Environmental Technology in Mining

Chapter II. Mine Ventilation

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Chapter 2. Mine ventilation

2.1. Introduction

- ✓ Mine ventilation objectives
- ✓ Pollutants and hazards
- ✓ Air quantity and quality

2.2. General theory of mine ventilation

- ✓ The Atkinson equation and the square law
- ✓ Determination of the friction factor
- ✓ Airway resistance

2.3. Mine ventilation systems

- ✓ Elements
- ✓ Layout
- ✓ Active devices
- ✓ Passive devices
- ✓ Auxiliary devices

Underground mine ventilation

One of the most important aspects of underground mining,
and an essential element to ensure safe production of minerals

Basic objectives of mine ventilation systems:

(1) To provide airflows of sufficient quantity and quality to **provide oxygen** in the working area

(2) To **dilute contaminants** (hazardous gases and dust) to safe concentrations and remove them from the mine

(3) To manage underground **temperatures**

Common types of air pollutants:

- ✓ Gases
- ✓ Products of combustion
- ✓ Diesel particulate matter
- ✓ Dusts
- ✓ Heat and humidity

Main hazards encountered in mine ventilation:

✓ **Natural conditions**:

Geology, depth, surface climate, gases contained in the rock mass, ground water and other fluids, and the physical and chemical properties of the rock

✓ **Design and engineering decisions**:

Methods used for mining and fragmentation of rock, types of power used underground, vehicles in the mine, materials storage in the mine, and mine layout

Quantity and quality requirements?

It will vary:

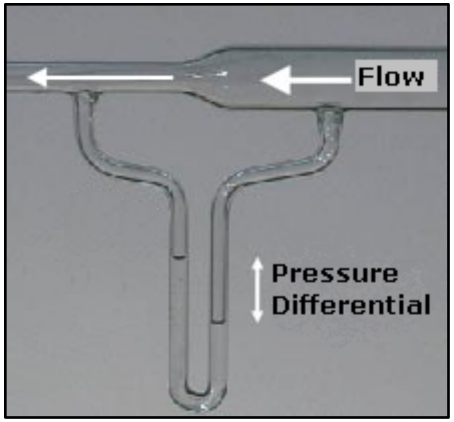
- ✓ From country to country
  (legal standards and requirements)
- ✓ Depending on the situation being ventilated
  (type of mine, equipment, etc.)

Overall requirement:

- ✓ Workers must be able to work
  (O_2 concentration ≥ 19.5%; and low concentration of contaminants)
- ✓ Comfort
  (temperature, etc.)
- ✓ Ventilation where no human intervention
  (oxygen supply to operate and cool machinery or to combustion processes)

THE BERNOULLI PRINCIPLE

Bernoulli's principle states that an increase in the speed of a fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy



Bernoulli's principle can be derived from the principle of conservation of energy. This states that, in a steady flow, the sum of all forms of energy in a fluid along a streamline is the same at all points on that streamline.

THE BERNOULLI EQUATION

$$P + \frac{u^2 \cdot \rho}{2} + \rho g h = constant \qquad \frac{P}{\rho \cdot g} + \frac{u^2}{2g} + h = constant$$

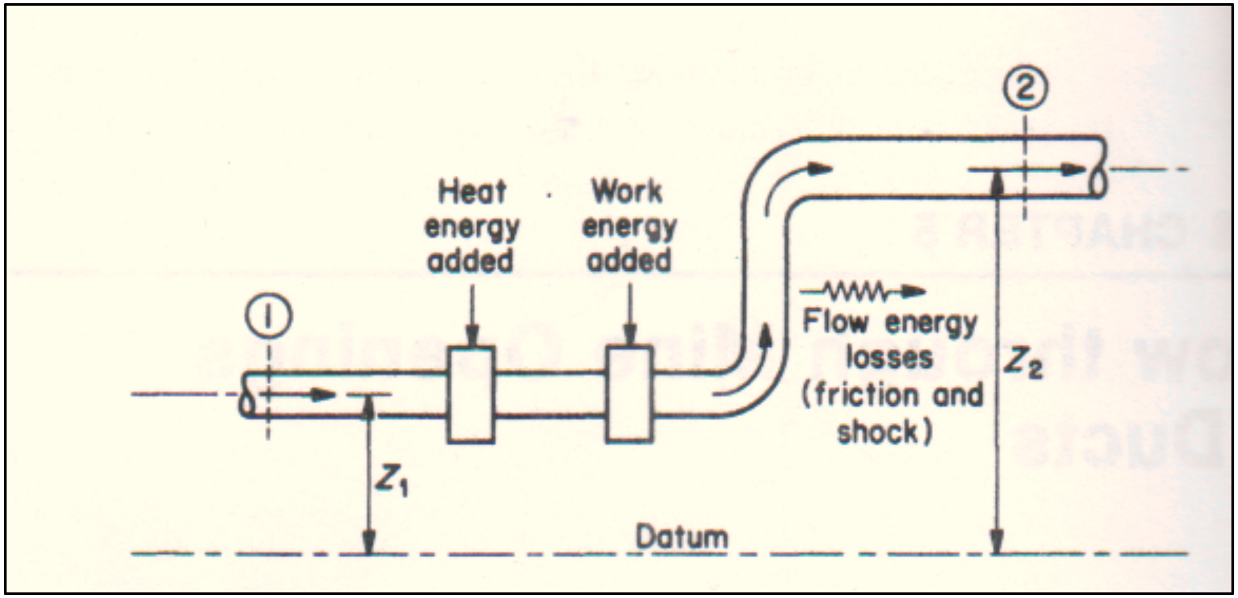
Static pressure — Dinamic pressure (kinetic energy) — Potential energy

This term is called total head or Energy Head (H).

THE BERNOULLI EQUATION

A fluid will move from a point of higher pressure to another of lower pressure

Flow creates resistance which implies a loss of energy by friction and shock



Energy 1 = Energy 2 + Energy loss (flow from point 1 to point 2)

THE BERNOULLI EQUATION

It is more important to determine the pressure difference between two points than the determination of the pressure in them.

The air flow originates because there is a pressure difference between two points of the system.

To overcome this pressure difference it is necessary to add energy to the system.

This energy is consumed in overcoming the energy losses of the system.

$$P_1 + \frac{{u_1}^2 \cdot \rho}{2} + \rho g h_1 + Hp = P_2 + \frac{{u_2}^2 \cdot \rho}{2} + \rho g h_2 + hf$$

Hp: Energy supplied by fan

hf: Energy losses

THE BERNOULLI EQUATION

To simplify in mining ventilating systems:

$$\cancel{P_1} + \cancel{\frac{u_1^2 \cdot \rho}{2}} + \cancel{\rho g h_1} + Hp = \cancel{P_2} + \cancel{\frac{u_2^2 \cdot \rho}{2}} + \cancel{\rho g h_2} + hf$$

Hp = hf

Pressure provided by fan = pressure drop by friction and shock

We assume:

No changes in static pressure.

No changes in density of the air.

Negligible impact of air speed in the air conduct between points 1 and 2.

Minimim changes in piezometric altitude through initial and end points.

THE ATKINSON EQUATION AND THE SQUARE LAW

Based in the Chezy-Darcy relationship (elemental fluid mechanics), the **pressure drop in the mine** is represented by this formula:

$$p = f L \frac{per}{A} \rho \frac{u^2}{2} \qquad \text{Pa}$$

being:

- f: friction factor
- L: Length of the mine
- per: Perimeter of the cross section of the mine
- A: Cross sectional area of the mine
- ρ: Density of the fluid (Air density in mine = 1.2 kg/m3)
- u: Airflow velocity inside the mine

THE ATKINSON EQUATION AND THE SQUARE LAW

- ✓ If the friction factor (f) is supossed constant in the airway and air density does not change, it can be defined a constant factor “k” called the Atkinson factor, with the following expression:

$$k = \frac{f\rho}{2} \qquad \frac{\text{kg}}{\text{m}^3}$$

giving

$$p = kL\frac{per}{A}u^2 \qquad \text{Pa}$$

- ✓ Atkinson equation may be written in terms of airflow, Q = u·A

$$p = kL\frac{per}{A^3}Q^2 \qquad \text{Pa}$$

- ✓ Now for any given airway, the lenght L, perimeter per, cross sectional área A, all are known.

THE ATKINSON EQUATION AND THE SQUARE LAW

- ✓ Ignoring its dependence upon the friction factor “f”, the friction factor varies only with the roughness of the airway. Hence we may collect all of those variables into a single characteristic number, R, for that airway:

$$R = kL\frac{per}{A^3} \qquad \frac{Ns^2}{m^8} \text{ or } \frac{kg}{m^7}$$

giving

$$p = RQ^2 \qquad \text{Pa}$$

- ✓ This simple equation is known as the Square Law of mine ventilation and its the most widely used relationship in subsurface ventilation engineering.
- ✓ R is called the Atkinson´s resistance of the airway
- ✓ The resistance of an airway, R, should ideally vary only with the geometry and roughness of the airway. However, it has been shown that R depends on the density of the air. Hence, any variation in the temperatura and/or pressure of the air in an airway will produce a change in the Atkinson resistance.

THE ATKINSON EQUATION AND THE SQUARE LAW

- ✓ Therefore, a clearer and more rational version of the Square Law can be derived:

$$p = R_t \rho Q^2 \qquad \text{Pa}$$

- ✓ Rt is termed the rational turbulence resistance, dependent only upon geometric factors:

$$R_t = \frac{f L per}{2 A^3} \qquad m^{-4}$$

- ✓ Values of k are usually quoted on the basis of standard density, 1.2 kg/m3. Then it can be written:

$$k_{1.2} = 0.6 f \qquad \frac{kg}{m^3}$$

$$R_{1.2} = 1.2 R_t \qquad \frac{Ns^2}{m^8}$$

DETERMINATION OF THE FRICTION FACTOR

By analogy with similar airways

- During ventilation surveys, measurements of frictional pressure drops, p, and correspongin airflows, Q, are made in a series of selected airways. The corresponding values of friction factor may then be calculated, and referred to standard density:

$$k_{1.2} = \frac{p}{Q^2} \frac{A^3}{L\,per} \frac{1.2}{\rho} \qquad \frac{\text{kg}}{\text{m}^3}$$

- Those values of k may subsequently be employed to predict the resistances of similar planned airways and, if necessary, at different air densities.
- Additionally, where a large number of similar airways exist, representative values of friction factor can be employed to reduce the number or lenghts of airways to be surveyed.

DETERMINATION OF THE FRICTION FACTOR

From design tables

- ✓ Since the 1920s, measurements of the type discussed in the previous subsection have been conducted in a wide variety of mines, countries and airway conditions. The following table has been compiled from a combination of reported tests.
- ✓ It should be mentioned that empirical design data of this type should be used only as a guide and when locally determined friction factors are unavailable.

	Friction factor, *k* kg/m^3	Coefficient of friction, *f* (dimensionless)
Rectangular Airways		
Smooth concrete lined	0.004	0. 0067
Shotcrete	0.0055	0.0092
Unlined with minor irregularities only	0.009	0.015
Girders on masonry or concrete walls	0.0095	0.0158
Unlined, typical conditions no major irregularities	0.012	0.020
Unlined, irregular sides	0.014	0.023
Unlined, rough or irregular conditions	0.016	0.027
Girders on side props	0.019	0.032
Drift with rough sides, stepped floor, handrails	0.04	0.067
Steel Arched Airways		
Smooth concrete all round	0.004	0.0067
Bricked between arches all round	0.006	0.01
Concrete slabs or timber lagging between flanges all round	0.0075	0.0125
Slabs or timber lagging between flanges to spring	0.009	0.015
Lagged behind arches	0.012	0.020
Arches poorly aligned, rough conditions	0.016	0.027

DETERMINATION OF THE FRICTION FACTOR

From design tables

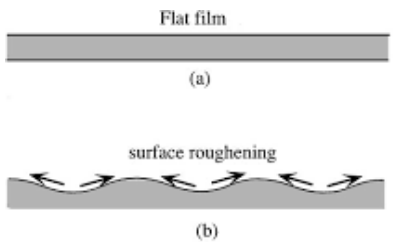
Metal Mines		
Arch-shaped level drifts, rock bolts and mesh	0.010	0.017
Arch-shaped ramps, rock bolts and mesh	0.014	0.023
Rectangular raise, untimbered, rock bolts and mesh	0.013	0.022
Bored raise	0.005	0.008
Beltway	0.014	0.023
TBM drift	0.0045	0.0075
Coal Mines: Rectangular entries, roof-bolted		
Intakes, clean conditions	0.009	0.015
Returns, some irregularities/ sloughing	0.01	0.017
Belt entries	0.005 to 0.011	0.0083 to 0.018
Cribbed entries	0.05 to 0.14	0.08 to 0.23

DETERMINATION OF THE FRICTION FACTOR

From geometric data

- ✓ The coefficient of friction, f, and, hence, the Atkinson friction factor, k, can be expressed as a function of the ratio e/d, where e is the height of the roughenings or asperities and d is the hydraulic diameter of the airway **(d = 4A/per)**.

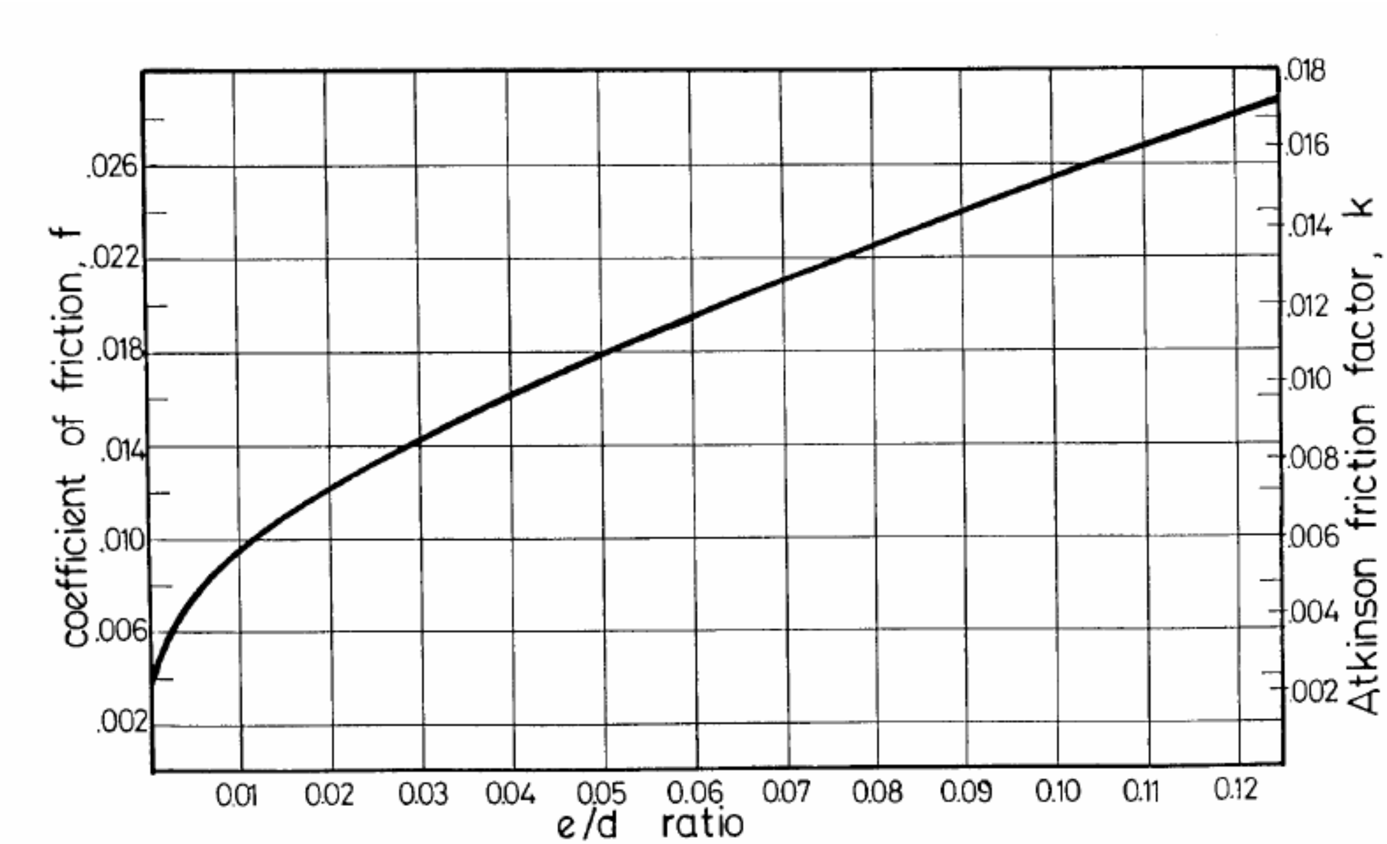
$$f = \frac{k_{1.2}}{0.6} = \frac{1}{4\,[2\log_{10}(d/e)+1.14]^2}$$



- ✓ The direct application of the e/d method is limited to those cases where the height of the asperities can be measured or predicted.

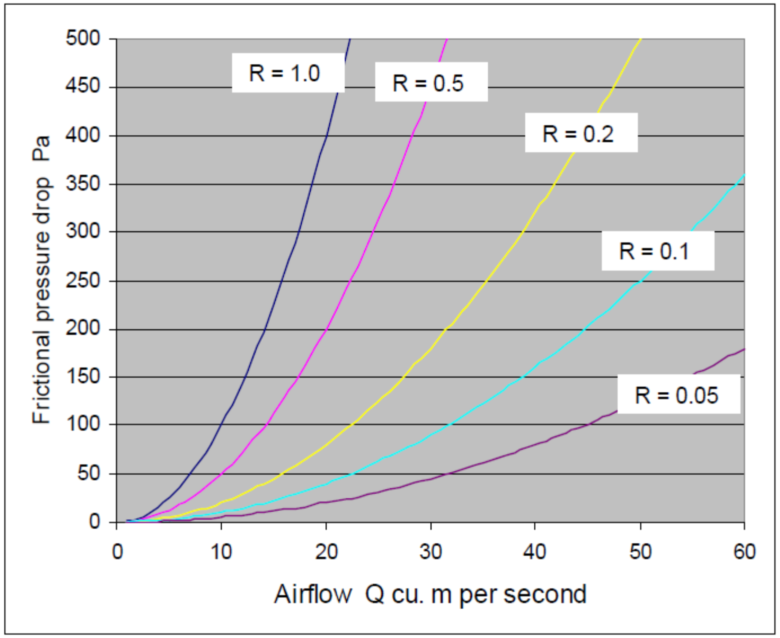
DETERMINATION OF THE FRICTION FACTOR

From geometric data



AIRWAY RESISTANCE

- ✓ The concept of airway resistance is of major importance in subsurface ventilation engineering. The simple form of the square law p = R·Q2 shows the resistance to be a constant of proportionality between frictional pressure drop, p, in a given airway and the square of the airflow, Q, passing through it at a specified value of air density. The parabolic form of the square law on a p, Q plot is known as the airway resistance curve.



AIRWAY RESISTANCE

Shock losses

- ✓ Whenever the airflow is required to change direction, additional vortices will be initiated.
- ✓ The propagation of those large scale eddies consumes mechanical energy (shock losses) and, hence, the resistance of the airway may increase significantly.
- ✓ This occurs at bends, junctions, changes in cross-section, obstructions, regulators and at points of entry or exit from the system.

AIRWAY RESISTANCE

Shock losses

The equivalent length method for shock losses:

- ✓ Suppose that in a subsurface airway of length L, there is a bend or other cause of a shock loss.
- ✓ The resistance of the airway will be greater than if that same airway contained no shock loss. We can express that additional resistance, Rshock, in terms of the length of corresponding straight airway which would have that same value of shock resistance.
- ✓ This "equivalent length" of shock loss, may be incorporated to give an Atkinson resistance of

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

The resistance due to the shock loss is

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

AIRWAY RESISTANCE

Shock losses

The equivalent length method for shock losses:

- ✓ The equivalent lenght has the following expression: (referred to the hydraulic mean diameter):

$$L_{eq} = 0.15 \cdot \frac{X}{k} \cdot d$$

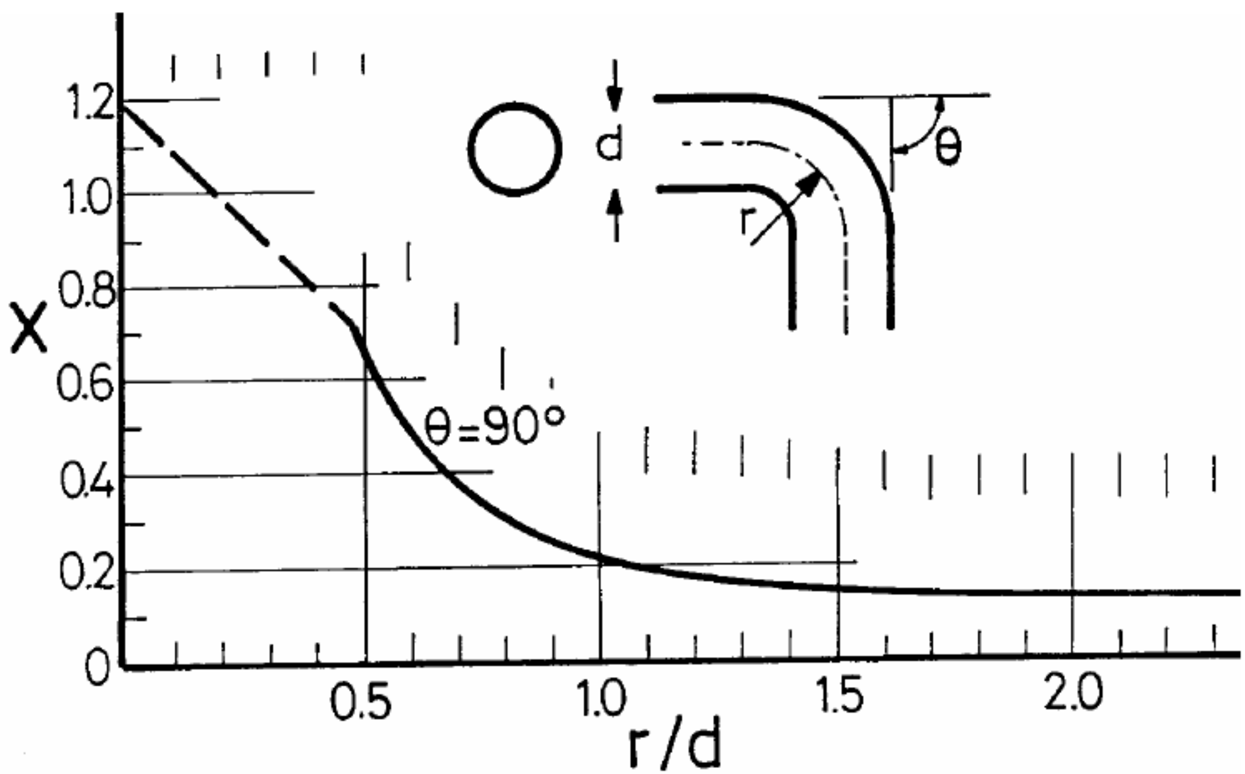
being:

- X: shock loss factor
- k: Atkinson factor

AIRWAY RESISTANCE

<u>Shock losses</u>

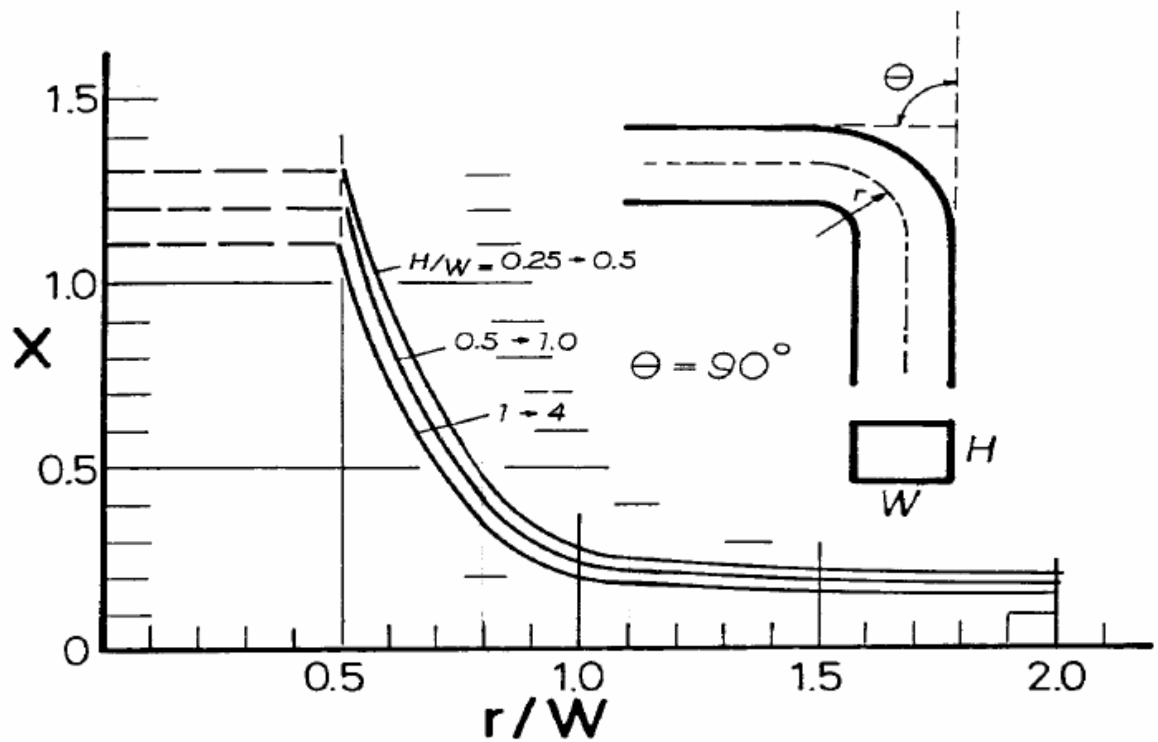
Calculation of shock loss factor. Right angle bend of circular cross section.



AIRWAY RESISTANCE

Shock losses

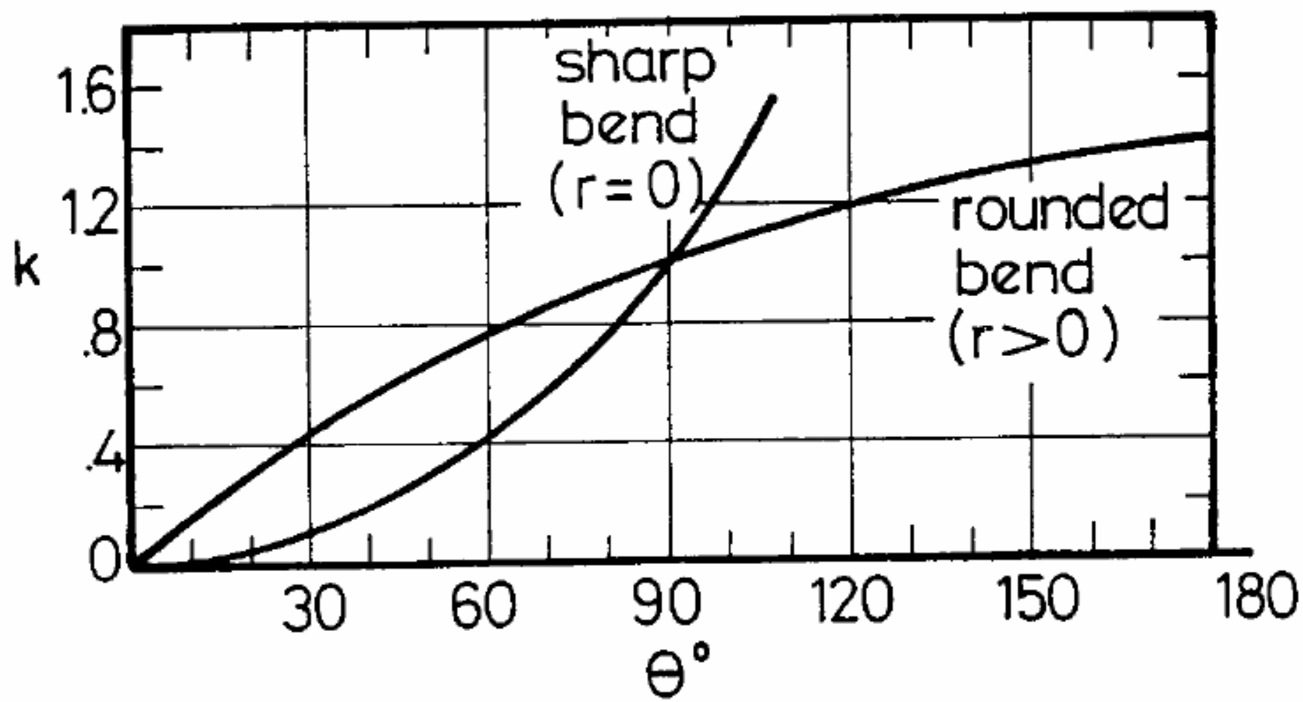
Calculation of shock loss factor. Right angle bend of rectangular cross section.



AIRWAY RESISTANCE

Shock losses

Calculation of shock loss factor. Correction to shock loss factor for bends of angles other than 90°.

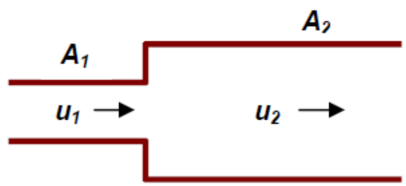


AIRWAY RESISTANCE

Shock losses

Calculation of shock loss factor. Changes in cross section

(a) Sudden enlargement:



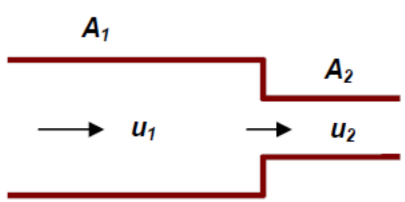
A = Cross sectional area

u = Air velocity

$$X_1 = \left[1 - \frac{A_1}{A_2}\right]^2$$

where X_1 is referred to Section 1.

(b) Sudden contraction:

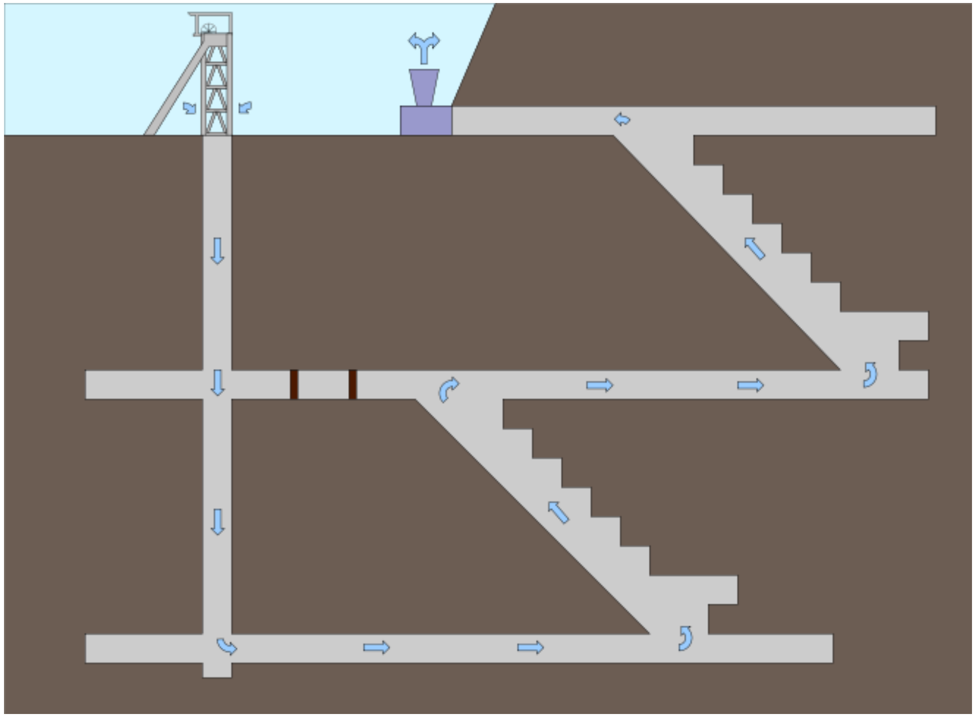


$$X_2 = 0.5\left[1 - \frac{A_2}{A_1}\right]^2$$

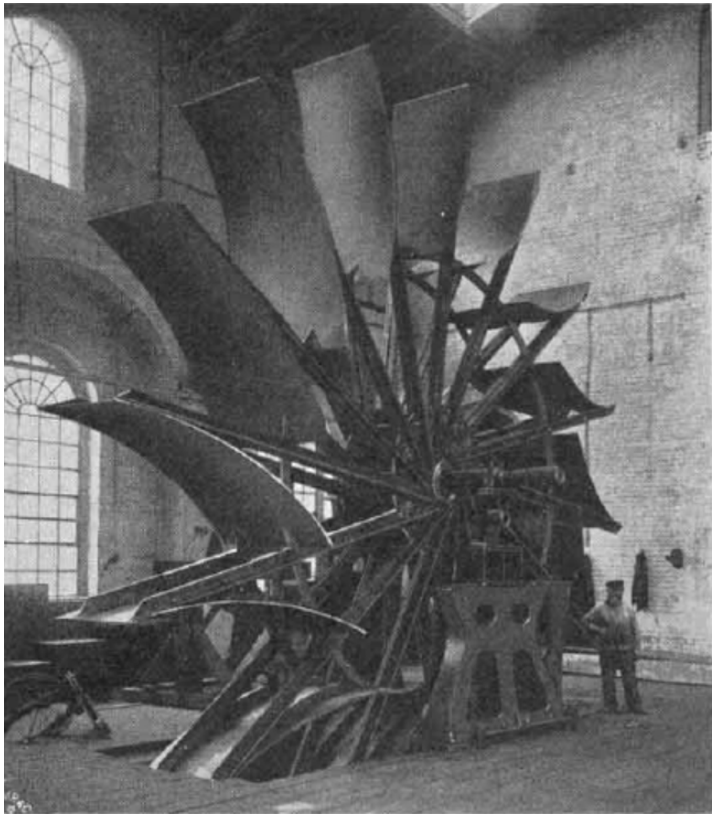
Elements of mine ventilation systems:

- ✓ Interconnected airways and working zones within the mine.
- ✓ Connections to the surface.
- ✓ Fans to produce airflow.
- ✓ Control devices to ensure that the air courses around the mine as required.

http://miningworldgenises.blogspot.com/2015/05/operating-multiple-fans.html



Schematic of underground mine ventilation



The mine ventilation fan, before 1908

Source: wikipedia

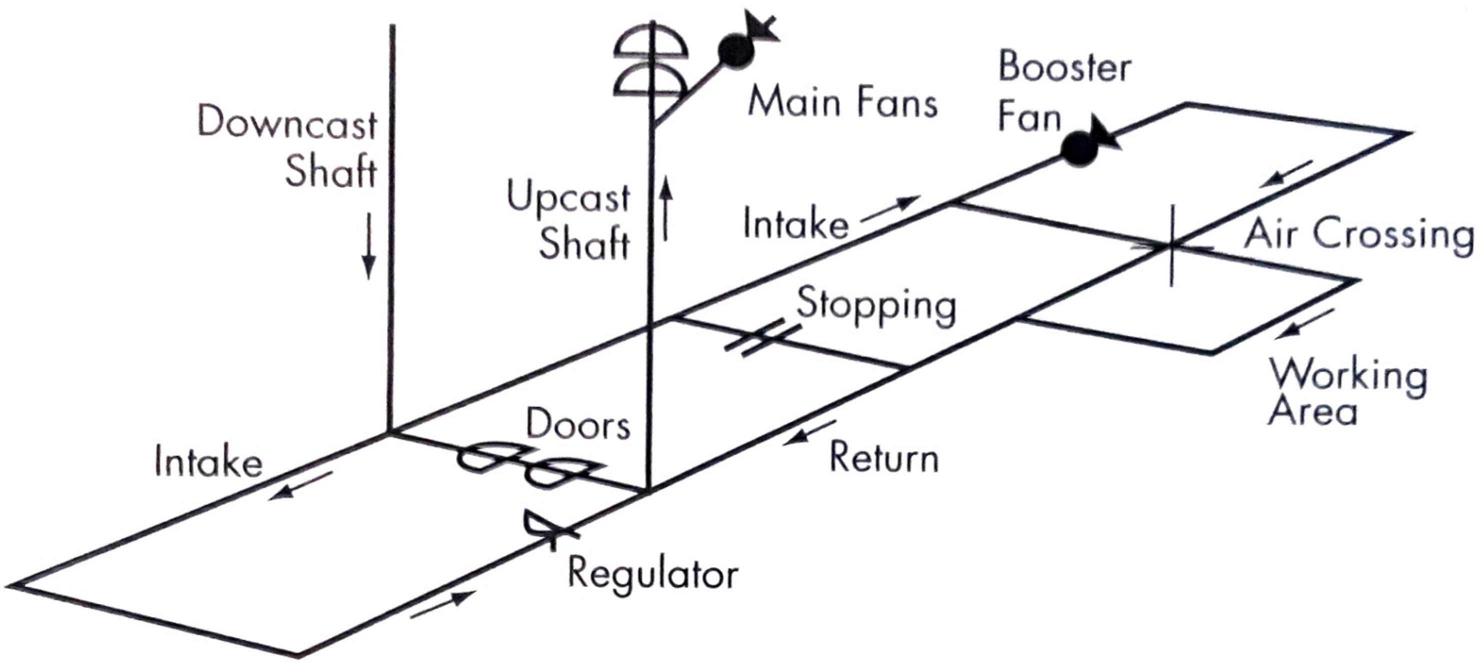
Ventilation systems:

Every underground mine is unique in terms of its geometry, layout, size, geology and pollutants

→ Pattern of airflows and pressure drops through the airways are highly variable

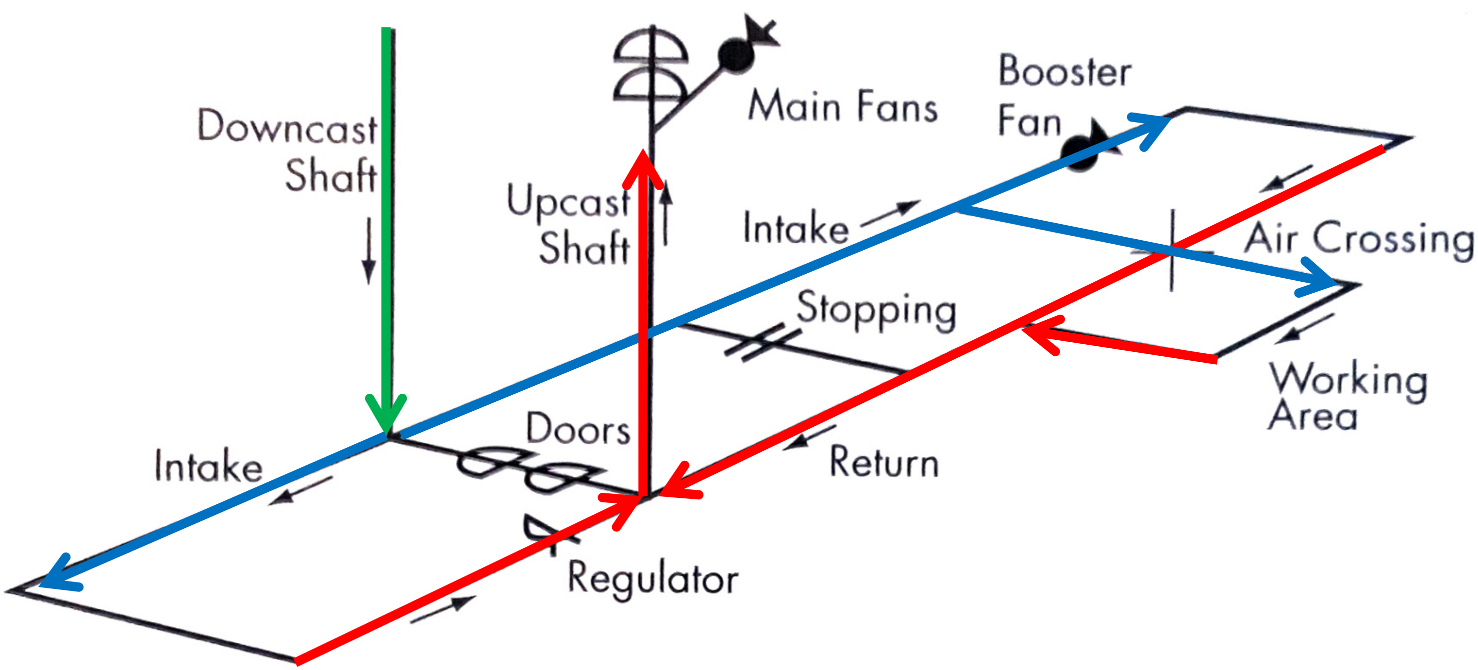
Certain features of ventilation systems are common

→ Main characteristics and elements of ventilation systems and infrastructure



Basic ventilation layout:

- ✓ **Fresh air** enters...
- ✓ **Air flows** along intake airways...
- ✓ **Contaminated air** returns back through return airways...
- ✓ **Return air** passes back to the surface...



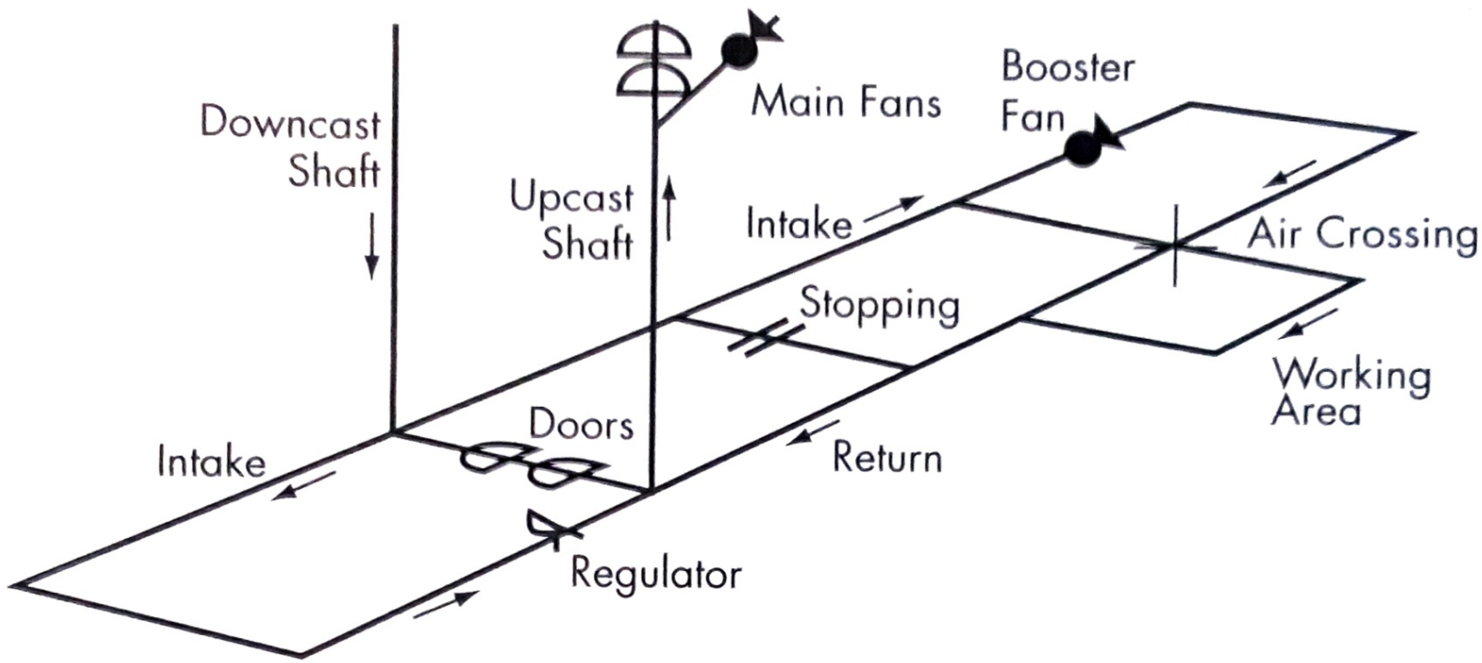
Control devices:

Airflow control devices are required to get the air to the areas where it is needed

✓ **Active devices** → add energy to air (main fans and booster fans)

✓ **Passive devices** → add resistance to flow routes (doors, regulators, air crossings and stoppings)

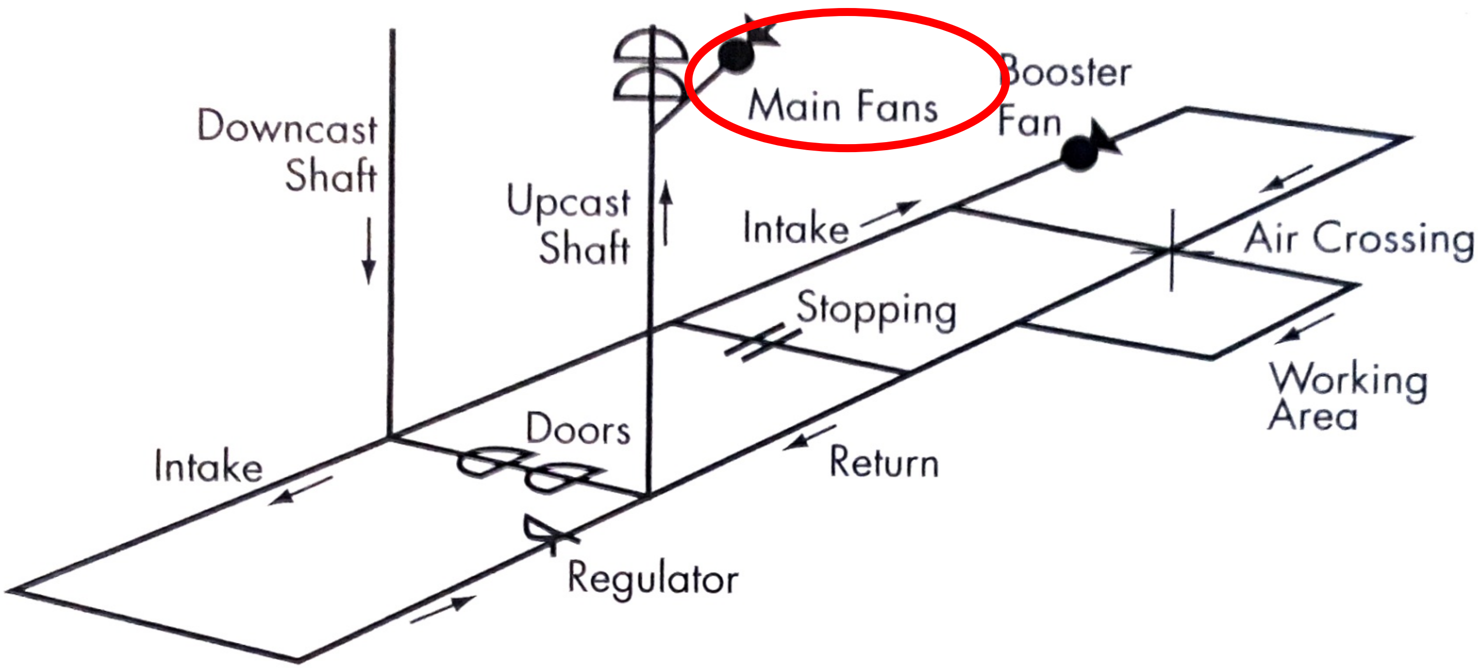
✓ **Auxiliary devices** → supply air to blind entries (brattices and duct systems)



Active devices → add energy to air (main fans and booster fans)

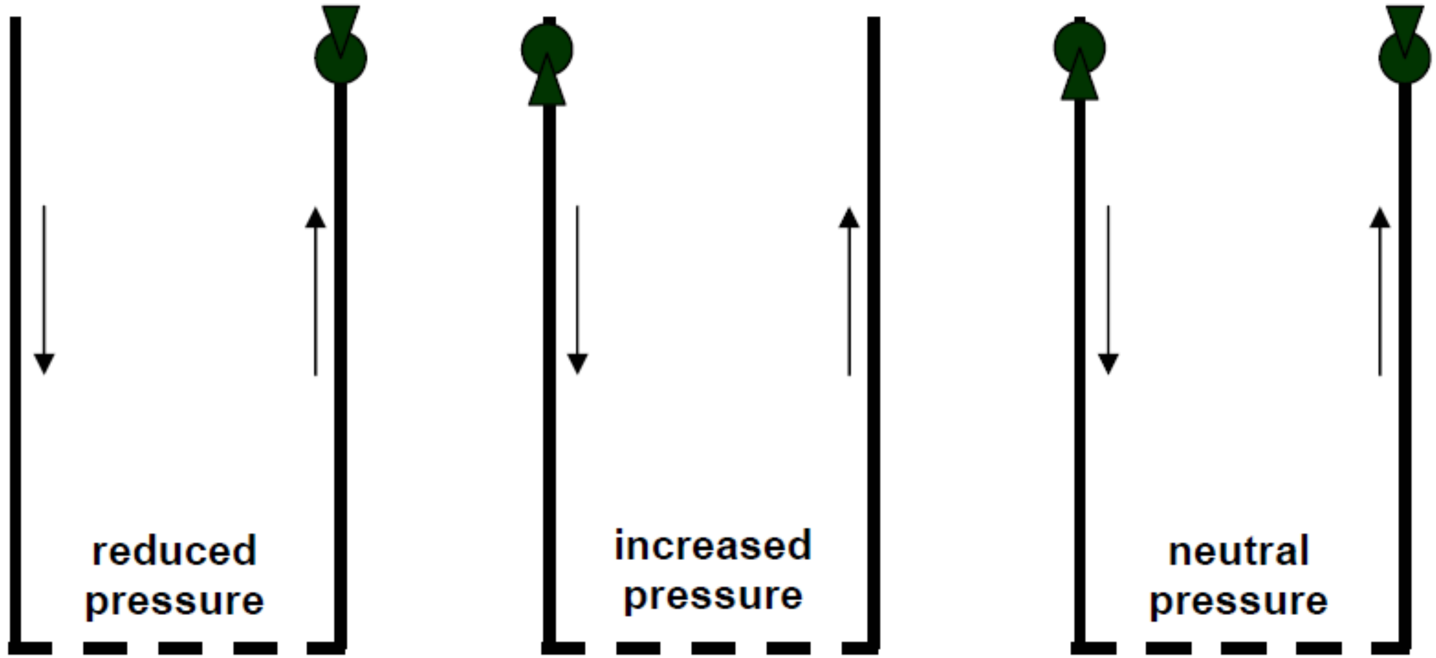
MAIN FANS:

- Are the primary means of producing and controlling the ventilation airflow
- Handle all the air passed through the mine
- Usually located at the surface



Main fan systems can be (possible location):

- Exhausting
- Forcing, or
- Push-pull (a combination of the two)



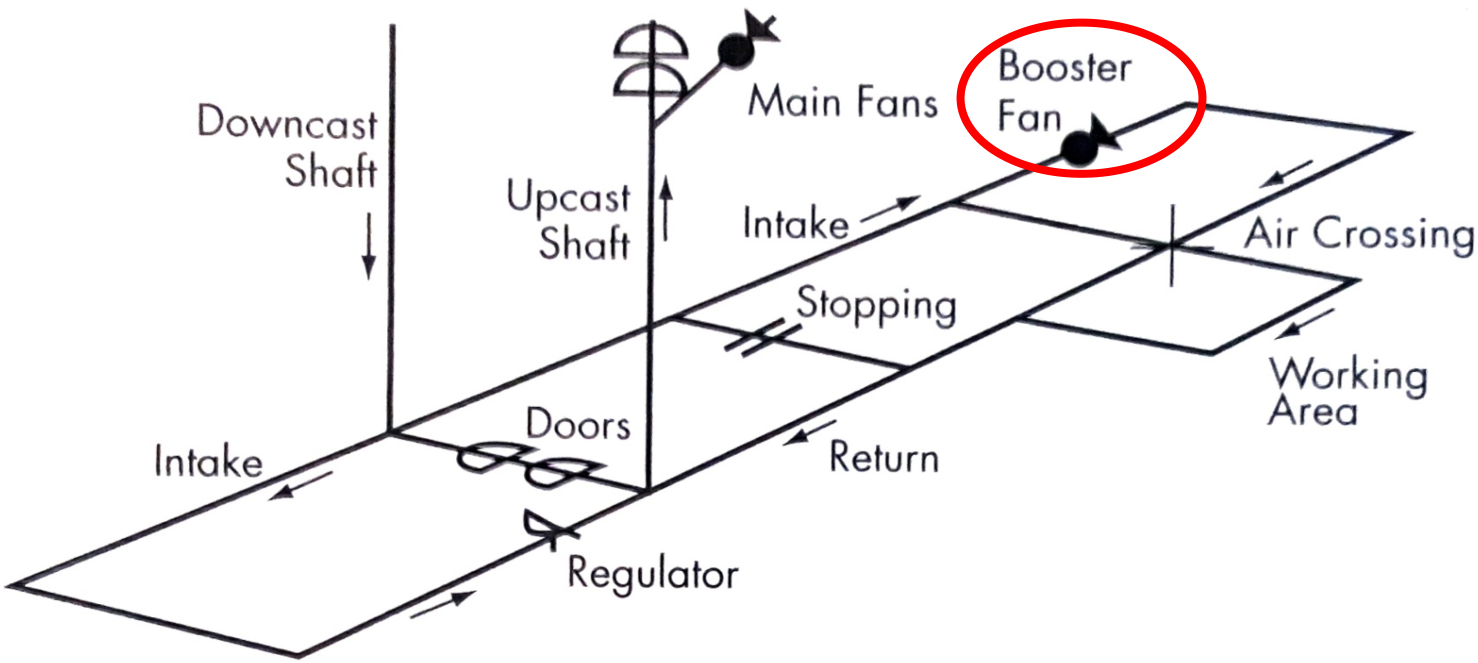
(a) Exhausting system (b) Forcing system (c) Push-pull system

- ✓ Fans generate energy and airflow by converting rotational mechanical energy into hydraulic energy
- ✓ Most commonly types of fans used in mine ventilation:
- ✓ Centrifugal fans and axial fans

Active devices → add energy to air (main fans and booster fans)

BOOSTER FANS:

- Boost the energy of the airflow
- Used to deliver air to the extremities of the mine (remote mining sections)



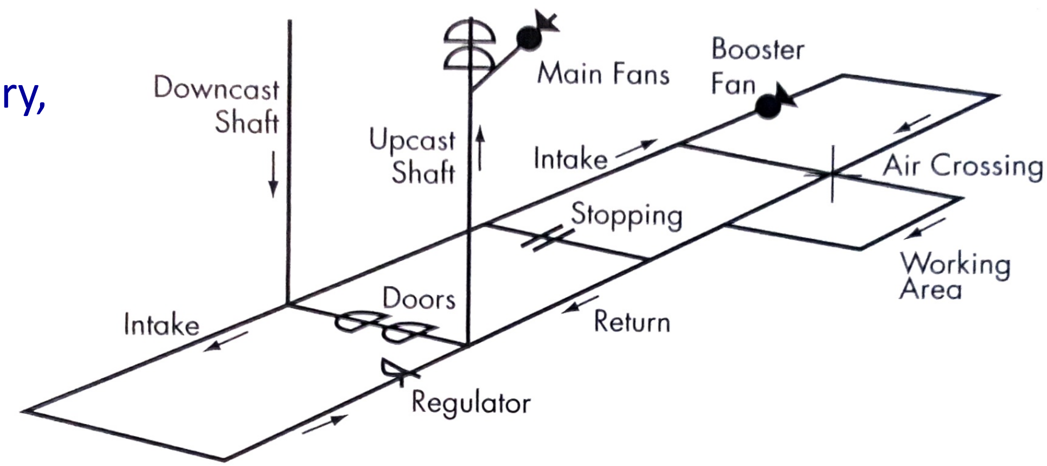
Passive devices → add resistance to flow routes (doors, regulators, air crossings and stoppings)

DOORS: employed to avoid short-circuiting of ventilation flow between intake and return. Sets of two or more doors with a chamber in between are called *airlocks*.

REGULATORS: air door fitted with an adjustable orifice, aimed at reducing the airflow in a particular section downstream.

AIR CROSSINGS: intersection between intake and return airways. The roof of one or the floor of the other is excavated to expand the zone of intersection. A concrete/metal/wood structure is assembled separating the two airways.

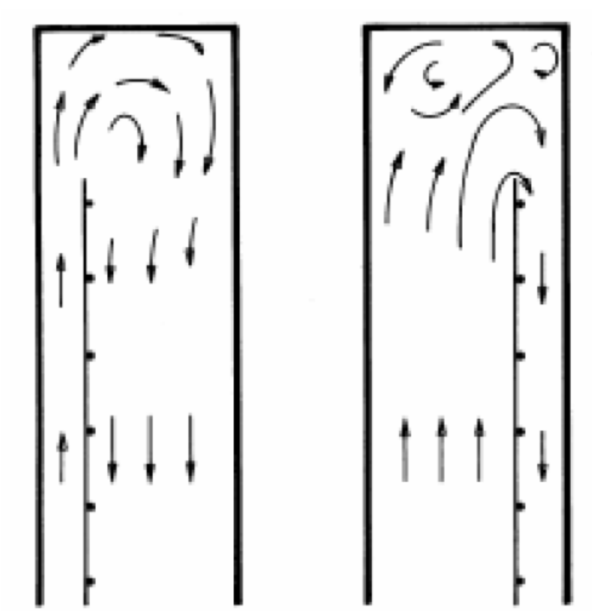
STOPPINGS: permanent blockage of an airway which is no longer required for access. Can be constructed from masonry, concrete blocks of fireproof timber. Backfilling is also used.



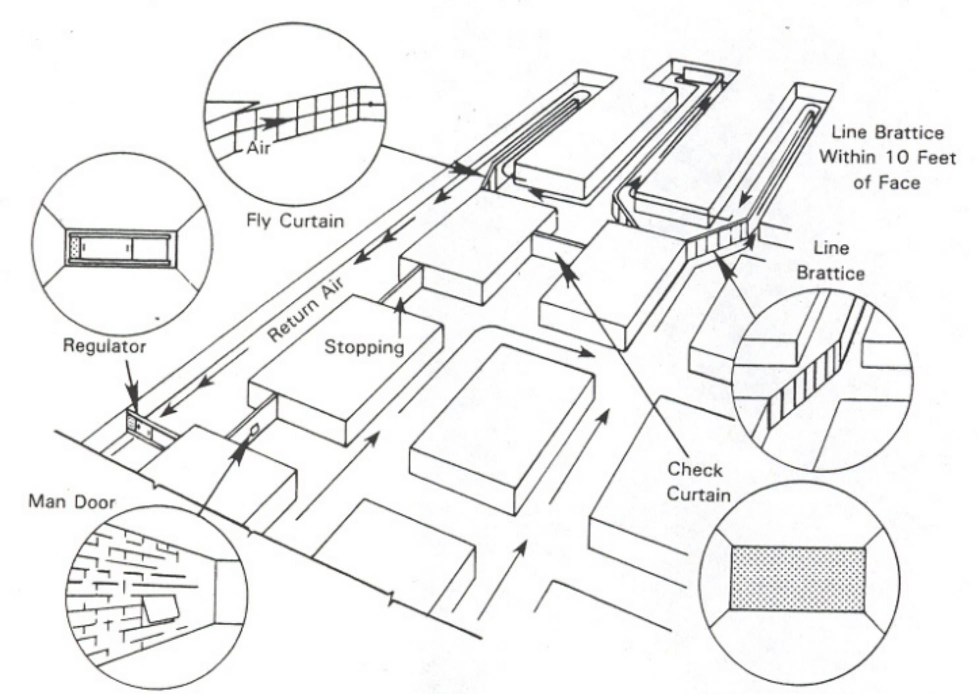
Auxiliary devices → supply air to blind entries (brattices and duct systems)

LINE BRATTICES:

Line brattice is a brattice cloth or plastic that is hung from floor to ceiling to channel air into a working area that otherwise wouldn't have adequate ventilation. It creates and artificial intake or return in dead-end headings.



Line brattices used in the forcing (left) and exhausting (right) modes

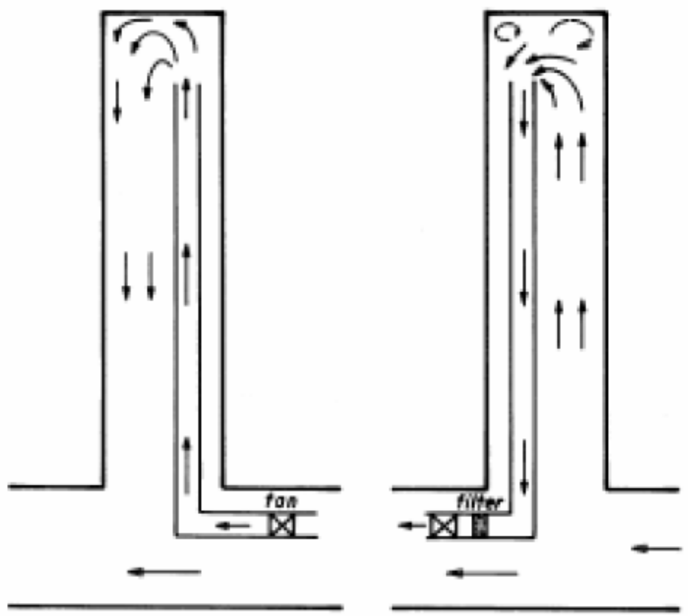


Example of line brattices application

Auxiliary devices → supply air to blind entries (brattices and duct systems)

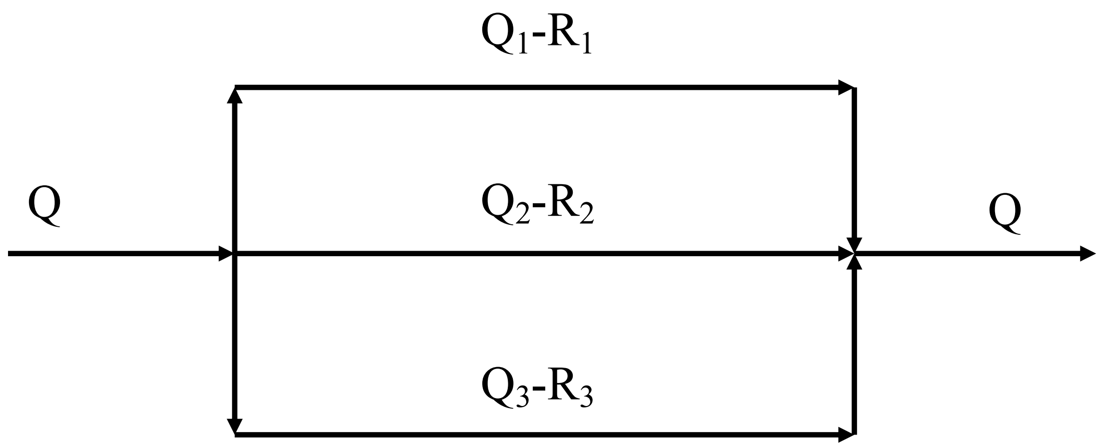
FAN AND DUCT SYSTEMS:

Consist of a duct (or several ducts connected together to form a ventilation network) and a fan (or fans) to provide the air movement in dead-end headings.



Fan and duct systems used in the forcing (left) and exhausting (right) modes

Example of duct system application



$$Q = Q_1 + Q_2 + Q_3$$

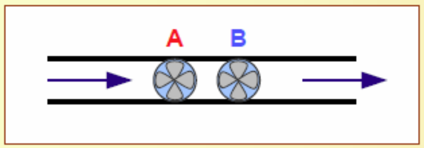
$$\Delta P = \Delta P_1 = \Delta P_2 = \Delta P_3$$

$$\Delta P = RQ^2 = R_1 Q_1^2 = R_2 Q_2^2 = R_3 Q_3^2$$

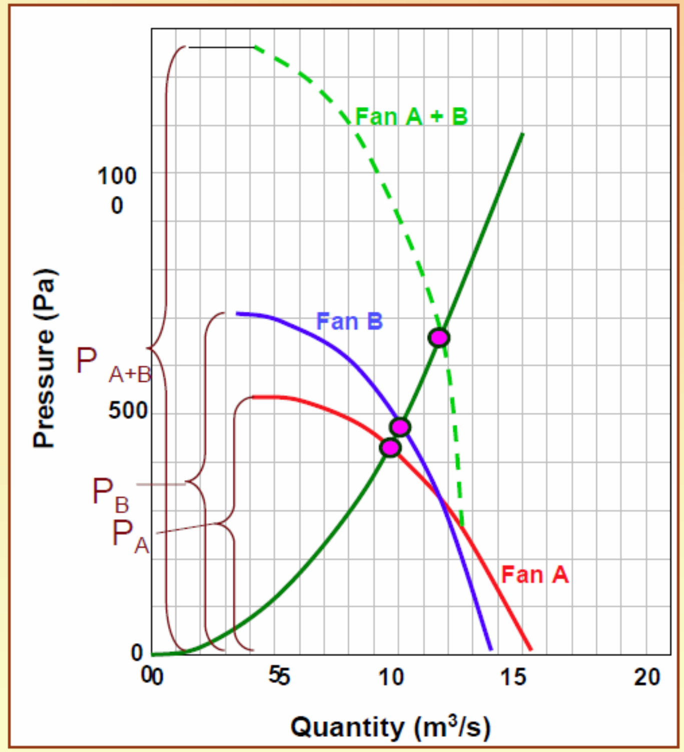
$$\sqrt{\frac{\Delta P}{R}} = \sqrt{\frac{\Delta P}{R_1}} + \sqrt{\frac{\Delta P}{R_2}} + \sqrt{\frac{\Delta P}{R_3}}$$

$$\sqrt{\frac{1}{R}} = \sqrt{\frac{1}{R_1}} + \sqrt{\frac{1}{R_2}} + \sqrt{\frac{1}{R_3}} = \sum \sqrt{\frac{1}{R_i}}$$

$$Q_i = Q \sqrt{\frac{R}{R_i}}$$

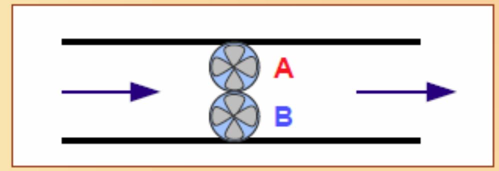


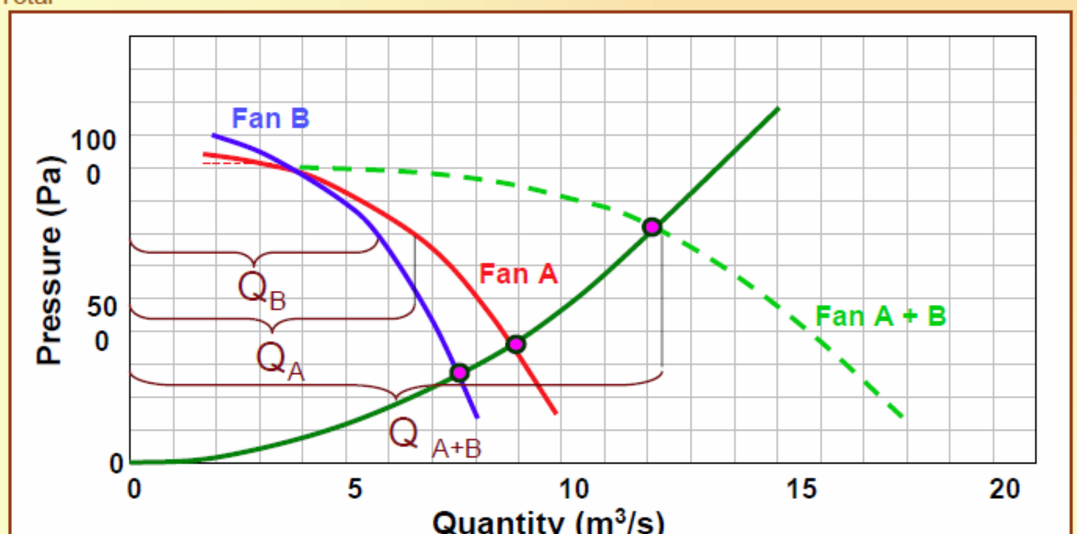
- Operate in the same system and handle the same air
- Fans may be bolted together or spaced along the duct
- Pressure increases for the same volume
- $P_{Total} = P1 + P2$



http://miningworldgenises.blogspot.com/2015/05/operating-multiple-fans.html

- Fans installed alongside each other and operate on the same system
- Volume increases for the same pressure
- $Q_{Total} = Q1 + Q2$





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