, rock density, Sp. heat.
t = age of stope in (sec).

Stope of dimension = 6m × 20m × 50m.

Age = 2 months.
k = 5.0 W/m°C
ρ = 2100 kg/m³
c = 900 J/kg°C.

$$A = 2[(6 \times 20) + (20 \times 50) + (50 \times 6)] \text{ m}^2$$

(c) Tunnel heat flow:

$$Q \text{ (in watts)} = 3.35 \cdot L \cdot k^{0.554} (VRT - T_0).$$

L = length of tunnel (m).
k = RTC.

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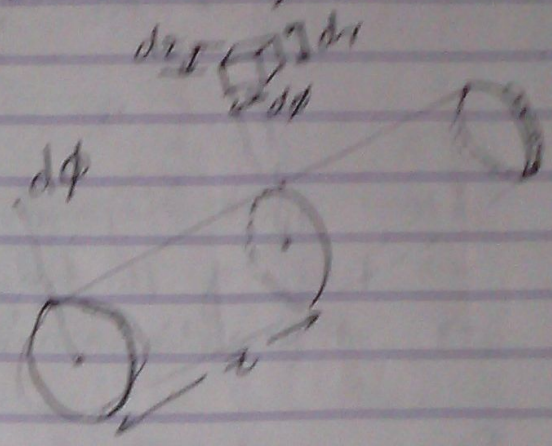
General Equation for 3D heat conduction into circular opening.

$$\frac{k}{\rho c}\left(\frac{\partial^2\theta}{\partial r^2}+\frac{1}{r}\frac{\partial\theta}{\partial r}+\frac{1}{r^2}\frac{\partial^2\theta}{\partial\phi^2}+\frac{\partial^2\theta}{\partial z^2}\right)=\frac{\partial\theta}{\partial t}$$

θ - temp
r - rad. from centre.
ϕ - Polar angle.
z - axial distance
t - time.



Assumptions:

→ neglecting the ~~variation~~ changes along z axis.
→ ~~neglecting the~~ Assumes radial symmetry.

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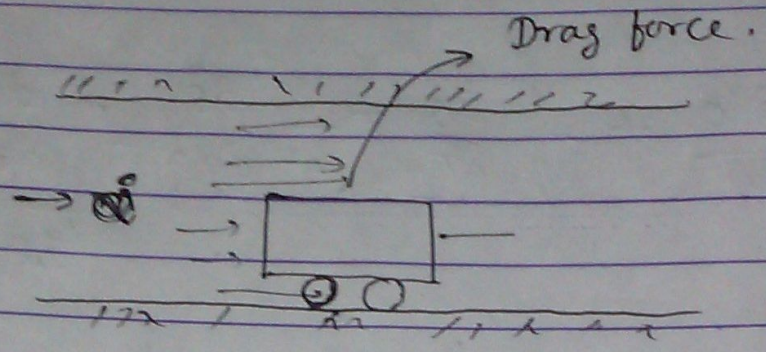
28/08/08

Shock loss due to obstructions:



Drag force depends upon:
→ Form of the body
→ Reynold's number.

Pressure due to Drag force on a body is:

$$\Delta P_D = \frac{C_D \rho v^2}{2}$$

C_D - Drag coefficient. (length, shape).

C_D takes care of the geometry ~~speed~~ of the obstruction

If Reynold no. is very high, C_D doesn't depend upon ~~C_D~~ Reynol no. For low Reynold no. it depends upon geometry & Reynol No.

For high Reynold no. it depends upon the geometry of ~~body~~ obstruction.

Shock ~~loss~~

~~Pressure loss~~ = Drag Force $F_D = P_D \times A_1$

A_1 - frontal projected Area of obstruction.

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$$\boxed{F = C_D \times A_1 \times \frac{1}{2} \rho u^2}$$

Shock Pressure loss = $P_s = \frac{F_D}{A}$

A - area of the airway.

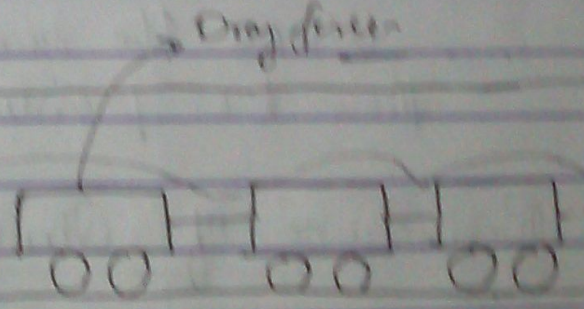
F_D = Drag force.

$$P_s = \left[\left(C_D \right) \times \left(\frac{1}{2} \rho u^2 \right) \cdot \left(\frac{A_1}{A} \right) \right] \quad \text{--- (1)}$$

Shock Pressure loss is measured in the terms of the whole air way. So, Area of cross section of the airway is used.

For single obstruction eq. (1) gives the expression of shock loss due to obstruction.

When the spacing between tubes will be high then the total shock loss will be:



$n \times P_s$

P_s - shock loss due to 1 tube.

n - No. of tubes.

If the spacing is not much:

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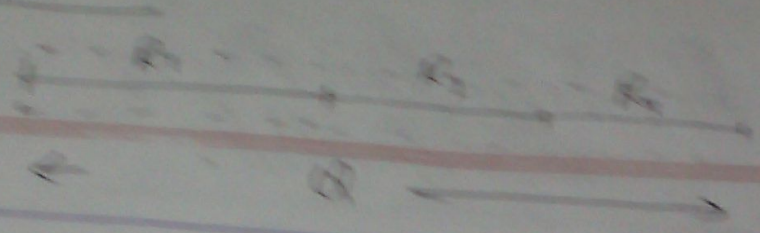

$$P = P_1 + P_2 + \cdots + P_n$$

$$\vec{a} = \vec{a}_1 = \vec{a}_2 = \cdots \vec{a}_n$$

$$P_1 = k_1 \vec{a}^2, \quad P_2 = k_2 \vec{a}^2, \quad \cdots \quad P_n = k_n \vec{a}^2$$

$$P = (k_1 + k_2 + \cdots + k_n)\,\vec{a}^2 \quad [\vec{a}_1 = \vec{a}_2 =$$

$$\left[\frac{P}{\vec{a}^2} = (k_1 + k_2 + \cdots + k_n) = k_{eq}\right]$$

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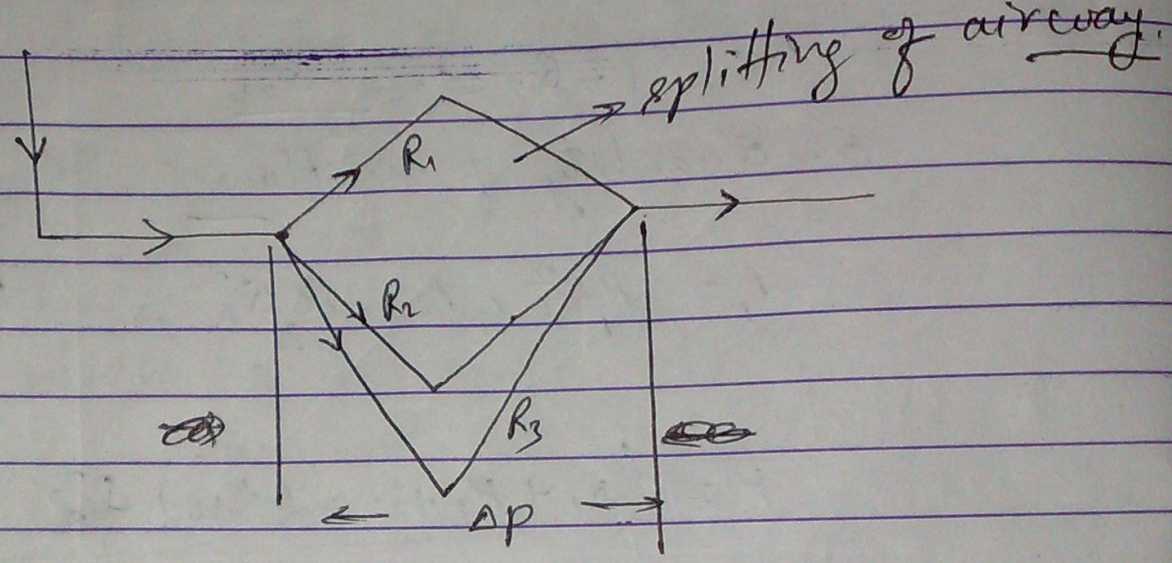
09/08

Resistance for Airways in Parallel.



* Regulator - placed in a district of quantity of air flow less.

* Booster fan - increases the circulation of air flow quantity in a ~~p~~ ~~air~~ of air way.

$$\Delta P = R_1 Q_1^2 = R_2 Q_2^2 = R_n Q_n^2$$

$$Q_0 = Q_1 + Q_2 + \cdots Q_n.$$

$$\Delta P = R_e Q^2$$

~~Root~~

$$Q = \sqrt{\frac{\Delta P}{R}}$$

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02/09/08

Cylindrical/ Polar coordinate.

Heat Conduction in 3D :

Simplified equation :

$$\frac{k}{\rho c}\left[\frac{\partial^2\theta}{\partial r^2} + \frac{1}{r}\frac{\partial\theta}{\partial r}\right] = \frac{\partial\theta}{\partial t} \quad -(1)$$

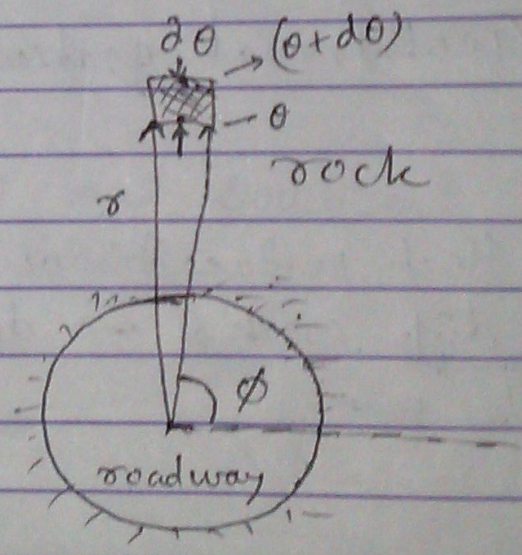
based on 2 assumptions:

1) Along axial direction changes negligible.

2) Radial symmetry.

θ – Temperature

ϕ – Polar L.



Eq (1) is PDE guiding the Radial heat conduction.

k – Thermal conductivity.

ρ – Density of rock.

c – Specific heat.

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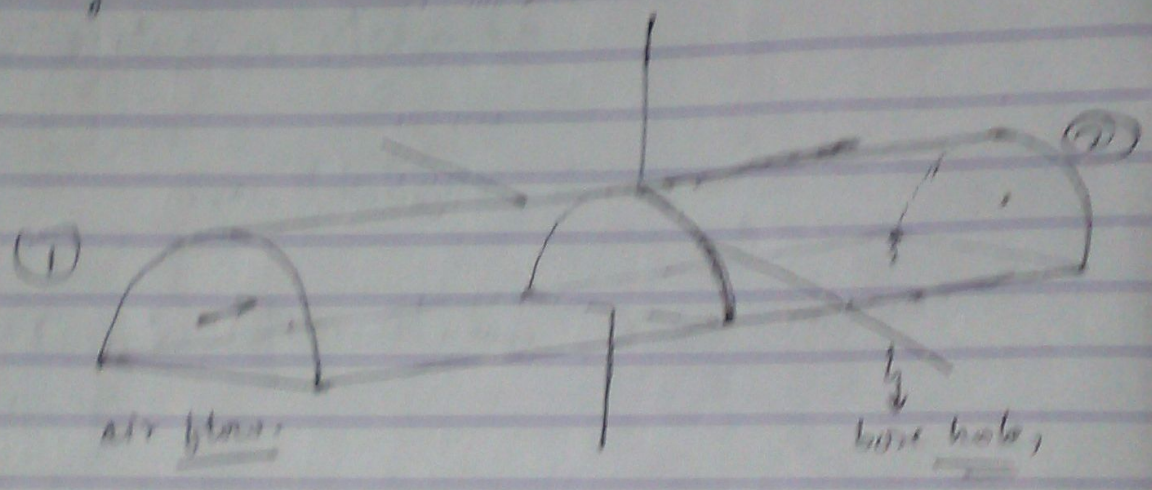
Q = heat flux = $k \frac{\partial \theta}{\partial r}\Big|_{at\ r_a}$

$$\boxed{Q = k \cdot \frac{b}{r_a}}$$

We can find crack inside thermal conductivity using this relation when provided the steady state conditions are existing.



Heat transfer from rock to air = $\dot{m}(h_2 - h_1)$

$\dot{m}$ = dry air mass flow rate.

For measuring 'b' we dig bore holes and measure the temp as a function of depth $\partial\theta/\partial r$.

r_a = equivalent radius of strung = $\frac{P}{2\pi}$.

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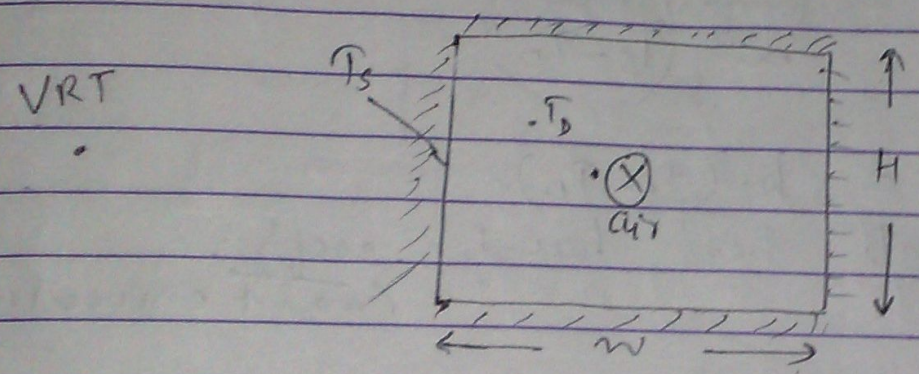
$\dot{m}(h_2 - h_1) = 2\pi k l b$.

$\left(\frac{kb}{r} \times 2\pi \times \left(\frac{l}{2\pi}\right) \frac{2\pi}{\ln}\right)$

↓

Insitu rock thermal conduct

rock



Factor for heat transfer: $(VRT - T_D)$

$= \underbrace{(VRT - T_s)}_{\text{(conduction)}} + \underbrace{(T_s - T_D)}_{\text{convection, radiation, evap.}}$

T_s - surface temp. of rock.

Solution for transient state gives T_s.

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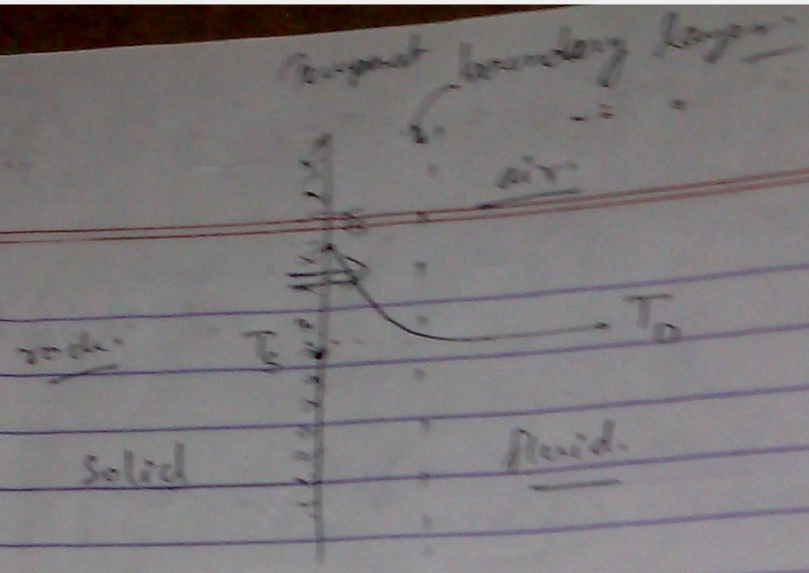

Heat flux $\propto$ (temp. diff of surface & air)

$$Q \propto (T_S - T_D)$$

$$Q = h \cdot (T_S - T_D)$$

h - overall heat transfer coeff.
(rad + convection).

Thinner boundary layer = lower resistance = Greater transfer of heat.

When Reynold's no is higher, boundary layer is thin. (Turbulent flow).

When rough surface is there;

Then also the boundary layer is thin.

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h is a function of Reynold's no. & roughness.

f (Re, roughness).

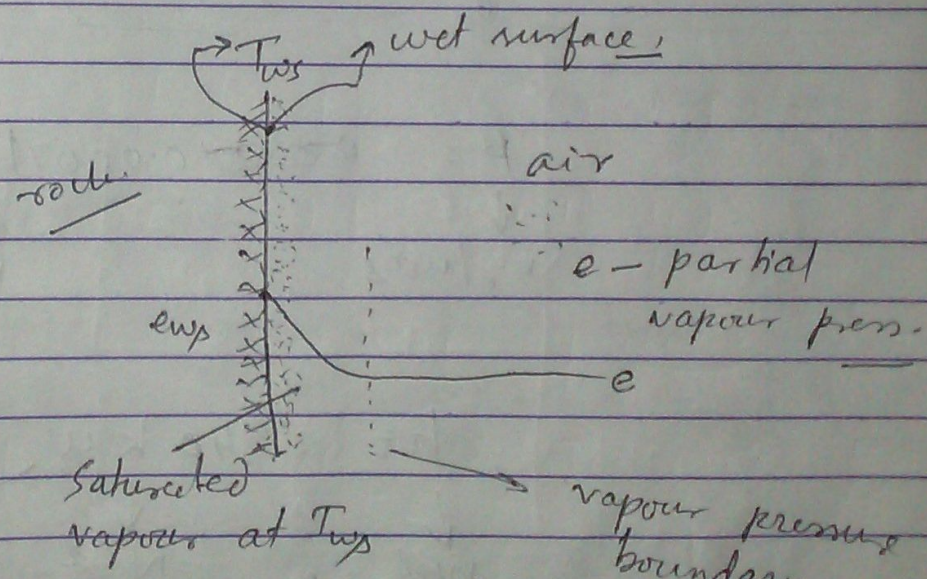
These two factors influence the thickness of boundary layer.

$$h = 3540 \cdot k \cdot u$$

k – friction coefficient = $f\rho/8$.

u – velocity of air.

unit of k = $\frac{Ns^2}{m^4}$.



e_{ws} – Saturation vapour pressure.

The thinner boundary layer faster is the transfer.

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mass transfer = molecular transfer
+ eddy (Mass = e).

Kinematic is by density is by kinematic
pressure

$$\text{eddy transfer} = \frac{(M_{eddy} = e)}{\rho}$$

$$\text{Molecular transfer} \left(\frac{kg}{m^2 s} \right) = \beta \left(\frac{M_{eddy} = e}{\rho} \right)$$

β = molecular transfer coeff.

Units of $\beta = \left(\frac{kg}{m^2 s} \right)$.

β = [illegible]
$\downarrow$ kg/m^2s $\qquad$ $\downarrow$ kg/m^2s

k = 3340 kN
$\downarrow$ kg/m^2s $\qquad$ $\downarrow$ $N s^2/m^2$ $\qquad$ $\left(\frac{N s^2}{m^2} \right)$

Clearly which [illegible] is [illegible] [illegible]
[illegible]

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mass transfer = moisture transfer

$= \alpha (e_{ws} - e)$.

Normalizing it by dividing it by Barometric pressure.

Mass transfer $= \alpha \dfrac{(e_{ws} - e)}{B}$

Moisture transfer $\left(\dfrac{kg}{m^2 - s}\right) = \beta \left(\dfrac{e_{ws} - e}{B}\right)$

β - moisture transfer coeff.

Units of $\beta = (kg/m^2 - s)$.

$\beta = 0.0007h$

$\beta \rightarrow kg/m^2 s$, $h \rightarrow W/m^2 \cdot °C$.

$h = 3540\, ku$

$h \rightarrow W/m^2 \cdot °C$, $k \rightarrow \dfrac{Ns^2}{m^4}$, $u \rightarrow (m/s)$

Steady state after 3 years of the excavation.

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Roadway length = 400m.

H/W = 3m/4m.

V = 2.5 m/s.

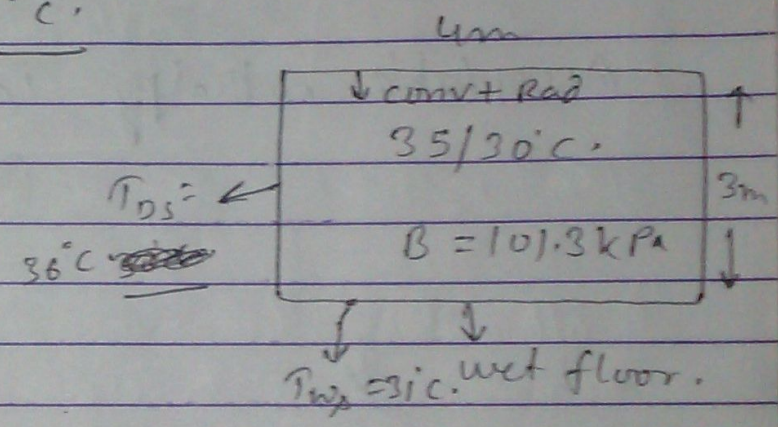
K = 0.01 $N s^2/m^4$.

T_D / T_W = 35°C / 30°C.

Floor completely wet, other surfaces dry.

T_{Ds} = 36°C.

T_{Ws} = 31°C.



~~Q = Ch(Ts - Tb)~~

Total { Dry surface → Sensible heat transfer (1)
+ wet surface = Sensible heat (2) + latent heat (3)

(1) = 10 × h(T_{Ds} − T_D) W

+ h = 354 k.u. = 8.35

(2) = 4 × h(T_{Ws} − T_D). W

+

(3) = β($\frac{e_{ws} - e}{B}$) × L [β = 0.0007h]

β = 6.195×10^{-3}

Total = 234.5 W/m.

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Evaporator coil capacity = [illegible]

[illegible]

[illegible]

$\Rightarrow$ To have [illegible] we can increase [illegible]

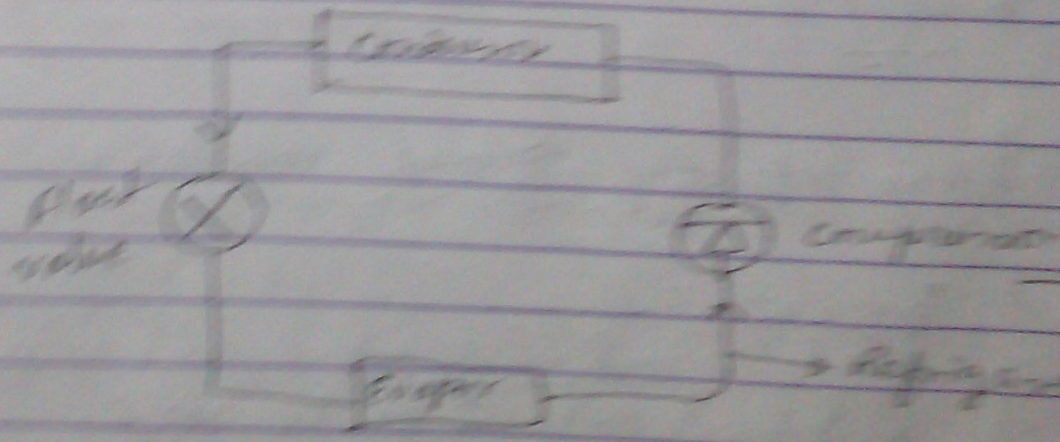
$\Rightarrow$

$$\left[\begin{array}{l} 35(100-95) = 5(100-x) \\ x = \text{capacity of the plant} \end{array}\right.$$

$x = 300$ TR

[Ice making]

Vapour Compression Refrigeration Cycle:



Refrigeration plant.

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Mine Ventilation

Mine ventilation is an essential due to most important

R_{gas} = 35 cu-ft

Natural Ventilation

Factor affecting Natural ventilation

Small and shallow mines are generally ventilated by natural means however ventilation in these cases are usually poor. All mines should preferably use mechanical ventilation. Natural ventilation does play a role in all mechanically ventilated mine.

Factors affecting Natural ventilation:

1) Temperature
2) Moisture content of air.
3) Moisture addition in the shaft
4) Odds in natural ventilation.

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04/09/08

Mine Ventilation

Home assignment due on next 15/09/08

~~prob no.~~

Page no: 315. Ex - 4.

Natural Ventilation:

~~Factors affecting Natural ventilation:~~

Small and shallow mines are sometimes ventilated by natural means however ventilation in these case are usually poor. All mines should preferably be mechanical ventilated. Natural ventilation does play a role in all mechanically ventilated mine.

Factors affecting Natural ventilation:

1) Temperature
2) Moisture content of air.
3) Moisture addition in DC shaft adds in natural ventilation.

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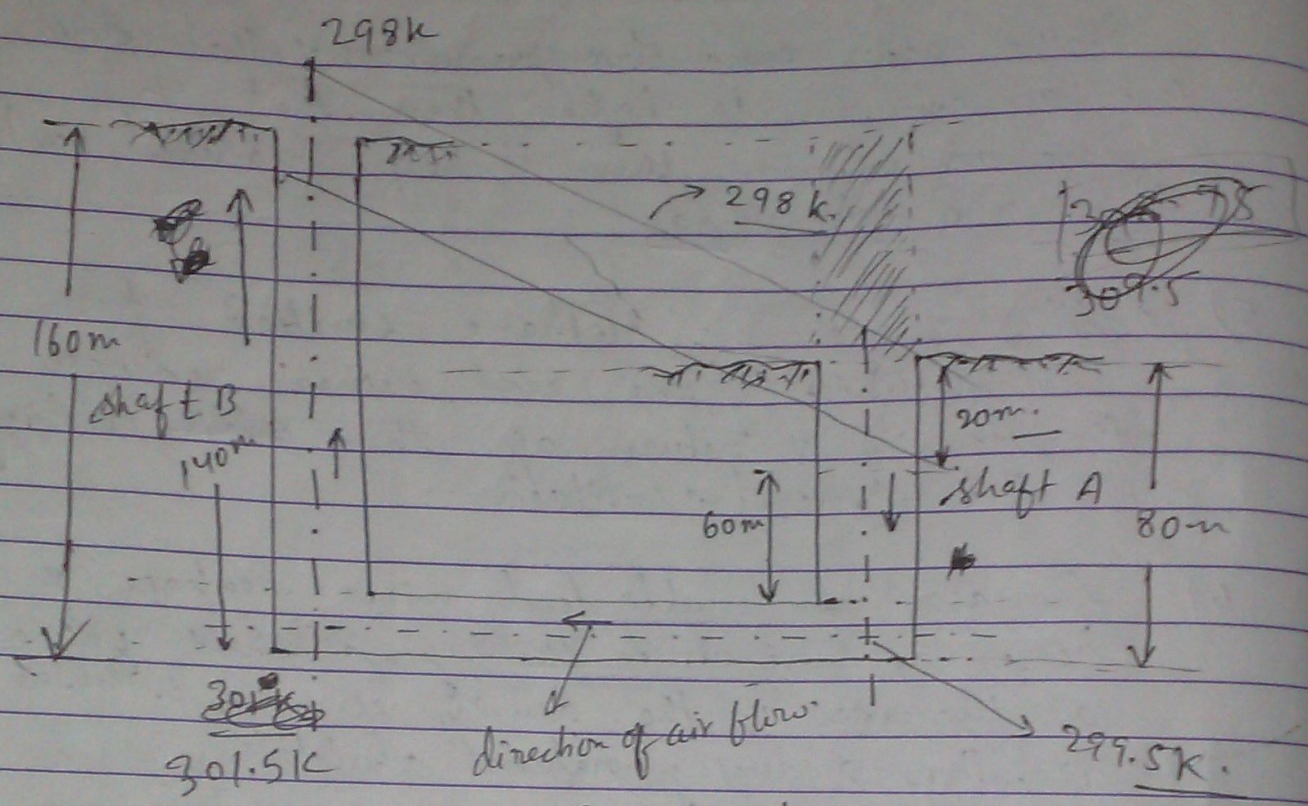
Surface temp diff. causes the reversal of air currents in natural ventilation



Geothermal grad - 1K for every 40m depth

Avg. temp of shaft B =

$$\frac{298 + 301.5}{2} = 299.75\ K$$

Av. temp of shaft A = $\frac{298 + 299.5}{2}$ =

298.75 K

So, $T_B > T_A$, so,

B is U.C shaft.

A is D.C shaft.

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If surface temp changes to : 308K.

then

$T_B = 304.75K = \left(\frac{301.5+308}{2}\right)$

$T_A = 303.75K$ (do)

Now effective temperature of whole air column in shaft A =

$$\frac{303.75+308}{2} = 305.875 \approx 305.88K$$

So, B av. $T_B = 304.75K$.

Av. $T_A = 305.88K$.

So, circulation of Air is from B to A.

In second case: B is D.C shaft, A is U.C shaft.

$\boxed{B \to A}$

[In winter] Suppose the surface temperature falls to 288K.

For A.

$$\text{Effective } T_{av} = \frac{288.75 + 288}{2} = 290.875K$$

For B:

$$T_{av} = \frac{288 + 301.5}{2} = 294.75K$$

So, A flow: $\boxed{A \to B}$

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Large seasonal temperature variation and shallow mines experience this change in the direction of ~~ventilation~~ air flow.

Measurement of Natural Ventilation Pressure:

$$N.V.P = D(\rho_u - \rho_D)g$$

ρ_u Density of air column in upcast shaft
ρ_D – " " " " " Downcast shaft.

D – depth of the downcast shaft.

N.P.V is also expressed in terms of head known as Motive column of air.

$$\text{Motive column of air} = \frac{N.V.P}{\rho_D g}$$

$$\rho_D = \left(\frac{B_D - 0.378 e_D}{287.1 T_D}\right) \times 10^3 \ kg/m^3$$

B_D – Barometric pressure in kPa.
e_D – Partial vap. pressure
T_D – Dry bulb temperature.

$$\rho_u = \left(\frac{B_u - 0.378 e_u}{287.1 T_u}\right) \times 10^3 \ kg/m^3$$

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$B_D = B_U = B.$

$$\boxed{NV.P = D_D \times g\left(\frac{B}{287.1T_D} - \frac{B}{287.1T_U}\right) \times 10^3 \text{ Pa.}}$$

08/09/08 → Mechanical Ventilation

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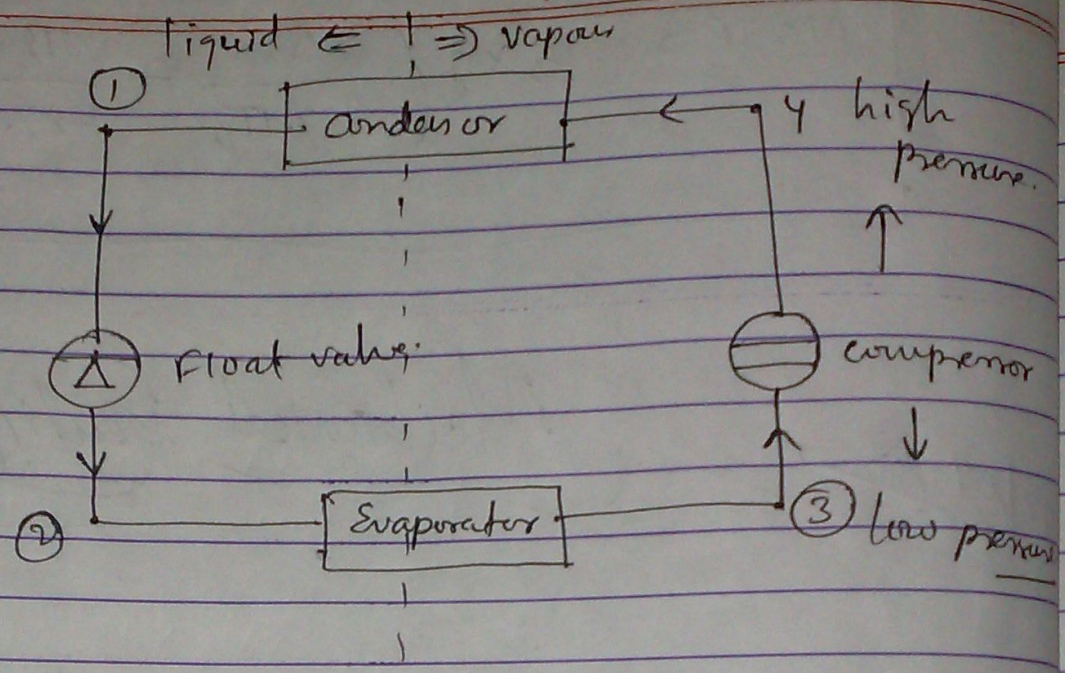
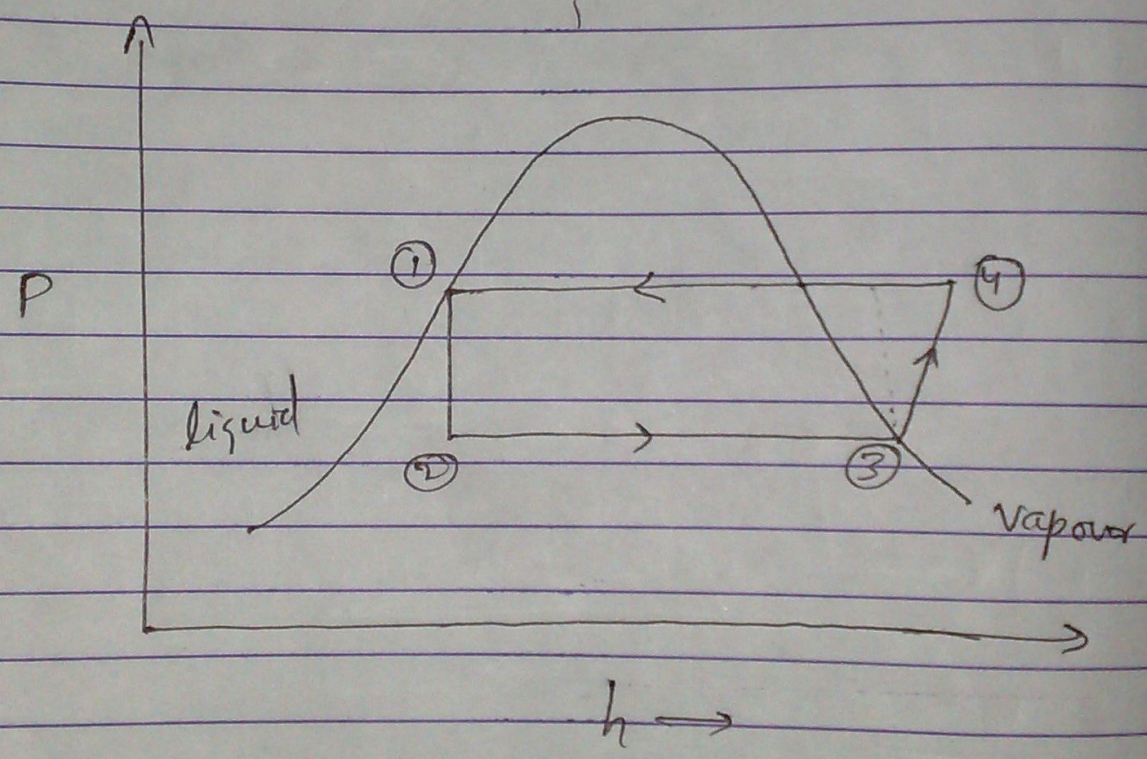
09/09/08

Air conditioning





$h_1 \approx h_2$ (Float valve energy consumption is negligible.)

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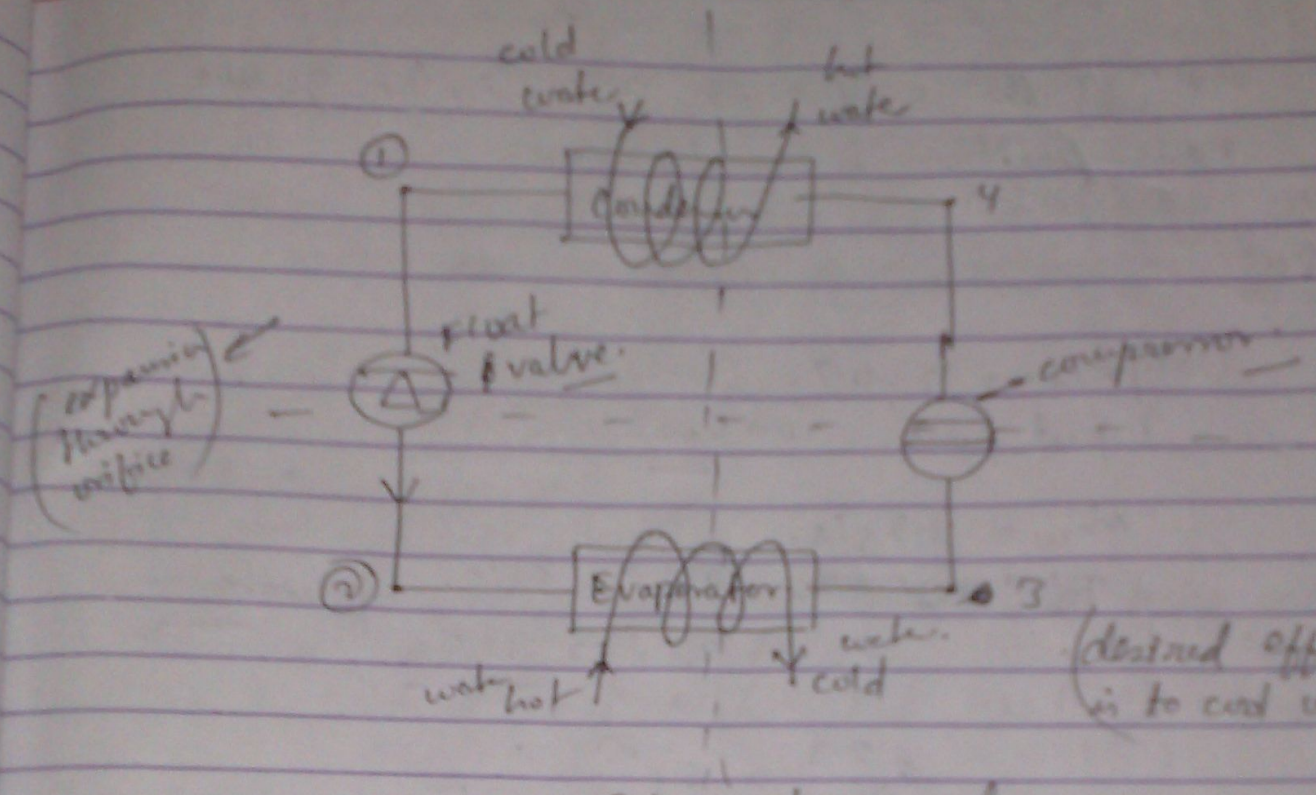

Refrigeration cycle.

$\dot{m}_r$ — mass flow rate of refrigerant.

$$\underbrace{\dot{m}_r(h_4-h_1)}_{\text{(condenser heat exchange)}} = \underbrace{\dot{m}_r(h_3-h_2)}_{\text{Evaporator heat exchange}} + \underbrace{\dot{m}_r(h_4-h_3)}_{\text{compressor output work}}$$

Coefficient of Performance = $\dfrac{(h_3-h_2)}{(h_4-h_3)}$

$$= \left[\frac{\text{Evaporator heat exchange}}{\text{Compressor work}}\right]$$

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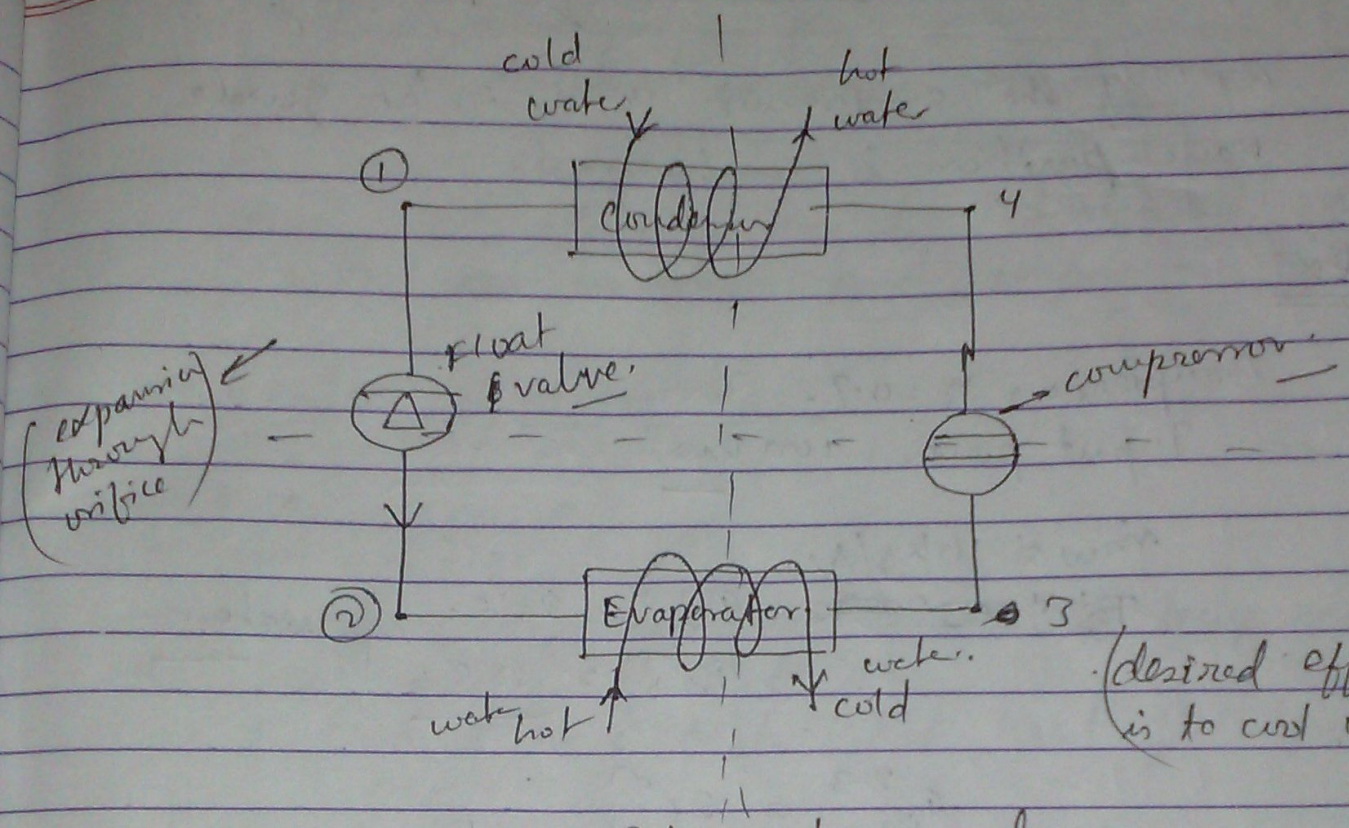

Refrigeration cycle.

$\dot{m}_r$ – mass flow rate of refrigerant.

$$\dot{m}_r(h_4-h_1) = \underbrace{\dot{m}_r(h_3-h_2)}_{\text{Evaporator heat exchange}} + \underbrace{\dot{m}_r(h_4-h_3)}_{\text{compressor output work}}$$

(condenser heat exchange)

Coefficient of Performance = $\dfrac{(h_3-h_2)}{(h_4-h_3)}$

~~work done by~~ $\left[\dfrac{\text{Evaporator heat exchange}}{\text{Compressor work}}\right]$

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~~Property of~~ COP is a property of refrigeration cycle which doesn't change so long as RPM of the compressor and inlet guide vane position is unchanged.

Ex:

Compressor = $\eta = 0.7$.
Input power = 100 kW.

$\dot{m}_w = 10 kg/s$.

$T_{in}^{1-4} = 25°C$.
$T_{out}^{1-4} = 32°C$.
} water

$T_{in}^{2-3} = 25°$
$T_{out}^{2-3} = ?$
} water.

Condenser heat exchange = $20 \times 4.18 \times (32-25)$.
$= 83.6 \times 7$
$= 585.2 W = 0.5852$

Compressor output power = 100×0.7.
$= 70 kW$.

$10 \times 4.18 (25 - x) = (70 - 0.585)$

$x = 25 - \frac{70 - 0.585}{41.8}$

$x = 19.7°C$

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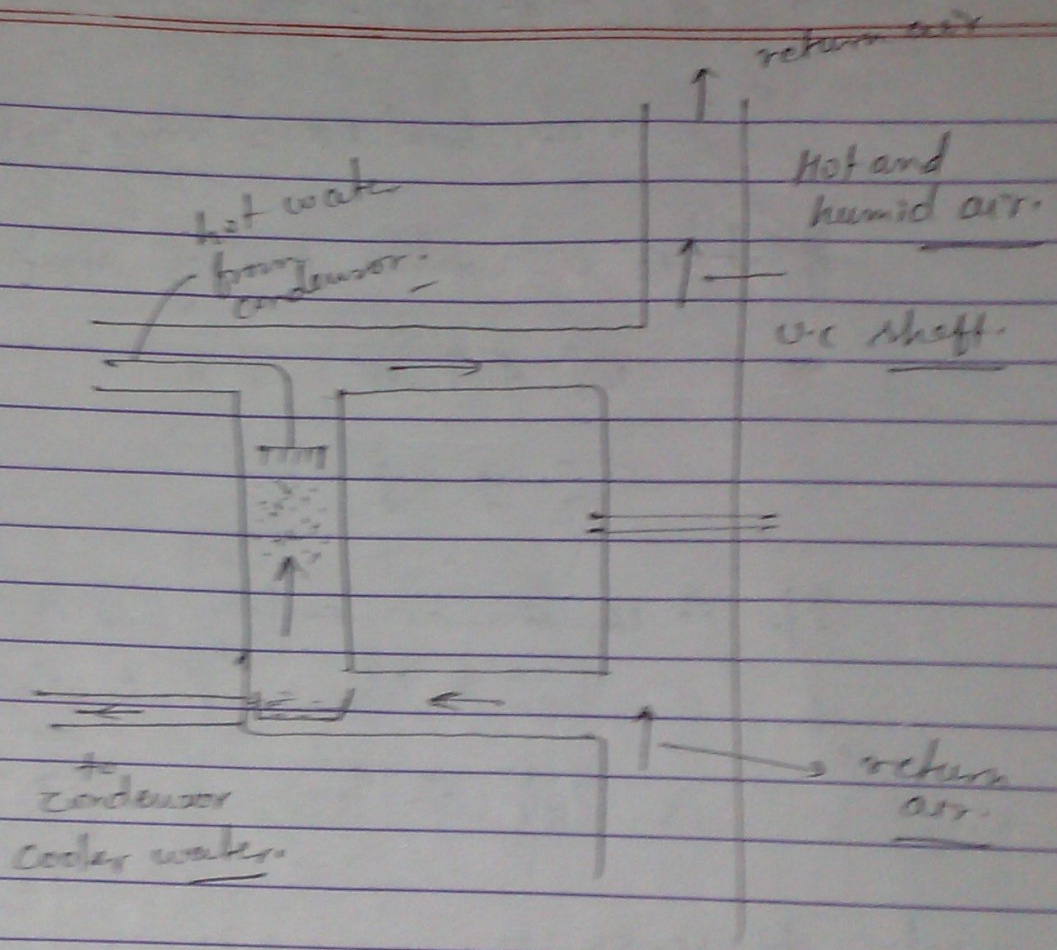
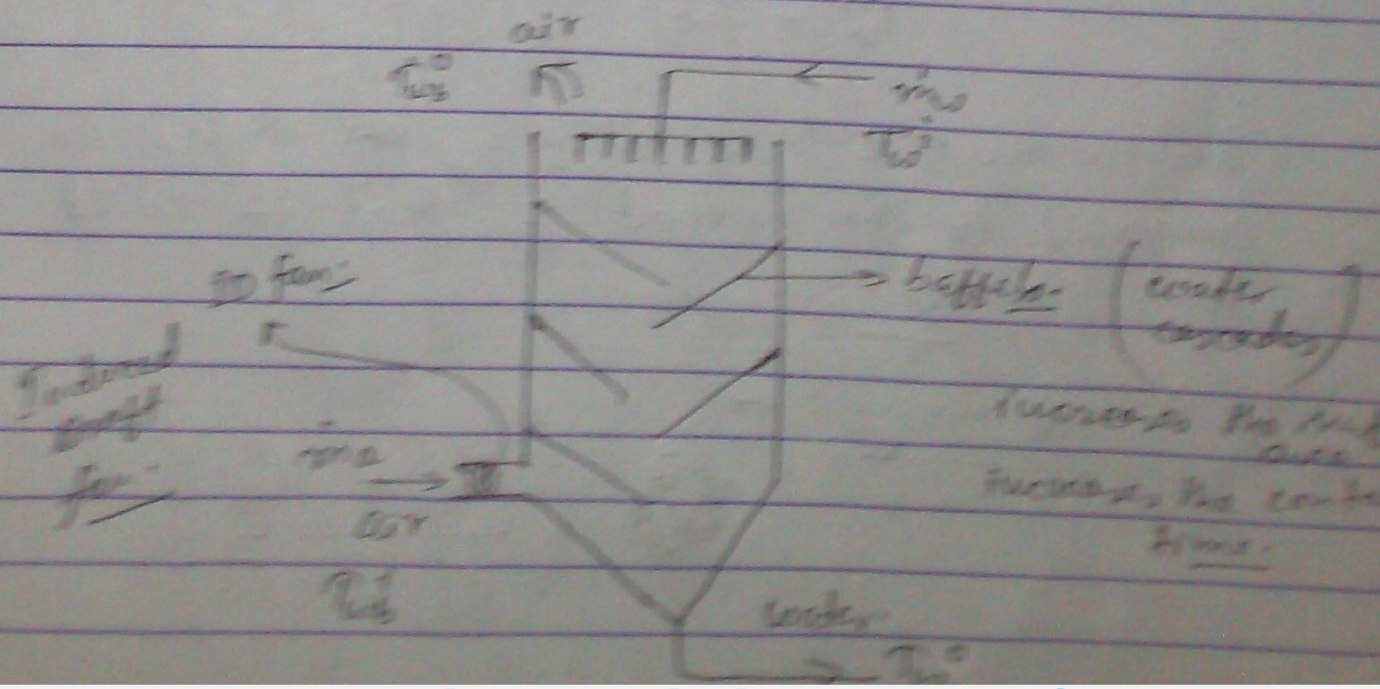
Large amount of air is passed through the hot water coming out of exchanger. to



Design of direct contact heat exchangers.



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For direct contact heat exchanger:

max heat exch = $m_h(S_{hi}^{o} - S_{hi}^{i})$ =

max heat ex = $m_{min}(h_{hi}) (T_{hi}^{o} - T_{ci}^{i})$

If it is a counter flow system:

$T_{hi}^{o} \leq T_{ci}^{i}$.

$T_{hi}^{o} \geq T_{ci}^{i}$

If it is a co flow system:

$T_{hi} > T_{ci}$

$T_{hi}^{o} < T_{ci}^{i}$

} Exact calculation can reached if infinite number of units is provided

Heat efficiency :-

$$\frac{T_{hi} - T_{ho}^{o}}{T_{hi}^{i} - T_{ci}^{i}}$$

The amount of heat taken by the units in comparison to the amount of heat it could have gained.

Max efficiency :-

$$\left(\frac{S_{hi} - S_{ci}^{i}}{} \right)$$

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For direct contact heat exchanger:

air heat exch = $m_a(S_{wb}^{o} - S_{wb}^{i})$ =

water heat ex = $m_w(4.18)(T_w^{i} - T_w^{o})$

If it is a water cooling system:

$T_w^{o} \nless T_{wb}^{i}$.

$T_{wb}^{o} \ngtr T_w^{i}$

If it is an air cooling system:

$T_{w_o} \ngtr T_{wb}^{i}$

$T_{wb}^{o} \nless T_w^{i}$

limit could have been reached if infinite contact time & surface area is provided.

Water efficiency :-

$$\frac{T_{wo}^{i} - T_w^{o}}{T_w^{i} - T_{wb}^{i}}$$

The amount of heat taken by water as compared to the amount of heat it could have gained.

Air efficiency :-

$$\left(\frac{S_{wb}^{i} - S_{wb}^{o}}{S_{wb}^{i} - S_w^{i}}\right)$$

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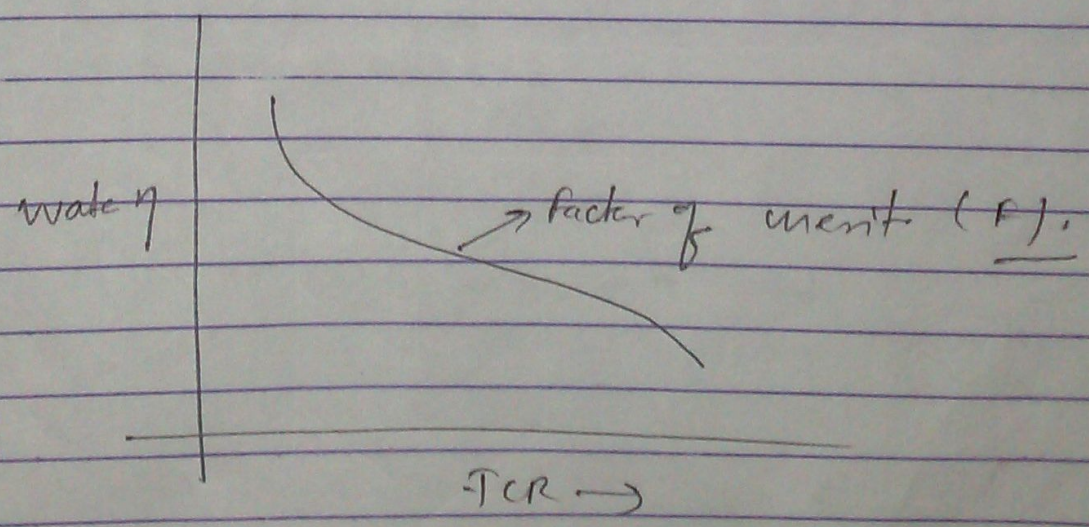
Thermal capacity ratio $\equiv R$

$$R = \frac{\text{Max. Possible heat ex. for water}}{\text{Max. Possible heat ex. for air}}.$$

$$= \frac{\dot{m}_w C_{pw} (T_{wi} - T_{wb})}{\dot{m}_a (S_{wb} - S_{wi})}$$

$$\simeq \frac{\dot{m}_w C_{pw} (T_{wi} - T_{wb})}{\dot{m}_a (h_1 - h_{at\ T_{wi}\ sat})}$$

R value is completely the function of inlet properties.



For a given cooling tower:

water $\eta = f(TCR)$.

F - indicates the performance of cooling tower. Higher F, better cooling tower.

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$$\boxed{zg + \frac{P}{\rho} + \frac{1}{2}V^2 = \text{constant}}$$ [[illegible] terms].

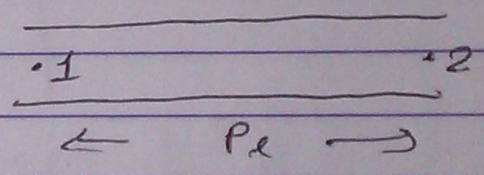
$$z_1 g + \frac{P_1}{\rho} + \frac{1}{2}v_1^2 = z_2 g + \frac{P_2}{\rho} + \frac{1}{2}v_2^2$$

~~for shallow mines~~ If we ignore the potential pressure difference.

$$\frac{P_1}{\rho} + \frac{1}{2}v_1^2 = \frac{P_2}{\rho} + \frac{1}{2}v_2^2$$

Modified Bernoulli equation:

$$P_1 + \frac{1}{2}v_1^2 = \frac{P_2}{\rho} + \frac{1}{2}v_2^2 + P_e$$



P_e – Pressure loss due to friction.

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29/07/08

Psychrometry

$$\phi = \frac{G}{TLV - B}$$ steady state formula.

Respirable dust generation. 2.5 g/min.

TLV – (Threshold Limit value).

~~Indra~~ Max. available conc. = 3 mg/m³ (Indian terminology)

B – background contamination level = 0.5 mg/m³.

$$\frac{2.5}{(3 - 0.5) \times 10^{-3}} = \frac{1\ g/min \times 10^{3}}{1\ kg/min} = 16.6\ m^3/$$

Psychrometry – Science of air and water vapour mixture.

Air = dry air + moisture.
↓
(ideal gas).

water vapour carries heat & and has a tremendous capacity for heat exchange. Latent heat present in water vapour is exchanged.

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Psychrometric Properties

~~Derived properties.~~

- Enthalpy
- Sigma heat
- Relative humidity
- Dew point temp
- Vapour Pressure
- Saturation vapour pressure
- Mixing ratio/moisture content
- Specific volume.
- Apparent density
- True density

~~Derived properties~~

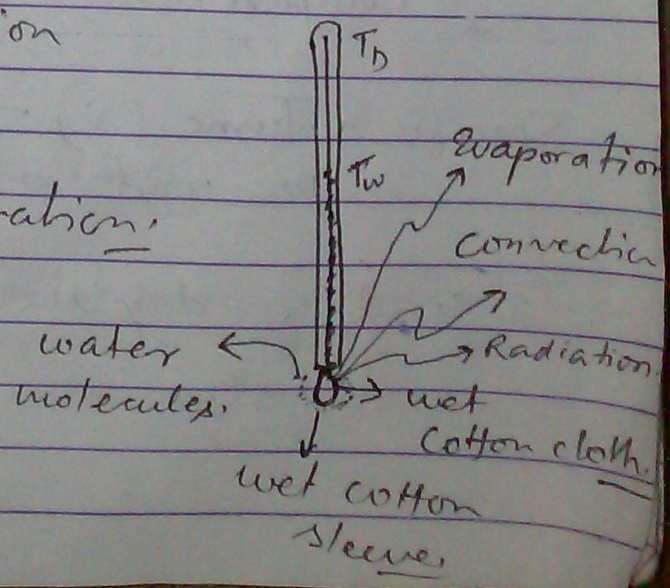
Basic properties:

t_{db} – T_D – dry bulb temp.
t_{wb} – T_W – wet " "
P – B – Barometric pressure.

wet bulb temp – moisture can be inducted in the atmosphere in ~~form~~ form of latent heat.

$(T_D - T_W)$ – degree of unsaturation of atmosphere.

higher differ higher unsaturation.



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