Subject:

24/07/2025

**DEPARTMENT OF MINING ENGINEERING**
**IIT (ISM) DHANBAD**

**LECTURE PLAN**

**Subject: Advanced Mine Ventilation (MND 401)**

Session: 2025-26; Semester: Monsoon

**Subject Teacher:** Prof. D. P. Mishra **(L – T – P : 3 – 0 – 0)**

| Topics | Lecture Hours |
|---|---|
| **Unit – 1: Introduction and basics of mine thermodynamics:** Overview and importance of advanced mine ventilation, Basics of mine thermodynamics, Earth crust-infinite reservoir of heat and variation of strata temperature with depth, Computation of thermodynamic properties of mine air. Heat transfer in mine airways: Unsteady/Transient state, Quasi-steady state and steady state heat transfer, Heat transfer due to conduction, logarithmic mean area approach and related problems, Heat transfer due to convection and radiation in mines, and related problems, Heat transfer at wet surfaces, computation of rate of condensation and evaporation in mine airways and conceptual problems, Computation of heat transfer in tunnels depending upon age factor with numerical problems. | 13 |
| **Unit – 2 : Heat flow into bord and pillar, and longwall workings:** Heat and mass transfer in bord and pillar panels, Heat and mass transfer in longwall panels: Sources of heat in longwall panels, Computation of heat load and climatic conditions in mine workings, Mitigative measures for hot and humid workings, Longwall ventilation practices: Global experience, A case study of a deep, hot and humid mine of the country. | 8 |
| **Unit – 3 : Incompressible and compressible flow ventilation analysis:** Computation of volume flow using equivalent resistance method and numerical examples, Computation of volume flow using direct analysis: Application of Kirchoff's first and second laws to solve field problems, Derivation of Hardy Cross iterative method.<br><br>Thermodynamic principles applied to mine ventilation network analysis, Equations considering no change and change in moisture content, Application of these equations to complete mine circuit, Computation of resistance of mine roadways with change in moisture content using Atkinson's equation and Darcy-Weisbach equation, related numerical problems. | 10 |
| **Unit – 4 : Mine air conditioning:** Improvement of workplace environment in underground, Basic vapour-compression refrigeration system, Pressure-enthalpy diagram and super-imposition of pressure-enthalpy diagram on vapour compression cycle, A case study of designing mine air-conditioning system. | 7 |
| **Unit – 5 : Monitoring and control of underground mine environment:** Advanced underground mine environmental monitoring systems, automation, and control. | 4 |

**List of Text/Reference Books**


- Subsurface Ventilation and Environmental Engineering - by M.J. McPherson
- Mine Ventilation and Air Conditioning - by H.L. Hartman, Jan Mutmansky and Y.J. Wang
- Mine Environmental Engineering, Vol. 1 & Vol. 2 - by Mritunjoy Sengupta
- Environmental Engineering in Mines - by V.S. Vutukuri and R.D. Lama
- Mine Environment and Ventilation - by G.B. Mishra
- Mine Ventilation - by S.P. Banerjee
- 1st-12th International Mine Ventilation Congress (IMVC) Volumes


24/07/25

**(D. P. Mishra)**
Professor

Subject: Mine Ventilation :-

→ Thermal capacity
→ Thermal conductivity
→ Thermal diffusivity

→ Thermal properties

* Three main types of geothermal energy sysTM :-

1) Direct use and district heating systems.

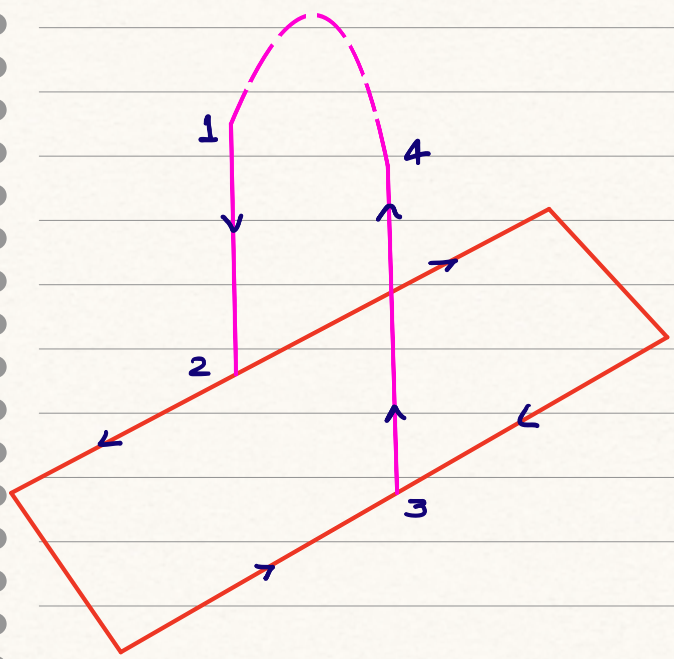
2) Geothermal power plants → for electricity generⁿ

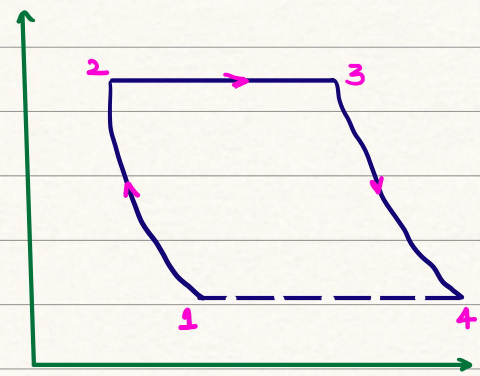
3) Geothermal heat pumps

# Mine Ventilation Thermodynamics

Subject:

- Specific Volume = $\dfrac{\text{Volume}}{\text{unit of dry mass of air}}$



Subject: 07/08/2025

| Location | Sl. No. | P (KPa) | T (K) | Sp. Vol. ($m^3/kg$) | $\rho$ ($kg/m^3$) |
|---|---|---|---|---|---|
| DC top | 1 | 101.59 | 283.15 | 0.8000 | 1.250 |
| DC bottom | 2 | 116.49 | 295.06 | 0.7270 | 1.375 |
| UC bottom | 3 | 113.99 | 322.84 | 0.8129 | 1.230 |
| UC top | 4 | 99.22 | 310.93 | 0.8995 | 1.112 |
| Fan outlet | 5 | 101.59 | 314.05 | 0.8873 | 1.127 |

NVP = ?    NVE = ? Net work/energy of ventilation x mass flow rate of air

$$\int_1^2 v.dp = R(T_2 - T_1) \times \frac{\ln(P_2/P_1)}{\ln(T_2/T_1)}$$

$$NVE = \frac{J/kg}{1000} \times \frac{kg}{s} = \frac{kJ}{s} = kW$$

Mass flow rate ; $M = \rho . Q$

$$\int_1^2 v.dp = 11356 \ J/kg \qquad \int_3^4 v.dp = -12621 \ J/kg$$

$$\int_2^3 vdp = -1923 \ J/kg \qquad \int_4^5 v.dp = 2117 \ J/kg$$

$$\int_5^1 v.dp = 0$$

$M = 1.112 \times 127.4 \ kg/s$

$= 141.6 \ kg/s$

$$\text{Net NVE} = \frac{1071 \ J/kg}{1000} \times 141.6 \ kg/s \times 1.2 \ kg/m^3$$

$$= 181.9 \ kPa$$

$$NVP = \frac{NVE}{sp.vol} = \frac{NVE}{(1/\rho)} = NVE \times \rho \quad (kPa)$$

Subject: 12/08/2025

## ★ Psychrometric Properties of air —

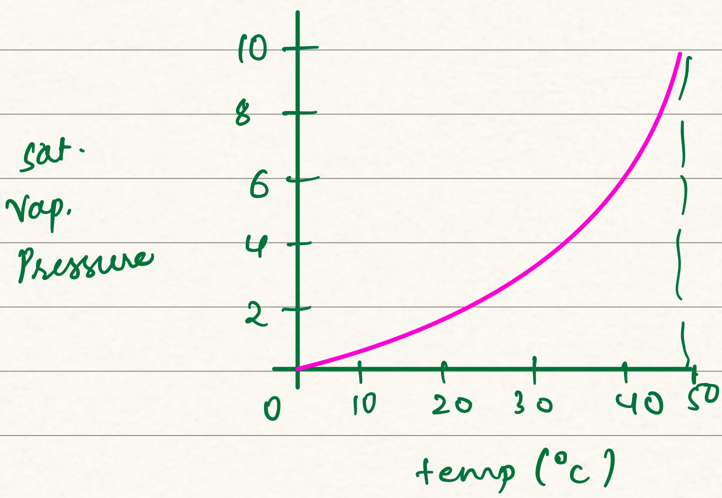
1.) Actual vapour pressure (e) —

$$e = e'_{wb} - 0.000644B\,(t_{db} - t_{wb}), \quad KPa$$

2.) Saturated vapour pressure (e') —

$$e'_{wb} = 0.6105 \exp\left(\frac{17.27\,t_{wb}}{t_{wb} + 237.3}\right), \quad KPa$$

e' depends on the temp.




★ Mixing Ratio —

$$m = \frac{0.622e}{B - e}, \quad kg/kg$$

$$= \frac{622e}{B-e}, \quad g/kg$$

$$\text{Relative Humidity } (\phi) = \frac{e}{e'_{db}} \times 100$$

★ Saturation Ratio —

$$\text{saturation Ratio} = \frac{\text{Mass of moisture present in unit mass of dry air}}{\text{Mass of moisture req. to saturate the air at the observed DBT.}}$$

Subject:

$$= \frac{\left(\frac{0.622e}{B-e}\right)}{\left(\frac{0.622e'}{B-e'}\right)} = \frac{(B-e')e}{(B-e)e'}$$

$$= \frac{e}{e'_{db}} \times 100$$

★ Specific Humidity (S) –

$$S = \frac{0.622e}{B-0.378e}, \ kg/kg$$

★ Enthalpy (H) –

$$H = U + PV$$

Absolute pressure

specific volume of air

Internal Energy

Absolute pressure = Atm. Pressure + Gauge Pressure

perfect vacuum

Enthalpy = sensible heat of dry air + sensible heat of water vap. + Latent heat of vap.

Enthalpy of unsaturated air

$$H = C_{pa}(T-273.15) + 0.001m\ C_{pv}(T-273.15) + 0.001\ ml$$

$$= C_{pa}.t + 0.001m\ C_{pv}\ t_{db} + 0.0001ml$$

$m = g/kg$

heat capacity of air

heat capacity of vapour

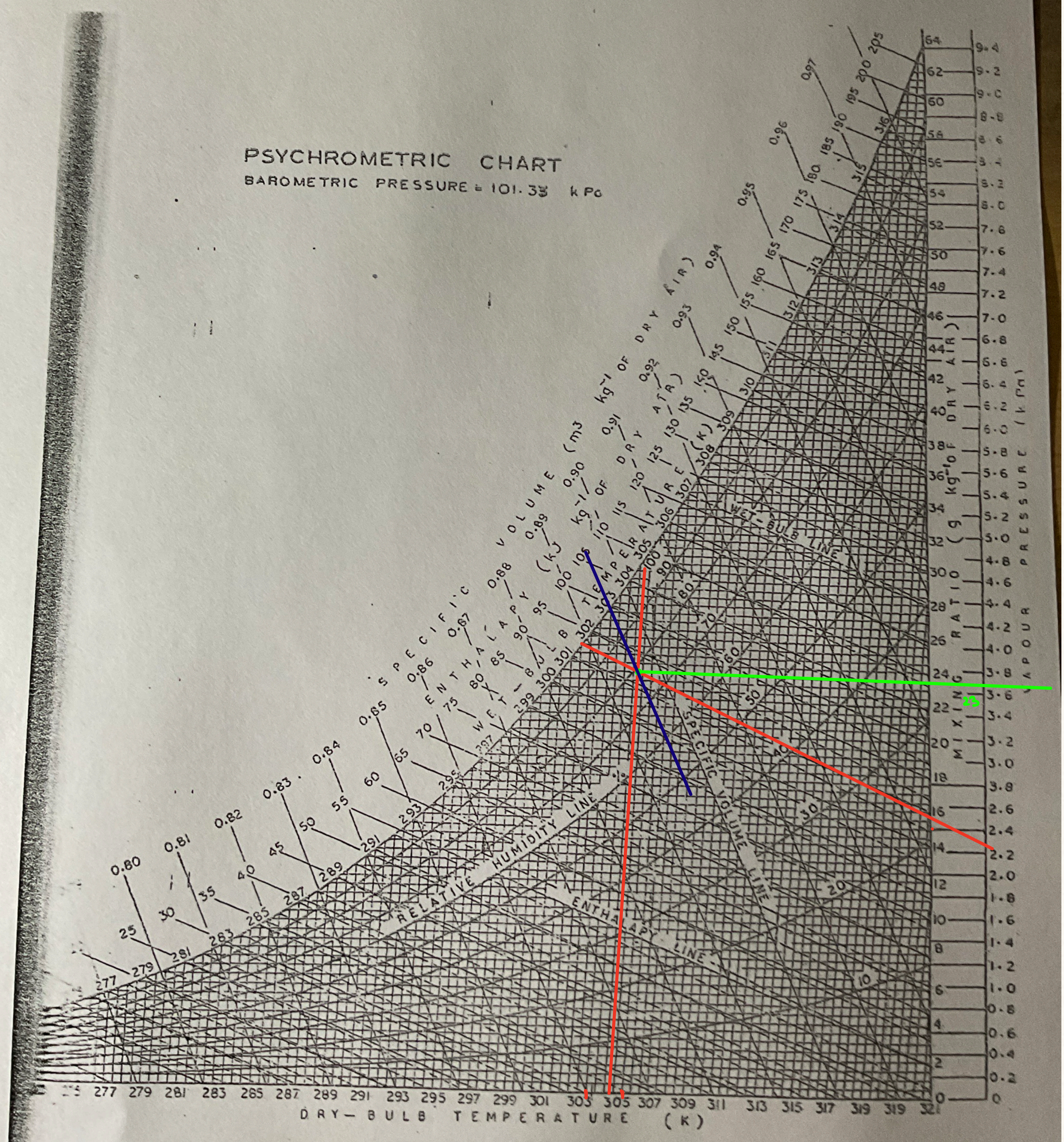



Fig. 3-9 Psychrometric Chart

$C_{pa} = 1005 \ J kg^{-1} K^{-1}$

$C_{pv} = 1860 \ J kg^{-1} K^{-1}$

Subject: / /

Q) Estimate the psychrometric properties of mine air using emperical equation relationship using the following given conditions :

Barometric Pressure, $B = 101.33$ kPa

| | |
|---|---|
| DBT = 32.5°C | DBT = 31.5°C |
| WBT = 29.5°C | WBT = 28.5°C |

Also compare these properties with those obtained from the psychrometric chart.

| Psychrometric properties of air | From empirical equation | From psychrometric chart |
|---|---|---|
| 1. Sat. Vapour Pressure | 3.89 KPa | — |
| 2. Actual vapour Press. | 3.69 KPa | 3.70 KPa |
| 3. Relative Humidity | 80.22 % | 80.2 % |
| 4. Specific Humidity | 0.023 Kg/Kg | — |
| 5. Mixing Ratio (m) | 23.5 g/Kg | 23.5 g/Kg |
| 6. Enthalpy (H) | 89.423 kJ/Kg | 91 kJ/Kg |

Saturated vap. pressure at WBT, $e'_{wb} = 0.6105 \exp\left(\frac{17.27 \times 29.5}{29.5 + 237.3}\right)$

$= 4.12$ KPa

Actual vapour pressure, $e_{wb} = e'_{wb} - 0.000644\,B\,(t_{db} - t_{wb})$

$= 4.12 - 0.000644\,(101.33)(3)$

$= 3.69$ KPa

Relative Humidity (RH), $\phi = \frac{e}{e'_{db}} \times 100$

$e'_{db} = 0.6105 \exp\left(\frac{17.27 \times 32.5}{32.5+237.3}\right) = 4.88$ KPa

Subject:

$$\phi = \frac{3.69}{4.88} \times 100 = 75.6\%$$

$$\text{Specific Humidity } (s) = \frac{0.622e}{B - 0.378e} = \frac{0.622 \times 3.69}{101.33 - 0.378 \times 3.69}$$

$$= 0.023 \text{ kg/kg}$$

$$\text{Mixing Ratio } (m) = \frac{0.622e}{B - e}$$

$$= \frac{0.622 \times 3.69}{101.33 - 3.69}$$

$$= 0.0235 \text{ kg/kg}$$

$$\text{Specific volume } (v) = \frac{287.1\, T_{db}}{1000\,(B - e)} \qquad \{m = g/kg\}$$

$$= \frac{287.1 \times (273.15 + 32.5)}{1000 \times (101.33 - 3.69)}$$

$$= 0.857 \text{ m}^3/\text{kg of dry air}$$

$$\text{Enthalpy } (H) = C_{pa}(T - 273.15) + 0.001\, m\, C_{pv}(T - 273.15) + 0.001\, m\, l$$

$(J kg^{-1} k)$ $C_{pa} = 995.68 + 0.029\, T_{db} = 996.6225 \text{ J kg}^{-1}\text{K}$

$(J kg^{-1} k^{-1})$ $C_{pv} = 1553.7 + 0.645\, T_{db} + \dfrac{35169}{T_{db}} = 2656.78 \text{ J kg}^{-1}\text{K}^{-1}$

$$l = 3.1636 \times 10^6 - 2428\, T_{db}$$

$$= 2.4 \times 10^6 \text{ J/kg}$$

$$H = 996.6225(305.65 - 273.15) + 0.001 \times 23.5 \times 2656.78\,(305.65 - 273.15) + 0.001 \times 23.5 \times 2.4 \times 10^6$$

$$= 89.42 \text{ kJ/kg}$$

Subject: 19/08/2025

## ☆ Heat Transfer in Mine Airways

Flow & thermal energy due to temp. difference.

Conservation of energy ;

$$I^2R = M C_{pa} (t_2 - t_1)$$

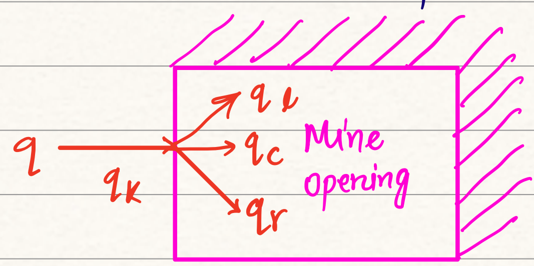
(kg/s) M → Mass flow rate of air

$(KJ\ kg^{-1} K^{-1})$ $C_{pa}$ → Sp. heat capacity of air


Heat flow rate ;

$$= M_w C_{pw} (t_{w_1} - t_{w_2})$$

$$= M_a C_{pa} (t_{a_1} - t_{a_2})$$




$q_k$ → conduction

$q_c$ → convection

$q_r$ → radiation

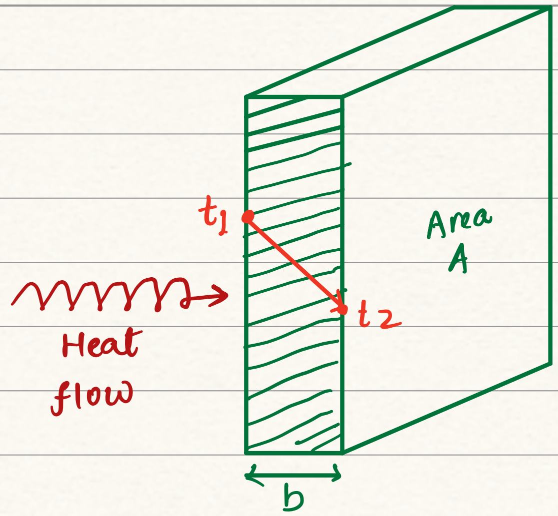
$q_l$ → latent heat transfer

$$q = q_k + q_c + q_r + q_l$$

$q_l$ → latent heat of evaporation ; latent heat of condensation

## ☆ Heat Transfer by Conduction

Subject:



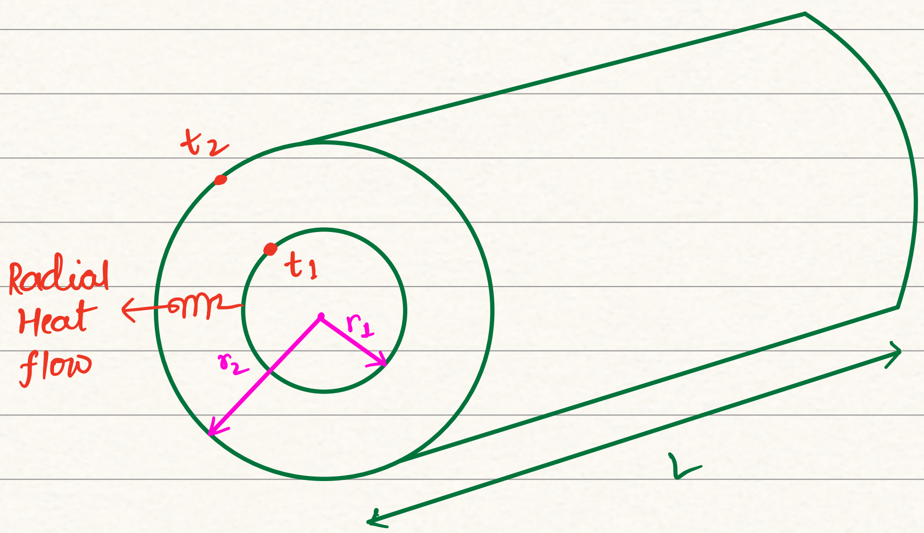

$(t_1 > t_2)$

Heat flow ;

$$q_K = \frac{K A (t_1 - t_2)}{b}$$

K = Thermal conductivity of material ($W m^{-1}\,°c^{-1}$)
A = Surface area ($m^2$)
b = Thickness of the material (b)

Heat transfer by conduction in cylindrical shapes ——




$(t_1 > t_2)$

$A_1$ = surface area of inner surface = $2\pi r_1 L$
$A_2$ = surface area of outer surface = $2\pi r_2 L$

Arithmetic mean = $\frac{A_1 + A_2}{2}$

Subject:

$$\text{Logarithmic mean} = \frac{A_2 - A_1}{\log_e\left(\frac{A_2}{A_1}\right)}$$

| Radius Ratios $r_2/r_1$ or $A_2/A_1$ | 1.1 | 1.2 | 1.5 | 2 | 3 | 5 |
|---|---|---|---|---|---|---|
| Error % using Avg. Area | 0.1 | 0.27 | 1.36 | 4.0 | 9.9 | 20.7 |

Q.) A steel pipe is 26 mm in diameter and is covered with insulation of 50 mm in thickness having $K = 0.2 \, W/m°C$. Calculate the rate of heat loss for meter length of pipe if temp. of inner & outer surfaces of insulation is 300°C & 40°C respectively. Use the avg. area & also determine the error because the log mean area is not used.

$r_1 = 13$ mm

thickness $= 50$ mm

$K = 0.2 \, W/m°C$

$t_1 = 300°C$ $\quad$ $t_2 = 40°C$

$r_2 = 50 + 13 = 63$ mm

$A_1 = 2\pi r_1 L = 2\pi(13)(1)$

$A_2 = 2\pi r_2 L = 2\pi(63)(1)$

$$A = \frac{A_1 + A_2}{2} = \pi(13) + \pi(63)$$

$= 76\pi \text{ mm}^2$

$= 0.2388 \text{ m}^2$

Subject: / /

$$q_k = \frac{KA(t_1 - t_2)}{b}$$

$$= \frac{0.2 \times 76\pi (300 - 40)}{50 \times 1000}$$

$$= 248.35 \text{ watt per m length}$$

$$\text{log mean area} = \frac{A_2 - A_1}{\log_e (A_2/A_1)} = 0.198 \, m^2$$

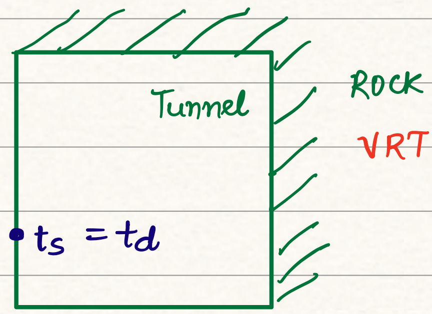
$$q_{log} = \frac{0.2 \times 0.198 (300 - 40)}{0.05} =$$

$$\text{Error \%} = \left( \frac{q_{av} - q_{log}}{q_{log}} \right) \times 100$$

$$= 20.5 \%$$

☆ Radial Heat Flow :—

VRT – Virgin Rock Temperature




In established tunnels

$$q = 3.35 \, LK (VRT - t_d)$$

Heat flux

$L \rightarrow$ Length of the tunnel (m)

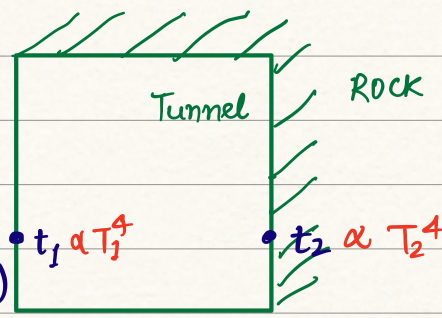
$K \rightarrow$ Thermal conductivity of rock strata $(W/m°c)$

Heat transfer by Radiation ;

$$q_r = 5.67 \times 10^{-8} (T_1^4 - T_2^4) . A_1 . F_{ev}$$

$q_r$ (watt)

$T_1$ & $T_2$ $\rightarrow$ Absolute temp. of surface (K)




$t_1 > t_2$

Subject:

$A_1 \rightarrow$ smaller surface out of $A_1$ & $A_2$ ($m^2$)

$F_{ev} \Rightarrow$ Emissivity & view factor

$\downarrow$

It is a geometric factor used to specify how much of the radiation that is emitted by each surface is if seen or visualized by the other.

The shiny metal surface radiates less energy than the dull or non-metallic surfaces. Therefore, the emissivity of polished metal surfaces is fairly low. In other words, there may no emissivity ($\varepsilon$).

Most material encountered in has very high emissivity has usually more than 95%.

Emissivity & view factor, Fev

$$F_{ev} = \frac{1}{\frac{1}{\varepsilon_1} + \frac{A_1}{A_2}\left(\frac{1}{\varepsilon_2} - 1\right)}$$

As per Stefan Boltzmann eq$^n$;

Radiative, $q_r = 5.67 \times 10^{-8} (T_1^4 - T_2^4) A_1 \cdot F_{ev}$

Heat transfer

$$F_{ev} = \frac{1}{\frac{1}{\varepsilon_1} + \frac{A_1}{A_2}\left(\frac{1}{\varepsilon_2} - 1\right)}$$

$$q_r = h_r (t_s - t_d) \cdot A_1 \cdot F_{ev}$$

Subject:

$t_s$ = Rock surface temperature

$t_d$ = Dry bulb temperature

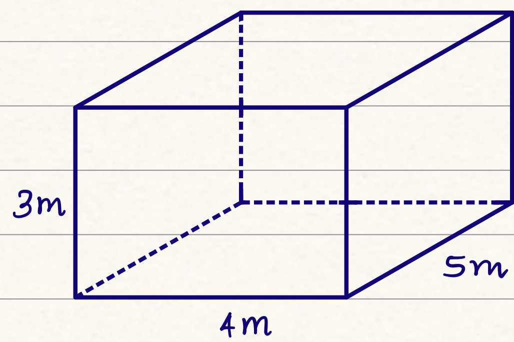
$h_r$ = Radiative heat transfer coefficient ($W\,m^{-2}\,°C^{-1}$)

$$h_r = 4 \times 5.67 \times 10^{-8} \times T_{avg}^3$$

Q.) A still pipe of 70mm diameter carrying hot water at 70°C passes through an UG opening of 5m X 4m X 3m. The pipe passes along the long side of the opening. Determine the emissivity & view factor and the rate of heat transfer by radiation into the opening due to radiation.

Assume that all surfaces in the opening have an emissivity of 0.95 & that the emissivity of the pipe is 0.8. The opening has an average temperature of 24°C.

$$\epsilon_p = 0.8$$
$$\epsilon_s = 0.95$$




$$F_{ev} = \frac{1}{\frac{1}{\epsilon_1} + \frac{A_1}{A_2}\left(\frac{1}{\epsilon_2} - 1\right)}$$

$$= \frac{1}{\frac{1}{\epsilon_p} + \frac{A_1}{A_2}\left(\frac{1}{\epsilon_s} - 1\right)}$$

$$= \frac{1}{\frac{1}{0.8} + \frac{2\pi(35\times10^{-3})\times 5}{2(5\times4 + 4\times3 + 5\times3)}\left(\frac{1}{0.95} - 1\right)}$$

$$= 0.80$$

$$q_r = 5.67 \times 10^{-8} \times (T_1^4 - T_2^4) \cdot A_1 \cdot F_{ev}$$
$$= 5.67 \times 10^{-8} \times \left((343.15)^4 - (297.15)^4\right) \times 1.1 \times 0.8$$
$$= 303 \text{ W}$$

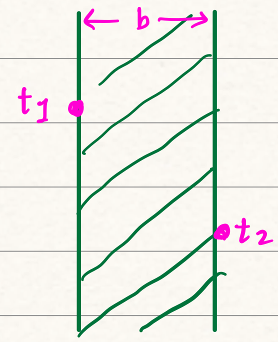
$$T_{avg} = 273.15 + \left(\frac{t_1 + t_2}{2}\right)$$
$$= 320.15 \text{ K}$$

$$q_r = h_r \times (t_1 - t_2) \times A_1 \cdot F_{ev}$$
$$h_r = 4 \times 5.67 \times 10^{-8} \times T_{avg}^3$$
$$= 7.44 \text{ W/m}^2 \,^\circ\text{C}$$
$$q_r = 7.44 \times (70 - 24) \times 1.1 \times 0.8$$
$$= 301 \text{ W}$$

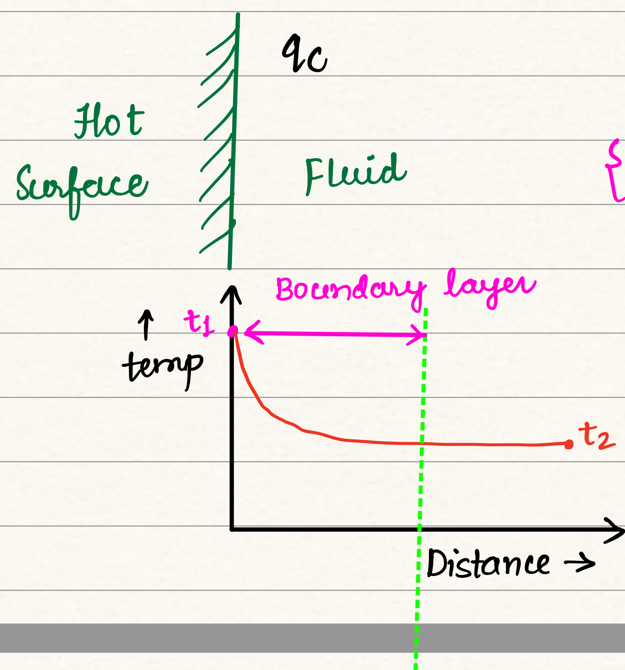
## ★ Heat Transfer by convection :—

Convective Heat Transfer

Heat transfer by conduction $\quad q_K = \dfrac{K \cdot A (t_1 - t_2)}{b}$



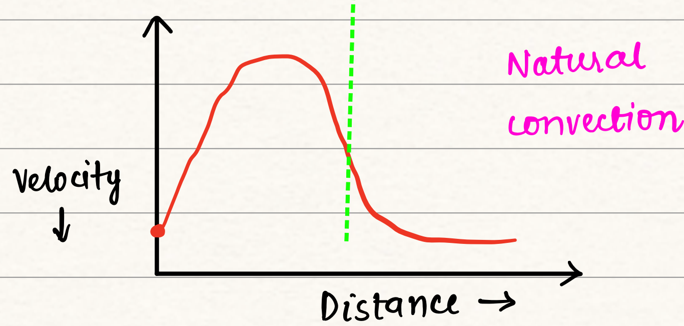

$t_1 > t_2$

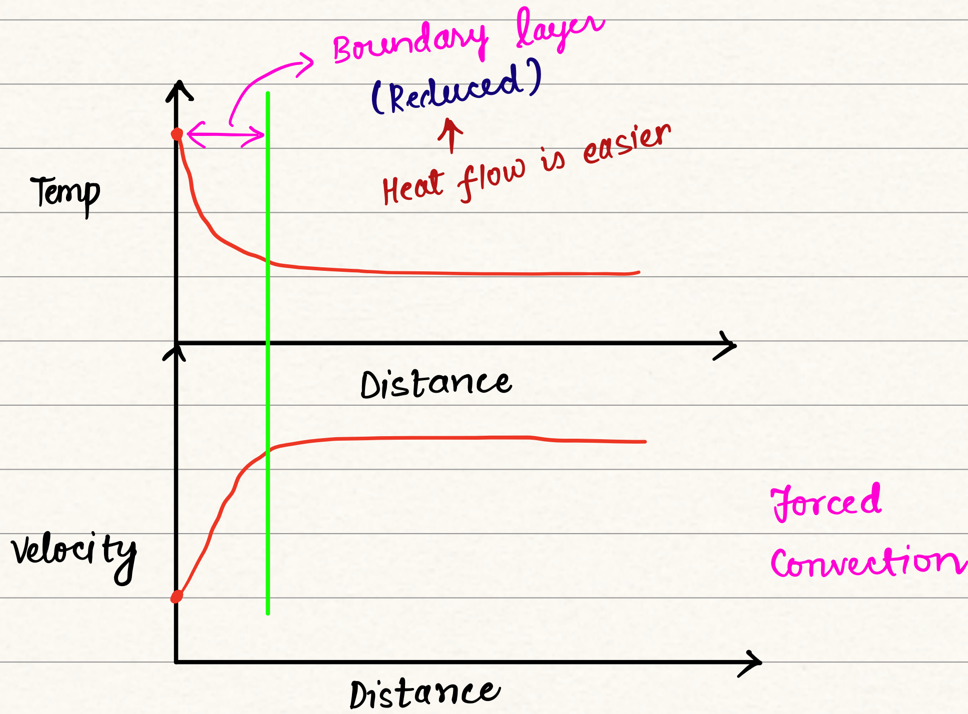



{ Fluid is in contact with hot surface }

Hotware Anaemometer

Subject:    /  /




$$q_c = h_c \times A \times (t_s - t_d) \quad \text{(watt)}$$

$q_c \rightarrow$ heat transfer by convection

$h_c \rightarrow$ convective heat transfer coefficient ($watt/m^2\,°c$)

$A \rightarrow$ Surface area ($m^2$)

$t_s \rightarrow$ hot surface temperature (°c)

$t_d \rightarrow$ dry ball temperature (°c)

Boundary layer depends on the nature of surface in terms of roughness (f or K) & turbulence (Re), velocity of air.

Subject:

$$f = \frac{K}{0.6}$$

K → Atkinson's friction factor $\left(\frac{Ns^2}{m^4}\right)$

Re (Reynold's number)

Turbulence defined by Reynolds number.

$$Re = \frac{\rho \cdot V \cdot De}{\mu}$$

$\rho$ → density of air (kg/m³)

V → velocity of airflow (m/s)

D → Diameter of opening (m) $\{De = D\}$

De → Equivalent Diameter (m)

$$De = \frac{4A}{P}$$

$\mu$ → viscosity

| Fluid | Temperature, °C | Viscosity, Ns²/m² |
|---|---|---|
| Air | 0 | $17.0 \times 10^{-6}$ |
| | 20 | $17.9 \times 10^{-6}$ |
| | 40 | $18.8 \times 10^{-6}$ |
| Water | 0 | $1.792 \times 10^{-3}$ |
| | 20 | $1.005 \times 10^{-3}$ |
| | 40 | $0.656 \times 10^{-3}$ |

$$h_c = \frac{Nu \cdot Ka}{D}$$

Nu → Nusselt number

Ka → Thermal conductivity of air, (W/m°C)

$Ka = 0.026$ W/m°C

$Ka = 2.2348 \times 10^{-4} \times T^{0.8353}$ (T in kelvin)

D → diameter

Subject:

$$Nu = \frac{0.35 \times f \times Re}{1 + \frac{1.592\,(15.217 \times f \times Re^{0.2} - 1)}{Re^{0.125}}}$$

$$f = \frac{K}{0.6}$$

$$\Delta P_f = \frac{K \cdot S \cdot Q^2}{A^3} = RQ^2 \quad \left\{ R = \frac{KS}{A^3} \right\}$$

Q) Calculate the convective heat flow from the rock surface using the following given data :

Dimensions of the airway ; $H = 2.5m$, $W = 3.5m$ & $L = 20m$

Atkinson's friction factor, $K = 0.014\ kg/m^3$ or $Ns^2/m^4$

Rocksurface temperature ; $t_s = 28°C$

Dry ball temperature ; $t_d = 25°C$

Airflow rate ; $Q = 30 m^3/s$

Thermal conductivity of air, $K_a = 0.026\ W/m°c$

Dynamic viscosity of air at 25°C $= 18.3 \times 10^{-6}\ Ns/m^2$

$$f = \frac{K}{0.6} = \frac{0.014}{0.6} = 0.023\ Ns^2/m^4$$

$$\{ \rho_{air} = 1.2\ kg/m^3 \}$$

$$Re = \frac{\rho . V . De}{\mu}$$

$$V = \frac{Q}{A}$$

$$De = \frac{4 \times (3.5 \times 2.5)}{2(3.5+2.5)} = 2.92$$

$$V = \frac{30}{(2.5 \times 3.5)} = 3.43\ m/s$$

$$= \frac{1.2 \times 3.43 \times 2.92}{18.3 \times 10^{-6}}$$

$$De = \frac{4A}{P}$$

$$= 656760$$

Subject:

$$Nu = \frac{0.35 \times f \times Re}{1 + \frac{1.592(15.217 \times f \times Re^{0.2} - 1)}{Re^{0.125}}}$$

$$Nu = \frac{0.35 \times 0.023 \times 656760}{1 + \frac{1.592(15.217 \times 0.023 \times 656760^{0.2} - 1)}{656760^{0.125}}}$$

$$= 2378$$

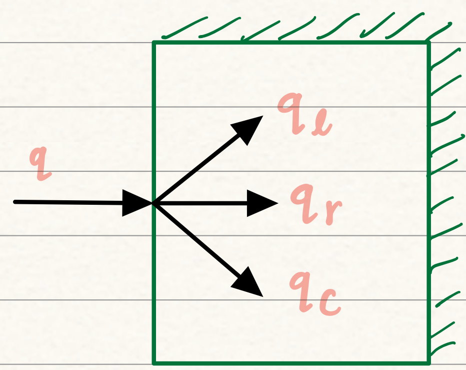
$$h_c = \frac{Nu \times K_a}{D}$$

$$h_c = \frac{2378 \times 0.026}{2.92} = 21.17 \ W/m^2 {}^\circ C$$

$$q_c = h_c \times A \times (t_s - t_d)$$
$$= 21.17 \times 240 \times (28 - 25)$$
$$= 15.24 \ kW$$

## ✯ Heat transfer at wet surface —

Total heat transfer at a hot surface in wet UG opening, $q$



Wet surface

$$q = q_l + q_c + q_r$$

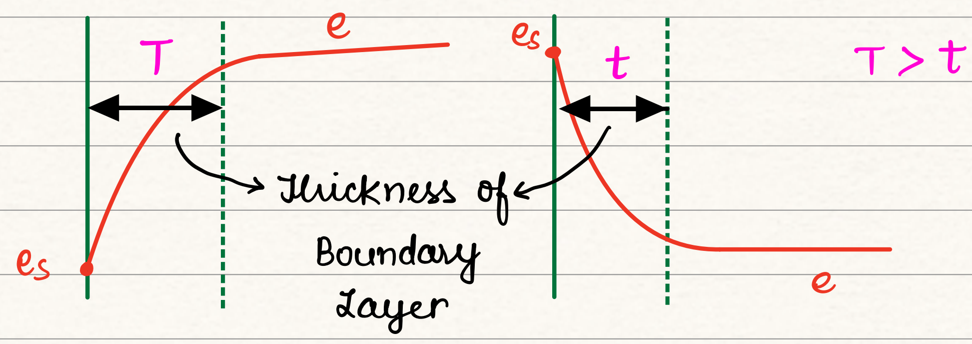
$q_c \rightarrow$ Convective heat transfer
$q_r \rightarrow$ Radiative heat transfer
$q_l \rightarrow$ Latent heat transfer

Due to Condensation

Due to evaporation

Subject: / /

## * Boundary layer (Vapour Pressure) :—




## * Latent heat transfer due to condensation or evaporation —

Latent heat transfer = Latent heat of evaporation or condensation (KJ/kg) ($\lambda$) × Rate of condensation or evaporation of moisture

$$\lambda = 2501 - 2.378\, t_s \ (KJ/kg)$$

$t_s$ → temp. of surface at which condensation or evaporation of moisture

$\lambda$ at 30°C = 2430 KJ/kg

For condensation ;

$$\text{Rate of condensation} = h_c \times A \left[ \frac{0.7 \times (\phi e'_{db} - e'_s)}{B} \right]$$

$$\text{Relative humidity } (\phi) = \frac{e}{e'_{db}}$$

$h_c$ → convective heat transfer coefficient (W/m² °C)

$A$ → surface area (m²)

$e'_s$ → saturated vapour pressure at surface temp.

Subject:

For evaporation ;

$$\text{Rate of evaporation} = h_c \times A \times \left[\frac{0.7\,(e'_s - \phi e'_{db})}{B}\right]$$

$B \rightarrow$ Barometric pressure

Q.) Following data are given for a mine roadway :

$t_{db} = 32°C$

$\phi = 90\%$

$h_c = 10.5\ W/m^2\,°C$

$A = 4m \times 3m$

$t_s = 20°C$

$B = 101\ kPa$

Calculate rate of condensation of moisture for unit length of mine roadway. Also calculate the latent heat transfer due to condensation.

$$\lambda = 2501 - 2.378\,(20) = 2453.44\ KJ/Kg$$

$$\text{Rate of condensation} = h_c \times A \times \left[\frac{0.7\,(\phi e'_{db} - \phi e'_s)}{B}\right]$$

$$e'_{db} = 0.6105 \exp\left(\frac{17.27\,t_{db}}{t_{db} + 237.3}\right)\ kPa$$

$$= 0.6105 \exp\left(\frac{17.27 \times 32}{32 + 237.3}\right) = 4.752\ kPa$$

$$A = 2 \times (4+3) \times 1 = 14m^2$$

$$e'_s = 0.6105 \exp\left(\frac{17.27 \times 20}{20 + 237.3}\right) = 3.1662\ kPa$$

$$\text{Rate of condensation} = 10.5 \times 14 \times \left[\frac{0.7 \times (0.9 \times 4.752 - 3.1662)}{101}\right]$$

Subject:

$= 1.319$

Latent heat transfer $= \lambda \times$ Rate of condensation
$= 2453.44 \times 1.319$
$= 2.763$ kW

★ Heat transfer in tunnels :—

$$q = 2\pi K T (t_{vr} - t_s) \quad \text{(Watt/ metre length)}$$

$K \rightarrow$ thermal conductivity of rock strata (W/m°C)
$T \rightarrow$ age factor
$t_{vr} \rightarrow$ virgin rock temperature (°C)
$t_s \rightarrow$ rock surface temperature (°C)

$$T = \frac{0.685}{F_0^{0.146}}$$

{ $F_0 \rightarrow$ Fourier's Number }
↓
Dimensionless number proposed by Joseph Fourier that characterises transient heat conduction. It is the ratio of diffusive or conductive heat transport rate to the heat storage rate.

$$\left\{ F_0 = \frac{\theta . a}{(D/2)^2} \right\}$$

$\theta \rightarrow$ age of the tunnel (sec)
$a \rightarrow$ difficulty of rock (m²/s)

$$a = \frac{K}{\rho . C} \quad (Wm^2/J)$$

$K \rightarrow$ thermal conductivity (W/m°c)
$\rho \rightarrow$ density of rock (kg/m³)
$c \rightarrow$ specific heat capacity (J/kg °c)
$D \rightarrow$ equivalent diameter of tunnel (m)

Q.) The following data are given :—
Age of tunnel = 1 year

Subject:

VRT = 50°C

K (thermal conductivity of rock) = 4.5 W/m°C

specific heat capacity of rock, C = 1162 J/kg°C

Density of rock, $\rho$ = 1384 kg/m³

Rock surface temperature, ts = 35°C

Diameter of tunnel, D = 2m

Calculate the heat flow for meter length of the tunnel.

Diffusivity of rock, $a = \frac{K}{\rho \cdot C}$

$$= \frac{4.5}{1384 \times 1162}$$

$$= 2.7 \times 10^{-6} \ (Wm^2/J)$$

Fourier's number (Fo) $= \frac{\theta \cdot a}{(D/2)^2}$

$$= \frac{1 \times 12 \times 30 \times 24 \times 60 \times 60 \times 2.7 \times 10^{-6}}{(2/2)^2}$$

$$= 87.033$$

Age factor, $T = \frac{0.685}{F_0^{0.146}} = \frac{0.685}{(87.033)^{0.146}}$

$$= 0.356$$

Now,

$$q = 2\pi K T \ (t_{vr} - t_s)$$

$$= 2\pi \times 4.5 \times 0.356 \ (50 - 35)$$

$$= 150.984 \text{ Watt}$$

Using the formula for radial heat flow in tunnels,

$$q = 3.35 \, LK \ (VRT - t_s)$$

$$= 3.35 \times 1 \times 4.5 \ (50 - 35)$$

Subject:

$= 226.12$ Watt

* Heat flow property of rocks degrade with age.

Q.) A steel pipe of 150 mm inside diameter and 160 mm outside diameter carries cold water ($10°C$) at 0.5 m/s along a mine airway. The air in the airway is at $24°C$ WBT and $27°C$ DBT at 100 kPa pressure. The air velocity is 3m/sec. Determine the rate of heat pickup by the water. Assume that the outer surface of the pipe is at a temperature of $11°C$ and temperature of inside surface is $10°C$. Also assume the convective heat transfer coefficient $h_c = 20.5\ W/m^2°C$, emissivity and view factor, $F_{ev} = 0.95$, saturated vapour pressure ($e'_s$) at $11°C$ $= 1.312$ kPa, vapour pressure, $e = 2.79$ kPa. Assume thermal conductivity coefficient of steel. $K = 45\ W/m°C$.

DBT of air = temperature of rock surface

Heat transfer taking place due to :
(i) radiation
(ii) convection
(iii) condensation
(iv) conduction

$$q = q_K + q_c + q_l + q_r$$

$$q_K = 3.35\, LK^{0.854} (t_2 - t_1)$$
$$= 3.35 \times 1 \times 45^{0.854} (11 - 10) \qquad \{L = 1m\}$$
$$= 86.47 \text{ Watt}$$

Subject:

$$q_c = h_c \cdot A \cdot (t_{db} - t_s)$$
$$= 20.5 \times 0.503 \times (27 - 11)$$
$$= 165 \text{ Watt}$$

$A = 2\pi r h$
$= \frac{160}{1000} \times \pi \times 1$
$= 0.503\, m^2$

$$q_r = h_r \cdot A \cdot (t_{db} - t_s)\, F_{ev}$$

$$h_r = 4 \times 5.67 \times 10^{-8} \times (T_{av})^3$$
$$= 5.6\ W/m^2\,°C$$

$T_{av} = \frac{27+11}{2} + 273.15$
$= 292.15\, K$

$$q_r = 5.6 \times 0.503 \times (27 - 11) \times 0.95$$
$$= 42.8\, W$$

$$q_l = \lambda \cdot h_c \cdot A \left[ \frac{0.7(\phi e'_{db} - e'_s)}{B} \right]$$

$$\lambda = 2501 - 2.378\, t_s$$
$$= 2501 - 2.378 \times 11$$
$$= 2475\ kJ/kg$$

$$q_l = 2475 \times 20.5 \times 0.503 \times \left( \frac{0.7(2.79 - 1.312)}{100} \right)$$

$$= 264 \text{ Watt}$$

Therefore ;

$$q = 86.47 + 165 + 42.8 + 264$$
$$= 558.27 \text{ Watt}$$

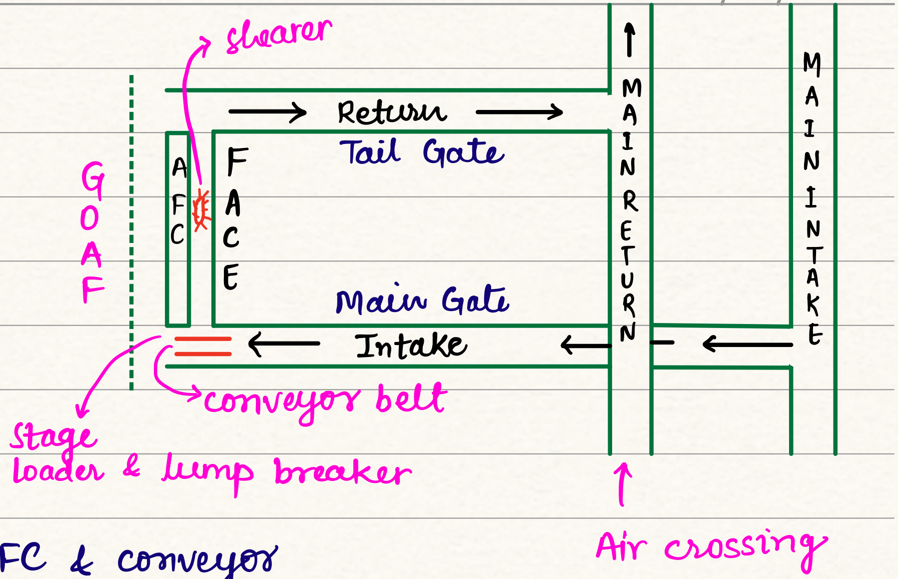
## ☆ Heat Flow into Bord & Pillar and Longwall workings —

* Sources of heat in a Longwall Panel :—

1.) Strata
2.) Conveyor Belt (Empty & Loaded)

Subject:

3.) Water pipe
4.) Power Pack
5.) Transformer
6.) Stage Loader
7.) Lump Breaker
8.) AFC
9.) Shearer
10.) Goaf
11.) Cut coal on AFC & conveyor




## 1.) Heat from gate belt :—

Total heat from gate belt = Heat due to linear surface + Heat due to spot source

$$P_{lin} = P_l + P_e + P_p$$

$$P_{spot} = P_{ht} - P_{lin} \qquad \{ P_{ht} = P_{spot} + P_{lin} \}$$

$$P_{ht} = \frac{P_1}{\eta} - (\pm P_g) \text{ kW}$$

$$P_1 = P_e + P_l + P_p + P_g$$

$P_e$ = Total power required to overcome friction offered by the empty belt

$$\boxed{P_e = \gamma m_1 . L . g . \mu . v . \cos\theta}$$

$P_l$ = Total power required to overcome friction offered by the loaded belt

$$\boxed{P_l = \gamma m_2 . L . g . \mu . \cos\theta}$$

Subject:

$rm_1$ = mass of $\underbrace{\text{rotating part}}_{\text{Idler}}$ per m length (kg/m)

$$\boxed{rm_1 = 0.00058\, W(d - 15.6)}$$

W = width of belt conveyor (mm)
d = diameter of troughing idlers (mm)
L = Length of belt conveyor (m)
V = speed of conveyor belt (m/s)
θ = angle of inclination of belt
μ = coefficient of friction

$$\boxed{\mu = 0.016 + \frac{8.8}{L}}$$

$rm_2$ = coal flow rate (kg/s)

$P_g$ = Power required to lift the material against gravity
(−) sign is applicable for dipping belt conveyor in $P_{nt}$ formula.

$$P_g = rm_2 \cdot L \cdot g \cdot \sin\theta$$

$P_p$ = Power required to overcome friction offered by pulley

$$P_p = 50 \cdot rm_1 \cdot g \cdot \mu \cdot v$$

2) Transformer :—

$$P_2 = P_n(1-\eta)\, P_f \quad (kW)$$

Subject: / /

$P_n$ = Nominal power rating of transformer (kW)
$P_f$ = power factor
$\eta$ = efficiency ($\simeq 95\%$ to $98\%$)

3.) Power Pack, Stage Loader, Lump Breaker, etc :—

$$P_3 = \left(0.15 + \frac{0.00008}{B}\right) \cdot P_n \quad (kW)$$

B = coal production from face (te/day)
$P_n$ = Total nominal power rating of all the machines (kW)

4.) Heat from AFC :—

$$\mu = 0.33$$

$$\text{Effective speed of AFC } (v) = \text{speed of AFC} \pm \frac{\text{speed of shearer}}{60}$$

5.) Shearer :—

Heat generated by shearer ;

$$P_4 = P_{cht}\,(50\%) + P_h$$

$P_{cht}$ = heat liberated due to cutting
$P_h$ = hauling power of shearer

$$P_{cht} = P_c\,(1 - \eta_m \eta_g) \quad (kW)$$

$P_c$ = power required for cutting (kW)
$\eta_m$ = motor efficiency
$\eta_g$ = gear efficiency

Subject: / /

$$P_c = FSE \times \text{volumetric cutting rate} \times 1000 \quad (kW)$$

FSE = Field specific Energy ($MJ/m^3$)

$$FSE = \frac{0.04\, A^{0.53}\,(1232 + D)}{D_W^{0.29}\; C^{0.92}\; D} \quad (MJ/m^3)$$

A = laboratory specific energy ($MJ/m^3$)
D = operating seam thickness (m)
$D_W$ = depth of working (m)
C = frequency of cleats
(Number of cleats per meter length in AFC)

$$P_h = P_{th} \times K_{mf}$$

$P_h$ = hauling power of shearer
$P_{th}$ = theoretical power
$K_{mf}$ = maintenance factor

$$P_{th} = \frac{h_s \cdot m \cdot g\,(\mu\cos\alpha \pm \sin\alpha)}{\eta_{mh}\,\eta_{gh} \cdot 60}$$

$h_s$ = haulage speed (m/s)
m = mass of shearer (te)
g = acceleration due to gravity ($m/s^2$)
$\mu$ = sliding rail
$\alpha$ = angle of inclination
(−) applicable when shearer is moving down
$\eta_{mh}$ = efficiency of haulage motor
$\eta_{gh}$ = efficiency of haulage gear

Subject:

## 6.) Heat from cut coal :—

Heat from cut coal conveyed by the AFC ;

$$\text{Heat} = \gamma m_2 \times \text{specific heat capacity of coal} \times \Delta T$$

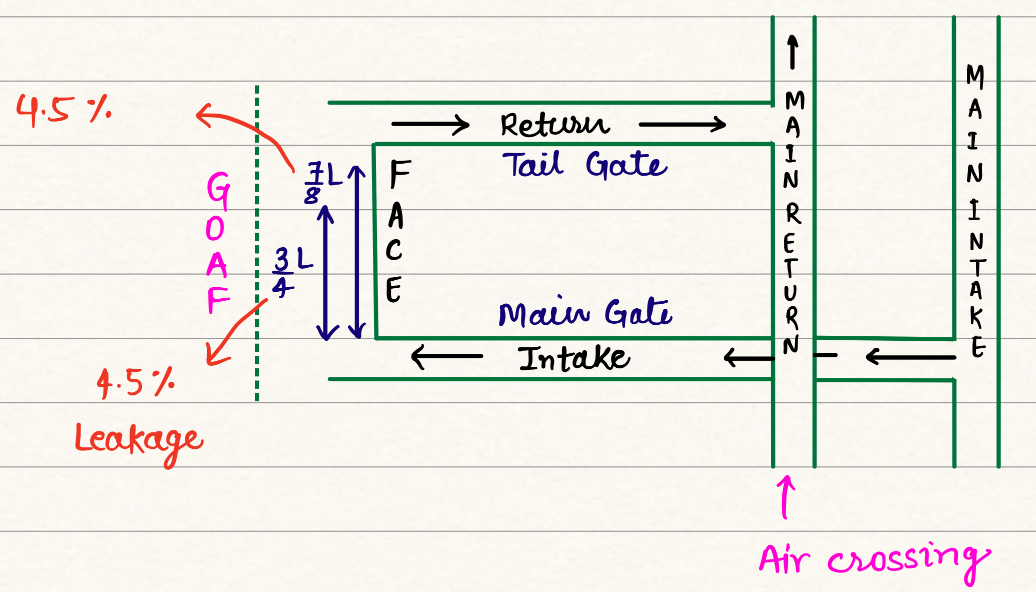
$\Delta T$ = temperature difference when coal is transported by AFC

$$\Delta T = 0.0024\, L^{0.8}\,(T_u - W_{b\,inlet})$$

$L$ = length of AFC which is conveying coal at a particular time
$T_u$ = heat from the cut coal just below the face immediately after cutting by shearer
$W_{b\,inlet}$ = wet bulb temperature at inlet of longwall face

$$T_u = (0.72 \times VRT) + 8.2$$

## 7.) Heat contributed by Goaf :—




30 % → Total air leakage

Subject: / /

Q.) The specifications of a belt conveyor running in the gate road of a longwall panel are given as follows:

Width of conveyor = 1000 mm
Diameter of troughing idler = 100 mm
Speed of conveyor = 2.2 m/s
Gradient of gate road = $1.7^\circ$ (dipping)
Efficiency of the drive motor = 90 %
Length of conveyor belt = 400 m
Density of coal = 1.382 te/$m^3$
Rate of coal transportation = 148.84 te/hr

Using this data, calculate the amount of spot & linear heat dissipitated by the belt conveyor in the gate road.

$$P_{ht} = P_{lin} + P_{spot}$$

$$P_{ht} = \frac{P_1}{\eta} - (\pm P_g)$$

$$P_1 = P_e + P_l + P_p + P_g$$

$$P_e = \gamma m_1 \cdot L \cdot g \cdot \mu \cdot v \cos\theta$$

$$\gamma m_1 = 0.00058\, W (d - 15.6)$$
$$= 0.00058 \times 1000 (100 - 15.6)$$
$$= 48.952 \text{ kg/m}$$

$$\mu = 0.016 + \frac{8.8}{400} = 0.038$$

$$P_e = 48.952 \times 400 \times 9.8 \times 0.038 \times 2.2 \times \cos 1.7^\circ$$
$$= 16035.09 \text{ W}$$

Subject:

Now, $P_l = \gamma m_2 \cdot L \cdot g \cdot \mu \cdot \cos\theta$

$= \frac{148840}{3600} \times 400 \times 9.8 \times 0.038 \times \cos(1.7^\circ)$

$= 6155.95\ W$

$P_p = 50 \cdot \gamma m_1 \cdot g \cdot \mu \cdot V$

$= 50 \times 48.952 \times 9.8 \times 0.038 \times 2.2$

$= 2005.26\ W$

$P_g = \gamma m_2 \cdot L \cdot g \cdot \sin\theta$

$= \frac{148840}{3600} \times 400 \times 9.8 \times \sin(1.7^\circ)$

$= 4808.01\ W$

Therefore, $P_1 = P_e + P_l + P_p + P_g$

$= 16035.09 + 6155.95 + 2005.26 + 4808.01$

$= 29004.31\ W$

$P_{ht} = \frac{29004.31}{0.9} - (-4808.01)$

$= 37035\ W$

Now, $P_{lin} = P_l + P_e + P_p$

$= 24196.3\ W$

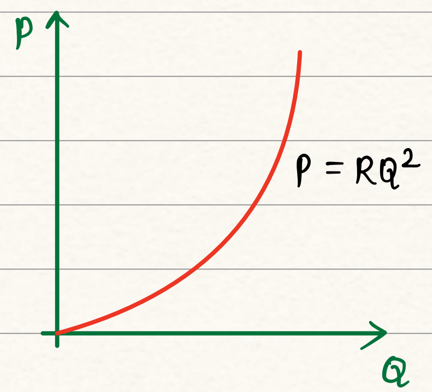
$P_{spot} = P_{ht} - P_{lin}$

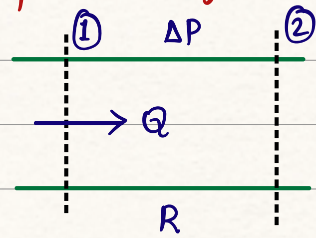
$= 37035 - 24196.3$

$= 12838.7\ W$

Subject: / /

## ★ Ventilation Network Analysis for Incompressible flow :—




$$R = \frac{\Delta P}{Q^2} \quad (Ns^2/m^8)$$

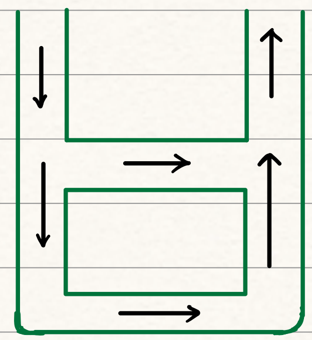
Vane Anaemometer → Continuous Traversing
(To measure air velocity) → Precise Traversing

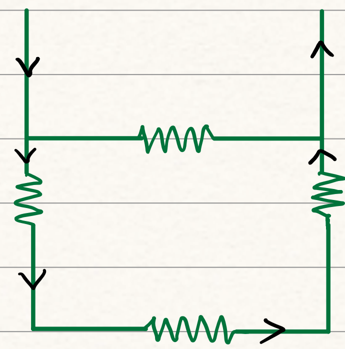
Manometer (To measure pressure)

$$R = \frac{KS}{A^3}$$

$\begin{cases} S = \text{Rubbing Area } (P \times L) \\ A = \text{Cross-sectional area} \end{cases}$

## # Terminologies associated with ventilation network :—





1.) **Ramified Network** :— It is a closed & interconnected system of branches through which the fluid or air may flow.

2.) **Junction/Node** :— It is a point at which at least three or more airways meet.

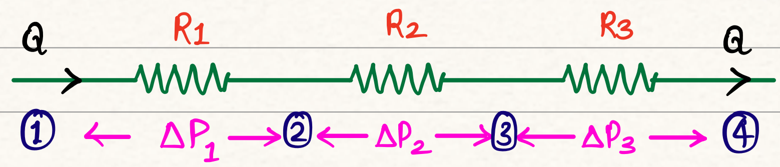
3.) **Branch** :— A single airway connecting two junctions.

4.) **Mesh/Loop** :— It is a closed path of connected branches within a network.

# Techniques for ventilation Network Analysis :—

1.) Equivalent resistant technique
2.) Analytical technique applying Kirchoff's law.
3.) Using physical models or analogues
4.) Successive approximation / iteration technique (Hardy - cross iteration)

## 1.) Equivalent Resistance Technique :




M → Mass flow rate of air (kg/s)

$M = \rho \cdot Q$

$$\Delta P = \Delta P_1 + \Delta P_2 + \Delta P_3$$

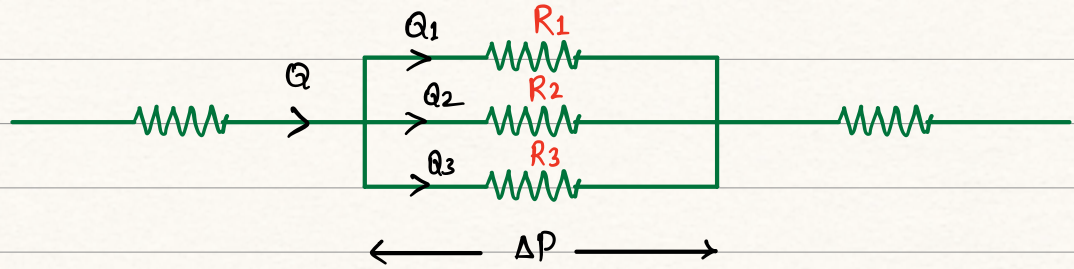
If, $R_s$ = equivalent resistance of airways in series

$$R_s Q^2 = R_1 Q^2 + R_2 Q^2 + R_3 Q^2$$

$$R_s = R_1 + R_2 + R_3$$

$$R_s = \sum_{i=1}^{n} R_i$$

Subject: / /




If, $R_p$ = equivalent resistance of airways in parallel

$$\Delta P = R_p Q^2 = R_1 Q_1^2 + R_2 Q_2^2 + R_3 Q_3^2$$

$$Q_1 = \sqrt{\frac{\Delta P}{R_1}} = Q\sqrt{\frac{R_p}{R_1}}$$

$$Q_2 = \sqrt{\frac{\Delta P}{R_2}} = Q\sqrt{\frac{R_p}{R_2}}$$

$$Q_3 = \sqrt{\frac{\Delta P}{R_3}} = Q\sqrt{\frac{R_p}{R_3}}$$

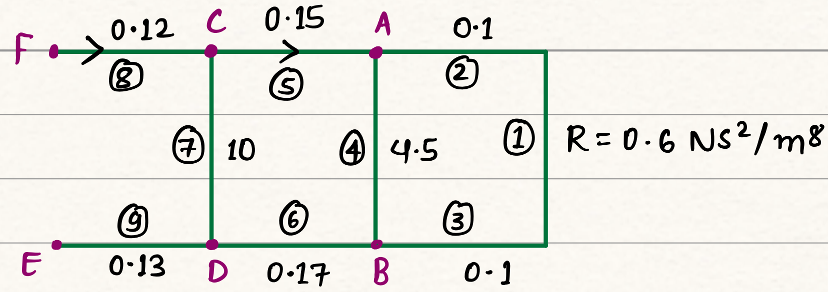
$$Q_i \propto \frac{1}{\sqrt{R_i}}$$

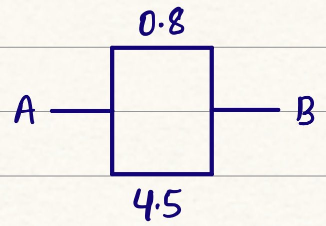
$$\sqrt{\frac{\Delta P}{R_p}} = \sqrt{\frac{\Delta P}{R_1}} + \sqrt{\frac{\Delta P}{R_2}} + \sqrt{\frac{\Delta P}{R_3}}$$

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

Q.) The figure illustrates 9 airways that form a part of a ventilation network. Find the equivalent resistance of the system. If total pressure loss taking place is causing the airflow of $50 m^3/s$. Calculate the airflow in each branch of the system.

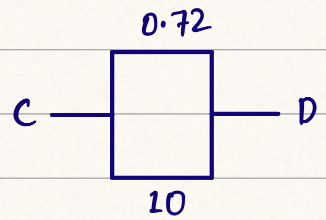
Subject: / /



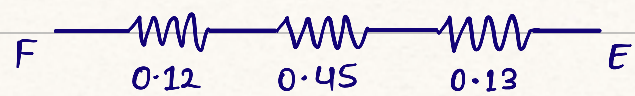

$$\frac{1}{\sqrt{R_{eq}}} = \frac{1}{\sqrt{0.8}} + \frac{1}{\sqrt{4.5}}$$

$$R_{eq} = 0.4$$




$$\frac{1}{\sqrt{R_{eq}}} = \frac{1}{\sqrt{0.72}} + \frac{1}{\sqrt{10}}$$

$$R_{eq} = 0.45$$




$$R_{eq} = 0.12 + 0.45 + 0.13$$

$$= 0.7 \ Ns^2/m^8$$

Now, $\Delta P = RQ^2$

$$\Delta P = 0.7 \times (50)^2$$

$$= 1750 \ Pa$$

For airflow, b/w C & D ;

$$0.72 Q^2 = 10(50 - Q)^2$$

$$\Rightarrow Q = 39.42 \ m^3/s$$

b/w A & B ;

$$0.8 Q^2 = 4.5 (39.42 - Q)^2$$

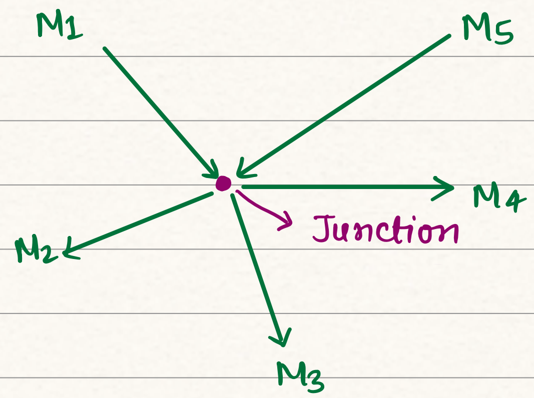
$$\Rightarrow Q = 24.40 \ m^3/s$$

Subject: / /

## 2.) Direct Analysis using Kirchoff's Law :—

(i) Kirchoff's 1st Law : Applied at Junction
(ii) Kirchoff's 2nd Law : Applied to a mesh/loop

According to Kirchoff's first law, Algebraic sum of mass flow rate at a junction is equal to 0.




$$M_1 - M_2 - M_3 - M_4 + M_5 = 0$$

M = mass flow rate (kg/s) $= \rho . Q$

$$\Rightarrow Q_1 - Q_2 - Q_3 - Q_4 + Q_5 = 0$$

$$\Rightarrow \underbrace{Q_1 + Q_5}_{\text{Inflow}} = \underbrace{Q_2 + Q_3 + Q_4}_{\text{Outflow}}$$

According to Kirchoff's 2nd law, the algebraic sum of frictional pressure drop around any closed mesh, fan pressure and natural ventilation pressure is zero.

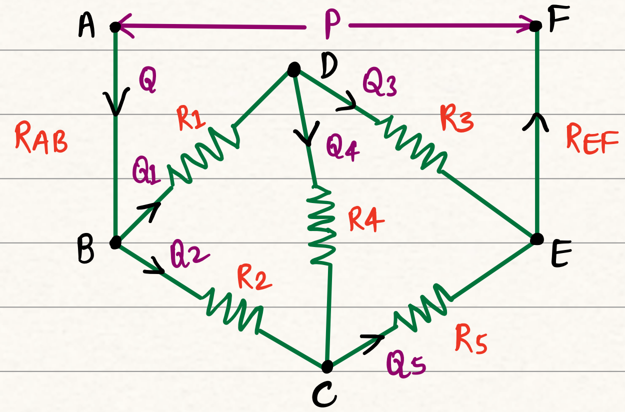
$$\sum_{i=1}^{n} (P_i - P_{fi}) - NVP_n = 0$$

$P_i$ = frictional pressure drop
$P_{fi}$ = fan pressure

Subject: / /

NVPn = total natural ventilation pressure

Frictional Pressure drop in ith mesh ($RQ^2$);




$$\left.\begin{aligned} Q &= Q_1 + Q_2 \\ Q_1 &= Q_3 + Q_4 \\ Q_2 + Q_4 &= Q_5 \end{aligned}\right\}$$ By Kirchoff's 1st Law

In a ventilation network,

let number of branches be 'b'

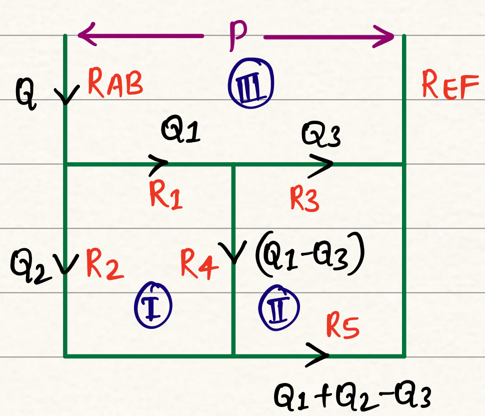
j = no. of junctions in network

The no. of independent equations = (j−1)

The no. of meshes to apply Kirchoff's 2nd Law = b−(j−1)

$$m = b - (j-1)$$

no. of meshes




no. of branches = 6

no. of junctions = 4

$m = b - (j-1)$

$= 6 - 3$

$= 3$

Subject: / /

Mesh I;

$$-R_2Q_2^2 + R_1Q_1^2 + R_4(Q_1-Q_3)^2 = 0$$

Mesh II;

$$-R_4(Q_1-Q_3)^2 + R_3Q_3^2 - R_5(Q_1+Q_2-Q_3)^2 = 0$$

Mesh III;

$$-R_{AB}Q^2 - (-P) - R_{EF}Q^2 - R_3Q_3^2 - R_1Q_1^2 = 0$$

↑

Pressure at A is more than F

Q.)