IIT(BHU) VARANASI

STUDENTS' NOTES

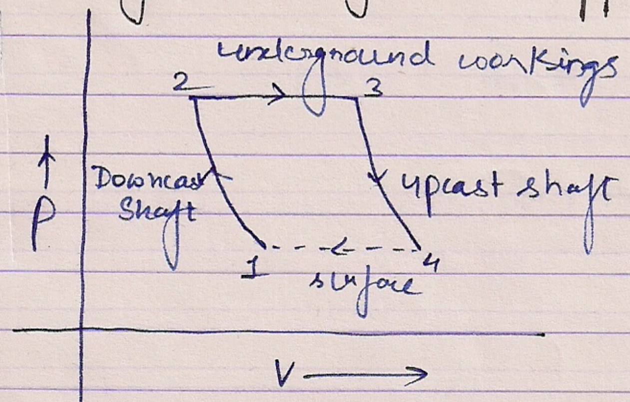
UNDERGROUND MINE ENVIRONMENT

FIFTH SEMESTER

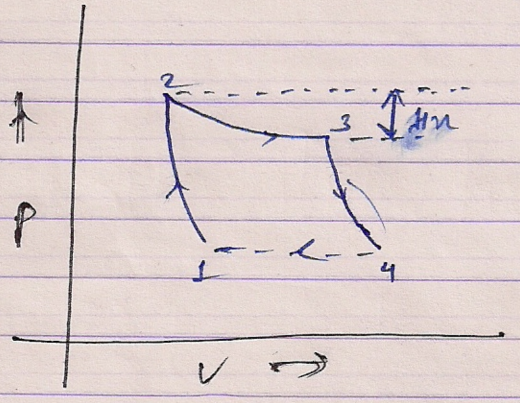
TOPIC-NUMERICAL IN VENTILATION

www.MINEPORTAL.in

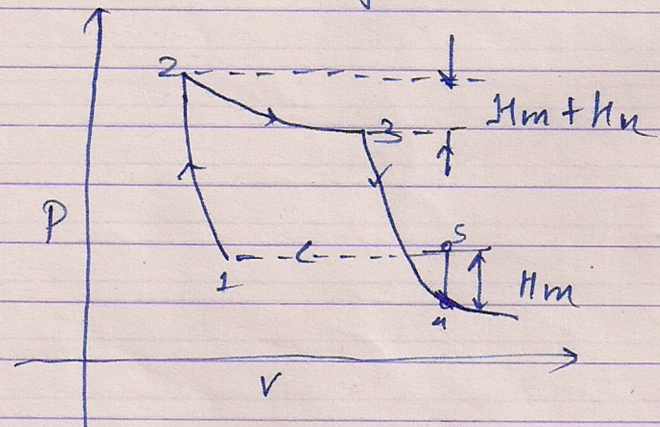
N·V·P by Thermodynamic approach:-



a) Theoretical cycle



b) Actual cycle, Natural ventilation only.



c) Actual cycle (Exhaust fan + Natural ventilation)

a) 1-2	b) 2-3	c) 3-4	d) 4-1
P → (+)	T(+)	P → (−)	
V → (−)	V(+)	V → (+)	
T → (+)	P(−)	T → (−)	

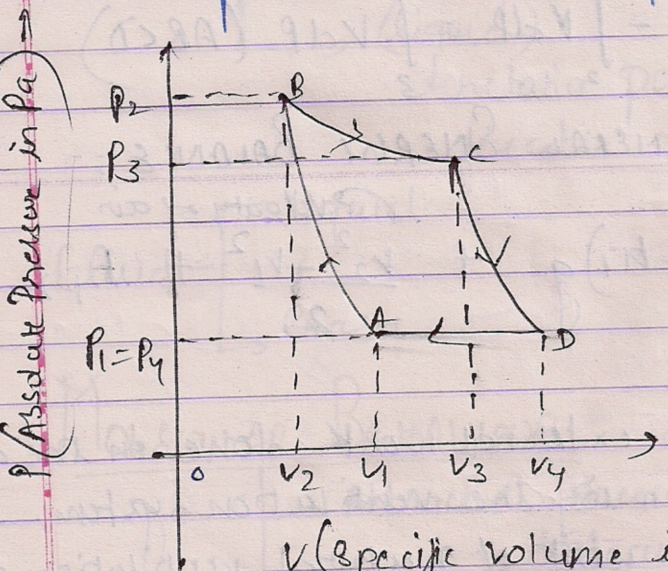
A mine can be like to a heat engine with the following cycle.

i) Air descending the downcast shaft undergoes auto-compression. As a result which, its pressure & temperature increases & specific volume decreases.

ii) Heat is added from the rock to the hot and compressed air as it travels through mine working thus increasing its temperature. As a result of this its specific volume increases but pressure decreases because of the air doing work against friction.

iii) In the upcast shaft, auto expansion leads to an increase in its specific volume but pressure and temperature will fall.

iv) Finally, it is rejected by the air at low temp. to the atmosphere and the air returns to the atmospheric condition of pressure, specific volume and temperature thus completing the cycle.



Unit Mass of Dry Air

There will be no heat exchange b/n shaft wall & air. Frictional Adiabatic Process (can also be Polytropic)

$W_{fei} = P_1V_1$ (OV_1AP_1)

$W_c = \int^2 P\,dv$ (V_1ABV_2) $\quad W_{fl0} = -P_2V_2\,(OV_2BP_2)$

Total work done $= W_{fi} + W_c + W_{HO}$

$$= P_1V_1 + \int_1^2 P\,dv - P_2V_2$$

$$= -\int_1^2 V\,dP \;(P_2BAP_1)$$

$$\int d(PV) = \int P\,dv + \int V\,dP$$

$$\int d(PV) = P_2V_2 - P_1V_1$$

$$W_W = -\int_2^3 V\,dP \;(P_2BCP_3)$$

$$W_{ac} = -\int_3^4 V\,dP \;(P_3CDP_4)$$

Total work done $= W_{dc} + W_\omega + W_{ac}$

$$= -\int_1^2 V\,dP - \int_2^3 V\,dP - \int_3^4 V\,dP \;(ABCD)$$

PRINCIPLE OF GENERAL ENERGY BALANCE :-

velocity of air

$$-\int_1^2 V\,dP = (h_2 - h_1)g + \frac{v_2^2 - v_1^2}{2} + F_{1-2} \quad (1)$$

When there is no external work done on the air, i.e. there is no fan in the ventilation system, the above work is the work of natural ventilation due to the addition of heat in the mine workings and can be equal to changes in potential & kinetic Energy of air & frictional work

$$-\int_2^3 V\,dP = (h_3 - h_2) \;-\;-\;-\;-\;- \quad (2)$$

$$-\int_3^4 V\,dP = (h_4 - h_3) \;-\;-\;-\;- \quad (3)$$

Combining ①, ② and ③

$$F_{1-4} = -\int_1^2 V dP - \int_2^3 V dP - \int_3^4 V dP$$

$$\boxed{F_{1-4} = W_t} \rightarrow \text{Dry air only}$$

INTRODUCTION TO FLUID MECHANICS:- Assuming air as a fluid for surface mine environment.

FLUID:- A fluid is a substance in which the constituent molecule are free to move relative to each other. Conversely, we can find in liquid and solid.

fluid → Normal T, P
- → (Solid) → relative position remains fixed under non destructive condition
- → (liquid) ↓ relative position doesn't remains fixed.

Fluid –
- → Liquid
- → Gases.

MOLECULAR BEHAVIOUR:-

- → Attractive forces → distance between two molecule decreases, very much attractive forces decreases
- → Repulsive forces → distance between very less, repulsive forces becomes very large.

SOLID:- attractive forces are dominating.

LIQUID:- repulsive forces are "

Solid $\xrightarrow[\text{due to some external forces}]{\text{attractive forces reduces}}$ Liquid $\xrightarrow[\text{of molecules increases}]{\text{internal K.E}}$ Gases.

PROPERTIES:-

a) Volume:- Volume of gas more than liquid

b) Pressure:- If pressure is applied to liquid, very slight change in volume occurs (incompressible) while for gases volume changes appreciably.

c) Density difference (immiscible):- when liquid of different densities are mixed together they will separate out in discrete layers by gravitational settlement but this will not happen with gases.

Air → mixture of gases → compressible in nature

VOLUME FLOW, MASS FLOW AND CONTINUITY EQN:-

Q - m^3/sec (Volume flow)

When there will be change in air density then that will also come into picture.

a) Mass Flow:- mass in kgs crossing through a section in per unit time (kgs/sec)

$$\rho = \frac{\text{Mass}}{\text{Volume}} \quad (kg/m^3)$$

$$\rho = \frac{\text{mass flow}}{\text{volume flow}} = \frac{M}{Q} = \frac{kg/sec}{m^3/sec} = \frac{M}{Q}$$

$$M = Q\rho$$

→ In static state condition, when there is no loss in airway

Mass flow at entry = mass flow at exit

$$M = Q\rho = \text{constant } kg/sec$$

→ In any continuous duct or airway the mass flow passing through all cross-sections along it's length are equal provided that the system is in steady state and there are no inflow and outflow of air or other gases between two ends.

$[M = Qe]$

simplest form of continuity equation.

VOLUME FLOW: $[Q = vA]$ m^3/sec

v = mean or avg. velocity of air

$M = \rho Q$

$M = \rho v A$

- If there is no change in air density

$Q = Av$ = constant * m^3/sec

fluid pressure = $\frac{\text{Force}}{\text{Area}}$

PRESSURE HEAD:

→ representing the pressure in units of m

$P = \frac{F}{A} = \rho g h$ → pressure head (m)

density of liquid is known; g constant

ATMOSPHERIC PRESSURE: - This is the pressure that will support 0.76 m of Hg column.

GAUGE PRESSURE: is the pressure difference between inside and outside the surface minceduct

Absolute pressure (+) = atmospheric pressure + gauge pressure (−) or (+)

Fluids In Motion:

Bernoulli's Equation: $m\left[\frac{u^2}{2} + zg + \frac{P}{\rho}\right] = \text{const}$

$$m\left\{\frac{u_1^2}{2} + z_1 g + \frac{P_1}{\rho}\right\} = m\left\{\frac{u_2^2}{2} + z_2 g + \frac{P_2}{\rho_2}\right\}$$

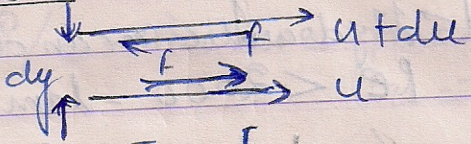
$$\left[\frac{u_1^2 - u_2^2}{2} + (z_1 - z_2)g + \frac{P_1 - P_2}{\rho} = 0\right]$$

Bernoulli's Equation:

I $\left[\frac{v_1^2}{2} + z_1 g + \frac{P_1}{\rho} = \frac{v_2^2}{2} + z_2 g + \frac{P_2}{\rho}\right]$

↪ Ideal fluid equ
→ no viscosity
→ no shear forces & frictional losses
→ Mechanical energy only (neglecting the thermal effect)

Viscosity:



$\tau = \frac{F}{A}$

Parallel motion of streamline in marine fluid

$\tau = \frac{F}{A} = \mu \frac{du}{dy}$

Shear stress is proportional to velocity gradient

μ = constant of proportionality
= coefficient of dynamic viscosity.

For air:-

$\mu_{air} = (17 + 0.045t) \times 10^{-6} \frac{NS}{m^2}$

$\mu_{water} = \left(\frac{64.72}{t + 31.766} - 0.2455\right) \times 10^{-3} \frac{NS}{m^2}$

temperature → 0–60°C

Kinematic Viscosity $= \frac{\mu}{\rho}$ m^2/sec

Molecular behaviour of Fluids:-

1) Attractive forces b/w the molecules
2) Phenomenon of relative velocity of different layers.

Frictional Pressure drop (F_{12})

In case of ~~sub~~ non-ideal fluid

$$\frac{U_1^2}{2} + Z_1 g + \frac{P_1}{\rho} = \frac{U_2^2}{2} + Z_2 g + \frac{P_2}{\rho} + F_{12} \ J/kg$$

Energy converted from the mechanical form to heat.

→ LAMINAR FLOW
→ TURBULENT FLOW
→ REYNOLD'S NUMBER.

Osborne Reynold

$$R_e = \frac{\rho u d}{\mu}$$

d → Hydraulic mean diameter $= \frac{4A}{P}$

$Re < 2000$ - laminar

FRICTIONAL LOSSES IN LAMINAR FLOW:- (F_{12})

A ventilation shaft of diameter 5m passes an air flow of $200\ m^3/sec$ at a mean density of $1.2\ kg/m^3$ & avg. temp $18°C$. Determine Reynold's number.

Soln- $\rho = 1.2$ $d = 5m$

$$\mu = (17 + 0.045 \times 291) \times 10^{6}$$

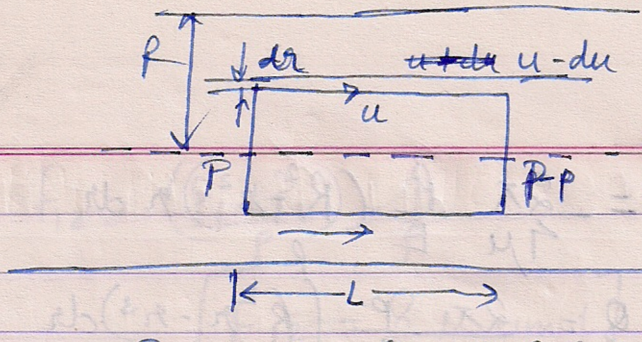
$$u = 200 / \pi \times (5/2)^2$$

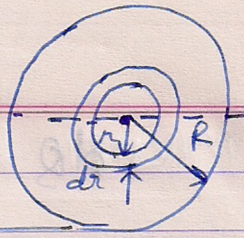
$$Re = \frac{1.2 \times 200 \times 5}{(17 + 0.045 \times 291) \times 10^{-6}}$$

$$Re = 39.8 \times 10^6$$

→ Assumptions:-

1) concentric cylinders of fluid along the pipe with zero velocity at the wall & max velocity at the centre & cylinder length is l & radii are r_1, r_2





$$P \times \pi r^2 = (2\pi r) L (\tau)$$

$$\left(\tau = -\mu \frac{du}{dr}\right)$$

$$P \times \cancel{\pi} r^2 = 2\cancel{\pi} r \times l \times -\mu \frac{du}{dr}$$

$$-P \times r\,dr = 2\mu l\, du$$

$$\int_u^0 du = \int_r^R -\left(\frac{P}{L}\right)\frac{r}{2\mu}\, dr$$

P/L – Pressure gradient

$$u = \cancel{\frac{-P}{L}\,\frac{1}{2\mu}\,\frac{r^2}{2}} + C$$

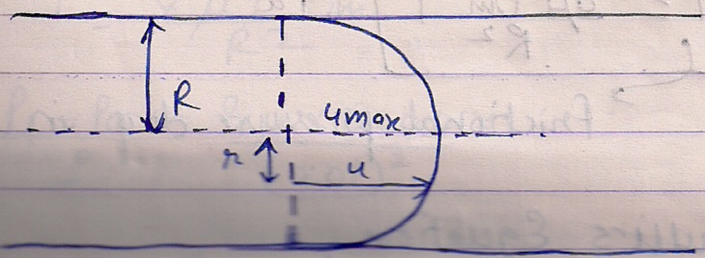
$$\cancel{r = R \quad u = 0}$$

$$-u = -\left(\frac{P}{L}\right)\frac{1}{2\mu}\left(\frac{R^2 - r^2}{2}\right)$$

$$\therefore \boxed{u = \frac{P}{2\mu L}\left(\frac{R^2 - r^2}{2}\right) \frac{m}{sec}}$$

At $r = 0$

$$u_{max} = \frac{P R^2}{4\mu L} \text{ m/sec.}$$



velocity profile for laminar flow

MEAN VELOCITY:-

$$U_m = \frac{Q}{A} \text{ m/s} \qquad Q \rightarrow m^3/s, \quad A \rightarrow m^2$$

$$dQ = (u)\, 2\pi r\, dr$$

$$dQ = \frac{2\pi}{4\mu} \frac{P}{L} (R^2 - r^2) r \, dr$$

$$Q = \frac{2\pi}{4\mu} \frac{P}{L} \int_0^R (R^2 r - r^3) dr$$

$$Q = \frac{\pi}{2\mu} \frac{P}{L} \left(\frac{R^2 r^2}{2} - \frac{r^4}{4} \right)_0^R$$

$$Q = \frac{\pi}{2\mu} \frac{P}{L} \left(\frac{R^4}{4} \right)$$

$$\left[Q = \frac{\pi R^4}{8\mu} \frac{P}{L} \right] \rightarrow \text{Poiseuille Equation}$$

<u>Pressure-drop quantity relationships:</u>

$$P = \left(\frac{8\mu L}{\pi R^4} \right) Q$$

$$\left[P = (R_L) Q \right] \text{ Pascals}$$

$$R_L = \frac{8\mu L}{\pi R^4} \quad Ns/m^5$$

$\rightarrow$ laminar resistance of the pipe.

$$U_m = \frac{Q}{A} = \frac{\pi R^4}{8\mu} \frac{P}{L} \cdot \frac{1}{\pi R^2}$$

$$\therefore \boxed{U_m = \frac{R^2}{8\mu} \frac{P}{L} \quad m/sec}$$

$$\text{or, } \boxed{P = \frac{8\mu U_m}{R^2} L} \quad Pa$$

$\rightarrow$ Frictional pressure drop in laminar flow

From Bernoulli's Equation

$$\frac{U_1^2 - U_2^2}{2} + (z_1 - z_2) g + \left(\frac{P_1 - P_2}{\rho} \right) = F_{12}$$

In compressible flow

$$z_1 = z_2 = h$$

$$U_1 = U_2 = U_m$$

$$F_{12} = \frac{(P_1 - P_2)}{\rho} = \frac{P}{\rho}$$

$$\boxed{F_{12} = \frac{8\,\mu\, u_m\, L}{\rho R^2}} \; J/kg$$

$$\therefore \boxed{\frac{u_1^2 - u_2^2}{2} + (z_1 - z_2)g + \frac{(P_1 - P_2)}{\rho} = \frac{8\,\mu\, U_m\, L}{\rho R^2}} \; J/Kg$$

Que:- A pipe of diameter 2 cm rises through a vertical distance 5m over the total pipe length of 2000m. water of mean temp 15°C flow up the tube to exit at atmospheric pressure 100 KPa. If the required flow rate 1·6 l/min. find the resistance of pipe. work done against friction & the head of water that must be applied at the pipe entrance.

Solu:- $\mu = (17 + 0.045 \times 298) \times 10^{-6}$

$L = 2000\ m$

$R = 0.01\ m$

$$R_L = \frac{8 \times \mu \times L}{\pi \times R^4}$$

$$= 1.55 \times 10^{13} \times 10^{-6}$$

$$= 1.55 \times 10^{7}$$

$$P = \frac{8 \mu L\, U_m}{R^2}$$

$$\frac{P_1 - P_2}{\rho} = \frac{8 \mu \times 2000 \times}{(0.01)^2}$$

FRICTIONAL LOSSES IN TURBULENT FLOW:-

Chezy-Darcy Equation

1769, Antoinc de chezy.

For open channel

$$u \propto \sqrt{\left(\frac{A}{per}\right)\frac{h}{L}}$$

per → weighted perimeter

$$\left[u = c\sqrt{\left(\frac{A}{per}\right)\left(\frac{h}{L}\right)}\ m/sec\right]$$ → Chezy Equation for channel flow

c → chezy coefficient

$$\left[\tau(per)L = A \cdot P\right]$$

$P = \rho g h$

$$\left[\tau = \frac{A}{(per)}\rho g\frac{h}{L}\right]\ N/m^2$$

Nature of flow is fully turbulent

$$\tau \propto \left(\frac{\rho u^2}{2}\right)\ J/m^3$$

$$\Rightarrow \tau = f\frac{\rho u^2}{2}$$

f → Dimensionless coefficient

$$\left[\frac{A}{(per)}\rho g\frac{h}{L} = f\frac{\rho u^2}{2}\right]$$

$$\text{or,} \Rightarrow u = \sqrt{\frac{2g}{f}}\sqrt{\frac{A}{(per)}\left(\frac{h}{L}\right)}\ m/sec$$

$$c = \sqrt{\frac{2g}{f}} - \frac{m^{1/2}}{s}$$

In case, circular channel

$$A = \frac{\pi d^2}{4},\ per = \pi d$$

Head loss, h (m)

$$u^2 = \frac{2g}{f} \frac{\pi d^2}{4} \times \frac{1}{\pi d} \frac{h}{l}$$

$$\left[h = \frac{4fL u^2}{2gd} \; m \right] \text{of fluid}$$

FRICTIONAL PRESSURE DROP:-

$$P = h\rho g$$

$$= 4f\frac{L}{d}\frac{\rho u^2}{2} \; Pa$$

Frictional work:-

$$F_{12} = \frac{P}{\rho} = 4f\frac{L}{d}\frac{u^2}{2} \quad J/kg$$

$\cancel{2r_h} = A$

for non-circular cross-section

r_h (Hydraulic Radius)

$$= \frac{A}{per} = \frac{\pi d^2}{4\pi d} = d/4$$

$u = Q/A \quad Q = Au$

$$P = \left(\frac{fL}{2} \frac{per}{A^3}\right) \rho Q^2 \quad \text{Pascal}$$

$$P = R_t \rho Q^2 \; \text{Pascal}$$

$$\left(R_t = \frac{fL}{2} \frac{Per}{A^3}\right) \rightarrow \text{Resistance}$$

INCOMPRESSIBLE FLUID:-

Bernaullis → for ideal fluid

$P = (R_t)\rho Q^2$

R_t → Turbulent resistance of the pipe

$$\Rightarrow \frac{fL}{2}\left(\frac{per}{A^3}\right) m^{-4}$$

$f =$

Coefficient of friction

Laminar flow

$$Q = \frac{\pi R^4}{8\mu}\frac{P}{L} \ m^3/s$$

$$P = \left(\frac{8\mu u L}{R^2}\right) \rightarrow$$

$$= \frac{8fL}{D}\frac{\rho u^2}{2}$$

$$f = \frac{16\mu}{\rho u d} \qquad f = \frac{16}{Re}$$

Question: A vertical shaft is 400m deep, 5m in diameter & wall roughening of height 5mm. An air flow of 150 m^3 per second passes at a mean density of 1.2 Kg/m^3. Taking the viscosity of air to be 17.9×10^{-6} NS/m^2 and ignoring the changes in K.E. Determine
(1) Turbulent resistance (2)
(3) Work done against friction. (4) Barometric pressure at shaft bottom if the shaft top pressure is 100 Kpa

{Assume coefficient of friction $f = 0.0049$}

h depth = 400 m

d = 5m wall thickness = 5mm

Air flow rate = 150 m^3/second = Q

$\rho = 1.2 \ kg/m^3$

Viscosity of air = 17.9×10^{-6} NS/m^2

$f = 0.0049$

$$Re \begin{cases} \rightarrow \text{Turbulence} \\ \rightarrow \text{Laminar} \end{cases}$$

$R_t = (\quad)$

$P = R_t Q^2 \rho$

Work done against friction $= \frac{P}{\rho}$

$$(z_1 - z_2)g + \frac{p_1 - p_2}{\rho} = F_{12}$$

$$p_2 = (z_1 - z_2)g\rho + p_1 - F_{12}\rho$$

SQUARE LAW OF MINE VENTILATION:

1854, J.J Atkinson

Chezy - Darcy relationship

$$\boxed{P = fL \frac{per}{A} \rho \frac{u^2}{2} \ Pa}$$

$f \rightarrow$ constant

$K = \frac{f\rho}{2}$ Kg/m³

$K \rightarrow$ Atkinson friction factor

$$P = KL \left(\frac{per}{A}\right) u^2 \ Pa$$

$$u = Q/A$$

$$\boxed{P = KL \left(\frac{per}{A^3}\right) Q^2} \ Pa$$

$$R = \left(\frac{KL\,per}{A^3}\right) \frac{Ns^2}{m^8} \text{ or } \frac{kg}{m^7}$$

$$P = (R)Q^2 \text{ Pascal}$$

$\rightarrow$ Square law of mine ventilation

$R \rightarrow$ Atkinson Resistance of airway.

$$R = KL\,per/A^3$$

$$K = \left(\frac{f\rho}{2}\right)$$

$$P = R_t \rho Q^2 \rightarrow R_t \rightarrow \left(\frac{fL}{2} \frac{per}{A^3}\right) m^{-4}$$

$\rho = 1.2$ kg/m³

$$P = K_{1.2} L \frac{per}{A^3} Q^2 \left(\frac{\rho}{1.2}\right) \text{ Pascal}$$

$$R = K_{1.2} L \frac{per}{A^3} \left(\frac{\rho}{1.2}\right) \frac{Ns^2}{m^8}$$

$$P = RQ^2$$

Determination Of Friction Factor :-

$$P = R Q^2 \qquad k = 0.6 f$$

$\hookrightarrow$ friction factor

The primary purpose of ~~a~~ coefficient of friction ~~of~~ or friction factor K is to able to predict the resistance of ~~unconstru~~ a planned but a unconstructed mine airway. There are three main methods of determining an appropriate value of this factor.

1) ~~By~~ **By Analogy With Similar Airways:-**

During ventilation survey, measurements of frictional pressure drop & corresponding air flow are made in a series of selected mine airway and to conduct additional test in it. the airway geometry & air density are also measured. The corresponding value of the friction factor may then be calculated

$$\left[\begin{array}{c} R = K_{1.2}\, L \dfrac{per}{A^3} \dfrac{\rho}{1.2} \dfrac{Ns^2}{m^8} \\ P = R Q^2 \\ \text{or} \quad K_{1.2} = \dfrac{P}{Q^2} \dfrac{A^3}{L(per)} \dfrac{1.2}{\rho} \dfrac{kg}{m^3} \end{array}\right]$$

Those values of K may subsequently be employed (or used) to predict the resistance of similar planned airways & if necessary at different air density.

2) **From Design Tables:** -1920 onwards

3) **From Geometric Data:-** for $K \longrightarrow f\left(\frac{e}{d}\right)$

From geometric data &

The coefficient of friction (f) & Atkinson factor (13)
can be expressed as a function of ratio of e to d.
Here, e → is the height of ~~roughening~~ roughening of
mine airway. d → Hydraulic Mean diameter.

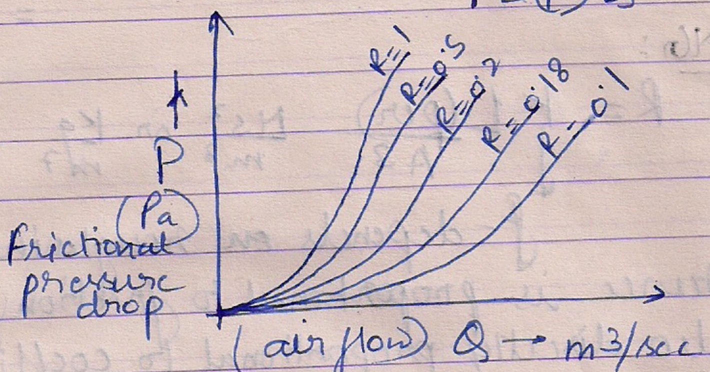
<u>for fully developed turbulent flow</u>

Van-Karman Equation

$$f = \frac{K_1 2}{0.6} = \frac{1}{4\left[2\log_{10}\left(\frac{d}{e}\right)+1.14\right]^2}$$

AIRWAY RESISTANCE:-

$$P = (R)\,Q^2$$



MINE RESISTANCE CURVE

FACTORS WHICH INFLUENCE MINE RESISTANCE:-

1) <u>SIZE OF THE MINE AIRWAY:-</u>

$$R = KL\frac{(per)}{A^3}\ \frac{Ns^2}{m^8} \text{ or } \frac{kg}{m^7} \rightarrow \text{For } 1$$

$$R \propto \frac{1}{A^{2.5}}$$

circular airway $R \propto \frac{1}{d^5}$

From these two relationship, it shows the tremendous effect of airway size on mine resistance. The cross-sectional area open for air flow is the dominant factor in governing mine airway resistance. ~~Dri~~ ~~or~~ Building an airway at only half its designed diameter will result in the resistance increased to 32 times i.e. 2^5 the original which in turn leads to the cost of passing air flow by a factor of 32

2) SHAPE OF AIRWAY:- $\rightarrow R \propto \frac{per}{A^3}$ ∴ $R \propto \frac{per}{A^{1/2}} \frac{1}{A^{2.5}}$

$\left(\frac{per}{A^{1/2}}\right) \rightarrow$ constant for a given cross-section

↳ Shape factor, for circular airway it is minimum $\frac{\pi d}{\sqrt{\frac{\pi}{4}} d}$ $= 3.5449$

3) AIRWAY LINING:

$$R = K L \frac{(per)}{A^3} \quad \frac{Ns^2}{m^8} \text{ or } \frac{kg}{m^7}$$

f - depends on roughening

Airway Resistance is proportional to friction factor (K) and hence also directly proportional to coefficient of friction (f). This f depends only on the roughness of the airway lining for fully developed turbulent flow

4) AIR DENSITY:-

$$P = RQ^2$$

FACTORS AFFECTING MINE RESISTANCE:-

$$P = (R)Q^2$$

i) Size of the airway ii) Shape of the airway
iii) Airway lining iv) Air density
v) Shock losses ← Shock loss factor

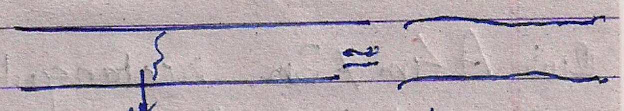
Whenever the air flow is required to change the direction, the resistance of the mine airway may increase significantly. Changes in airflow direction occurs at bend point, junction point, changes in cross-section, obstruction, regulator and at point of entry and exit from the system. The effect of shock losses remain the most uncertain of all the factor that affect mine airway resistance. This is because fairly minor modification in geometry can cause significant changes in the mine airway resistance.

$$P_{shock} = \underbrace{x}_{\text{Shock loss factor will vary on the nature of geometry of airway}} \underbrace{\left(\frac{\rho u^2}{2}\right)}_{\text{velocity pressure}} \text{ Pa}$$

$$P_{shock} = \frac{x\rho}{2} \frac{Q^2}{A^2}$$

$$\boxed{P_{shock} = (R_{shock})\,Q^2} \qquad R_{shock} = \frac{x\rho}{2A^2} \ \frac{Ns^2}{m^8}$$

EQUIVALENT LENGTH:-



Suppose that in a subsurface mine airway of length L there is bend or other causes of shock losses the resistance of the airway will be greater than if the same airway contain no shock losses.

$$P = KL \frac{(per)}{A^3} Q^2 \quad Pa$$

$$R = KL \frac{per}{A^3} \quad Ns^2 m^{-8}$$

$$\rho = 1.2 \, kg/m^3$$

$k_{1.2} = 0.6 \, f \, kg/m^3 \quad R_{1.2} = 1.2 \, kL \, Ns^2 m^{-8}$

$$P = k_{1.2} \, l \, \frac{per}{A^3} Q^2 \frac{\rho}{1.2} \quad Pa$$

$$R = k_{1.2} \, l \, \frac{per}{A^3} \frac{\rho}{1.2} \quad Ns^2 m^{-8}$$

$$R_{shock} = k_{1.2} (L + L_{eq}) \frac{per}{A^3} \cdot \frac{\rho}{1.2} \quad Ns^2 m^{-8}$$

$$R_{shock} = K \, L_{eq} \frac{per}{A^3} \frac{\rho}{1.2} \quad Ns^2 m^{-8}$$

$$R_{shock} = \frac{x \rho}{2A^2}$$

$$\frac{x\rho}{2A^2} = \cancel{K_{1.2}} \, K \, L_{eq} \frac{per}{A^3} \frac{\rho}{1.2}$$

or $\left[L_{eq} = \frac{1.2 \, x}{2K} \left(\frac{A}{per} \right) \, m \right]$.

$$d = \frac{4A}{per}$$

$$L_{eq} = \frac{1.2 \, x (d)}{8K} = 0.15 \frac{x}{K} \text{ (Hydraulic diameter)}$$

Qu: A 4m × 3m rectangular tunnel is 450m long and contains 1 right angle ~~bend~~ of central line radius of curvature 2.5m. The airway is unlined but is in good condition with major irregularities trimmed from the side. If the tunnel is to pass 60 m³/sec of air at a mean density of $1.1\ Kg/m^3$. Calculate the Atkinson & rational resistance at that density and frictional pressure drop. Assume the value of K to be $0.012\ Kg/m^3$ & $x = 0.75$

Solution:- $\rho = 1.1$

$$R = K_{1.2}\ L\ \frac{per}{A^3}\ \frac{\rho}{1.2}\ Ns^2 m^{-8}$$

$$= \cancel{0.75} = 0.04010\ Ns^2 m^{-8}$$

For the bend

$$R\ shock = x\left(\frac{\rho}{2A^2}\right)$$

$$= 0.00286\ Ns^2 m^{8}$$

$$R_{Total} = 0.04010 + 0.00286 = 0.04296\ Ns^2 m^{-8}$$

$$L_{eq} = 0.15\ \frac{x}{K}\ d = 32.15m$$

$$R = K(L + L_{eq})\ \frac{per}{A^3}\ \frac{\rho}{1.2} = 0.04296\ Ns^2 m^{-8}$$

$$R_t = f(L + L_{eq})\ \frac{per}{2A^3}$$

$$= 0.03906\ m^{-4}$$

$$R = \rho R_t$$

$$= 0.04296\ Ns^2 m^{-8}$$

$$P = R_{1.1}\ Q^2$$

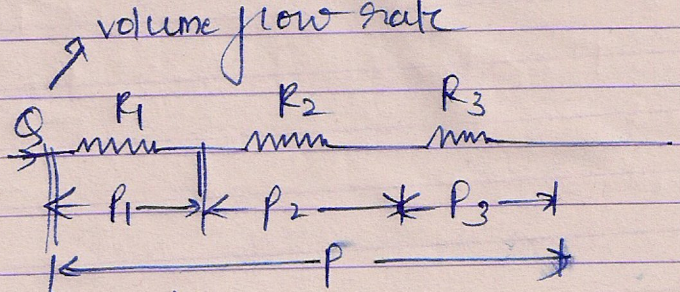
$$= 155 Pa$$

$$P = \rho R_t Q^2$$

$$= 1.1 \times 0.03906 \times 60^2$$

Mine Resistance And Distribution Of Mine Air.

1) Series
2) Parallel
3) Compound



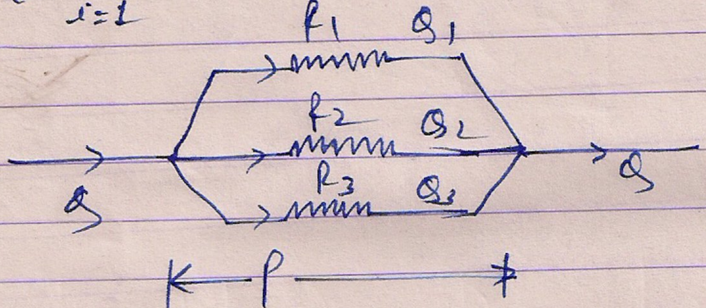
P_1, P_2, P_3 - are the pressure drop
then for the series combination

$$P_1 = R_1 Q^2 \quad P_2 = R_2 Q^2 \quad P_3 = R_3 Q^2$$

$$P = P_1 + P_2 + P_3$$
$$= (R_1 + R_2 + R_3) Q^2$$
$$P = R_{equivalent} Q^2$$

$\therefore$ ~~so~~ $R_{eq} = R_1 + R_2 + R_3$

$$R_{eq} = \sum_{i=1}^{n} R_i$$



$$Q_1 = \sqrt{\frac{P}{R_1}} \quad Q_2 = \sqrt{\frac{P}{R_2}} \quad Q_3 = \sqrt{\frac{P}{R_3}}$$

$$Q = Q_1 + Q_2 + Q_3$$

$$\sqrt{P} \times \frac{1}{\sqrt{R_{eq}}} = \sqrt{P}\left(\frac{1}{\sqrt{R_1}} + \frac{1}{\sqrt{R_2}} + \frac{1}{\sqrt{R_3}}\right)$$

$$\therefore \frac{1}{\sqrt{R_{eq}}} = \frac{1}{\sqrt{R_1}} + \frac{1}{}$$

$$\sqrt{\frac{1}{R_{eq}}} = \sqrt{\frac{1}{R_1}} + \sqrt{\frac{1}{R_2}} + \sqrt{\frac{1}{R_3}}$$

For n airways.

$$\frac{1}{\sqrt{R_{eq}}} = \sum_{i=1}^{n} \frac{1}{\sqrt{R_i}}$$

Since $P = R_1 Q_1^2 = R_2 Q_2^2 = R_3 Q_3^2$

$$Q_1 \propto \frac{1}{\sqrt{R_1}} \quad \& \quad Q_2 \propto \frac{1}{\sqrt{R_2}}, \quad Q_3 \propto \frac{1}{\sqrt{R_3}}$$

$$\therefore Q \propto \left(\frac{1}{\sqrt{R_{eq}}} \cancel{\propto} \frac{1}{\sqrt{R_1}} + \frac{1}{\sqrt{R_2}} + \frac{1}{\sqrt{R_3}} \right) Q \propto \frac{1}{\sqrt{R_{eq}}}$$

$$\left\{ Q_1 = Q\left(\sqrt{\frac{R_{eq}}{R_1}}\right), \quad Q_2 = Q\sqrt{\frac{R_{eq}}{R_2}}, \quad Q_3 = Q\sqrt{\frac{R_{eq}}{R_3}} \right\}$$

The above equation gives the ~~followin~~ volume flow rate distributed through airway connected in parallel depending on their resistance. If this volume flow rate differ from the requirement, one of the following 3 methods is used to redistribute the volume flow rate

1) By increasing the resistance of one airway, by ~~2)~~ By ~~bui~~ building it ~~in~~ a regulator. this causes higher volume flow rate into other mine airway.

2) By increasing volume flow rate in an ~~mine~~ airway by installing a Booster fan

3) By reducing the resistance of the airway in which volume rate has to be increased.

COMPOUND CIRCUIT:- Hardy cross method and their algorithm.

AIR POWER:- work done against friction $= F = \frac{P}{\rho}\ \frac{J}{kg}$

$$M = Q\rho$$

air power $= F \cdot M$

$$= F \cdot \rho Q = \frac{P}{\rho} \cdot \rho Q = PQ = RQ^2 Q$$

$$= RQ^3$$

$$= R_t \rho Q^3 \text{ Watt}$$