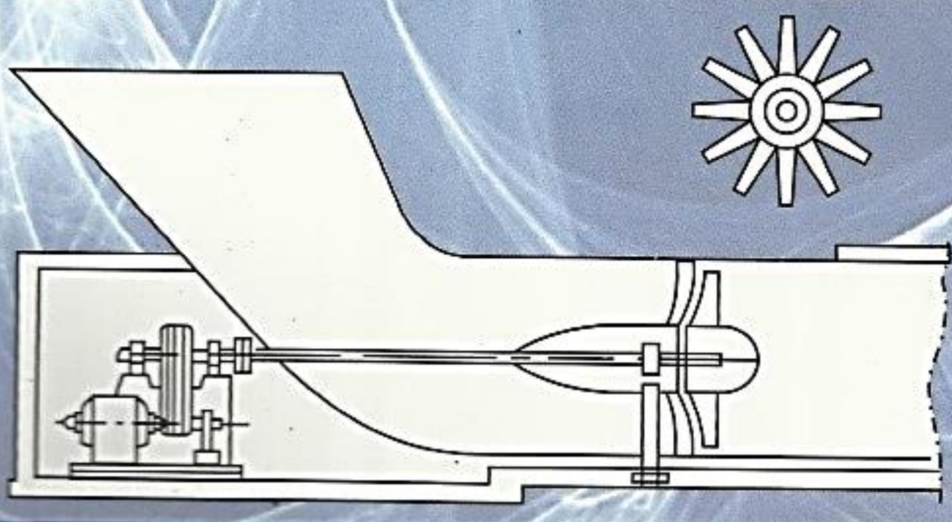
2nd Edition

MINE VENTILATION



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PREFACE

Mining Development Cell as a part of the Inspectorate of Mines & Minerals Department, Punjab was established in 1993. Its main function besides other was to develop curricula and books in subjects of mining for the students of Punjab School of Mine Katas and Mines Survey Institute Makerwal. It was felt that books already available on mining subjects are mainly for degree courses and were beyond the reach of most of the students firstly because they were too costly and secondly their contents were beyond the syllabus of diploma/certificate level courses.

The first edition of "Mine Ventilation" was written in June 2001 for the students of Punjab School of Mines, Katas District Chakwal and Mine Survey Institute Makerwal, District Mianwali. It needed many correction & improvement. Mining Development Cell put all its effort to bring the new addition without any mistake, tried to improved contents and text on the topics.

The Director Mining Development Cell, Engr. Muhammad Tehzib Hassan Ansari is thankful to Engr. Muhammad Khalid Pervaiz, Ex-Chief Inspector of Mines, Punjab, Engr. Abdul Sattar Mian, Chief inspector of Mines, Punjab and his colleagues Engr. Hafiz Hamid Iqbal and Engr. Rana Nasrullah Khan. Assistant Directors for extending full co-operation guidance and assistance to revised this book. The book has been prepared in consultation of various mining books e.g. Universal Mining School Courses, Elements of Mining by lewis and Clarke, Mining Engineers hand Book by Robert Peele and A manual on mines Rescue, Safety & Gas Detection to make it a model guide book for Diploma Level studies.

Mining Development Cell is grateful to Dr. Muhammad Yaqoob of Mining Engineering Department university of Engineering & Technology Lahore, for his valuable assistance in reviewing and editing this book.

Mining Development Cell would be grateful for any comments and suggestions.

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CHAPTER 01

ATMOSPHERE

1.1. The Atmosphere

It is an envelope of mixture of various gases extending upto a height of about 200 kilometers above sea level, surrounding solid plus liquid (water bodies) earth. The density of the atmosphere is 1.2 kg/m^3 at sea level; 8 x 10^{-7} kg/m^3 at 100km; and 1 x 10^{-10} kg/m^3 at 200 km. Ninety percent of its mass is contained in the lowest 30 km.

Composition of the Atmospheric Air

The atmosphere in which we breathe is not a single gas but a mechanical mixture of several gases. The composition of dry air at sea level by volume is as under:-

Name of Gas	Percentage By Volume
Oxygen	20.95
Nitrogen	78.09
Carbon Dioxide	0.03
Argon and Inert gases	0.93
Total	**100.00**

For practical purposes, we can say that pure dry air contains of 79% of nitrogen and 21% of oxygen. The inert gases and nitrogen are almost identical in their properties and carbon dioxide may be neglected altogether. Specific gravity of pure dry air is 1.00.

1.1.1 Maintenance of Natural Balance of Oxygen

very living creature including human beings needs oxygen as the life line. The nature has provided oxygen in the atmosphere to maintain life on earth. Human beings inhale oxygen and exhale carbon dioxide whereas plants on the other hand inhale carbon dioxide and exhale oxygen. This way oxygen cycle is naturally balanced for living and working on the earth.

Those, working underground face oxygen deficiency as it is consumed by lamps, men, machinery and chemical reactions. It is, therefore, necessary that fresh air should be adequately circulated in all underground mines where persons are working. This will ensure supply of fresh air or oxygen to make working conditions comfortable and will result in maximum human efficiency. The circulating air will dilute harmful gases and dusts. Constant circulation of fresh air is like blood circulating in our bodies which keeps us alive.

1.2 Factors Polluting the Mine Atmosphere:

Aspects of Atmospheric Air Pollution

There are two main aspects of air pollution; quality, and temperature and humidity of air.

a) Quality of air: It is the purity of air. Mine gases and dusts pollute the air quality.

b) Temperature and Humidity of air: It is the temperature and/or humidity increases above or decreases below the respective working comfortable specified limits. These are caused by heat transfer to or from the air, and similarly evaporation of water into or condensation of moisture from the air. There are various sources of heat transfer to the air in mines; e. g. compression of air in shafts and nearly vertical openings, geothermal gradient raises the temperature of the strata with depth, ground water, machinery, lights, human metabolism, blasting, rock movement, energy losses in airflow, oxidation of coal, etc. Humidity is increased by groundwater evaporation.

Mine gases and dusts are discussed next.

1.3 Mine Air

This differs from ordinary atmospheric air chiefly in containing a smaller percentage of oxygen, a larger percentage of carbon dioxide, and varying quantities of other gaseous compounds.

Mine Gases

Gases found in mines are:-

1. Oxygen
2. Nitrogen
3. Carbon dioxide
4. Firedamp
5. Blackdamp
6. White damp
7. Stink damp
8. Afterdamp
9. Oxides of Nitrogen
10. Sulphur Dioxide
11. Hydrogen

We shall discuss each gas as per sub-headings given below:-

a. Their Properties
b. Detection
c. Permissible Limits
d. Physiological Effects

1) OXYGEN

a) Properties

Oxygen is a colourless, odourless and tasteless gas. Specific gravity is 1.11 as compared to air as 1.00. It is present everywhere in the atmosphere and is used for breathing of men and animals. It supports life and combustion. Its percentage in the mine air is lowered by the addition of other gases. It may be condensed to liquid at –182 degrees Celsius at atmospheric pressure.

b) Detection

It is generally not necessary to detect the presence of oxygen. It is the lack of oxygen, which leads to dangerous conditions.

c) Depletion/Permissible limit

The effect of depletion of oxygen can be summarized as follows; -

20.93%	:	All kinds of lamps burn freely;
19%	:	Oil Safety lamps give about one–half their normal illumination;
17%	:	Oil lamps are extinguished;
16%	:	Candles are extinguished;
12.5%	:	Carbide lamps are extinguished;
2%	:	All combustion ceases, including smoldering.

Oxygen deficiency, if in a serious degree, is very dangerous. Since a man may not be aware of the deficiency owing to his mind becoming confused and his senses dulled.

Oxygen should not be less than 19% in any case in any mine.

d) Physiological Effects

Percentage	Effects
20.9	No effect. Normal atmospheric condition.
17.00	Faster, deep breathing.
15.00	Dizziness, buzzing in ears, rapid heartbeat.
12.50	Lung ventilation considerably increased on exertion.
10.00	Nausea and headache gradually develop. Lips turn blue.
8.00	Breathing becomes very rapid. Palpitations and mental confusion occur.
7.00	Unconsciousness occurs rapidly and death usually follows.

Uses: Administered either pure or as a component of other gas in all cases of respiration difficulties.

2. NITROGEN

a) Properties

Nitrogen is a colourless, odourless, and tasteless gas. It is slightly soluble in water and is little lighter than air having specific gravity of 0.97. It is the most abundant element which exist as a gas in nature. It forms 78.11% by volume of atmospheric air. It is non-poisonous but does not support life and is also non-inflammable and incombustible in air.

b) Detection

There is no available method to detect and measure Nitrogen.

c) Permissible Limit

No definite permissible limits are fixed except 78.11 percent which is present in the normal air.

d) Physiological Effects

At normal pressure it has no physiological effect on men or animals, provided sufficient oxygen is present. It acts as a diluent of the oxygen in the atmosphere. Under pressure (as in marine diving) it can dissolve in the blood and lead to a condition known as the bends. Nitrogen narcosis is also a risk at high pressures.

Uses

1. In mining its major use is for firefighting purposes.
2. Compounds of nitrogen are much used in the manufacture of explosives.
3. Commercially it may be used as a refrigerant, a propellant gas and to provide inert shielding in welding.

3). CARBON DIOXIDE

a) Properties

Although this gas is present in negligible quantities in pure air (0.03%), it is a product of oxidation, combustion and the important process of respiration (breathing). It is present in all mines to a greater or lesser degree. It is colourless, odourless but has acidic taste. It has specific gravity of 1.52 that is heavier than air. It is very soluble in water under ordinary pressure and temperature.

b) Detection

Since it is heavier than air, it is found in lower parts of the mine openings, i.e., near floors. Its presence increases the rate of breathing.

c) Permissible Limit

Although the normal air contains 0.03% Carbon dioxide the permissible limit up to which work persons can be allowed to work in the mine is 0.5%.

d) Physiological Effects

Percentage	Effects
0.03	None: This amount is present in normal air.
0.50	Lung ventilation is increased by 5 %.
2.00	Lung ventilation increased by 50 %.
3.00	Lung ventilation is increased by 100 %.
5.00	Lung ventilation is increased by 300%.
5.00-10.00	Violent headache, man feels very much tired.
10.00-15.00	Intolerable headache, collapse.

Uses: It is used in fire extinguishers and to inertise mine atmospheres.

4). FIRE DAMP

The chief inflammable constituent of firedamp is methane (CH_4).

It is the most common and inflammable gas which is present in mines. It has been the root cause of many mine explosions with the loss of countless lives.

Where the term "gas" is used by miners it is generally firedamp that they refer to.

It has no colour, taste or smell when pure. Often however, it is found mixed with other flammable gases which change the mixture to a sweet pleasant smell.

The gas does not support life. It is not itself poisonous. In fact it has a slight anaesthetic effect. It is slightly soluble in water.

Occurrence

Firedamp is a compound of carbon and hydrogen. It is thought to have been produced from the decay of vegetation at the same time when coal seams were being laid down.

Firedamp is usually present in small or large quantities in almost all coal mines. It is also found in some metalliferous mines and in natural gas fields.

It is generally given off from coal seams in three ways.

a) Gradual exudation – bleeding from the coal itself.

b) Blowers–continuous discharge of gas for a period from a definite point of issue.

c) Outbursts – Sudden discharge of gas.

a) Properties

i) It has no colour, taste but has smell by which firedamp can be recognized
ii) It is lighter than air, having a specific gravity of 0.553. It is, therefore, found in rise workings or in cavities near the roof.
iii) It is slightly soluble in water.
iv) It is called a hydrocarbon and belongs to a class of hydrocarbons known as paraffin series. Other members of this series are ethane (C_2H_6), Propane (C_3H_8), Butane (C_4H_{10}), Pentane (C_5H_{12})
v) It is a combustible gas. When suitably ignited, it burns in air with a pale blue flame.
vi) When mixed with air in certain proportion, the resultant firedamp air mixture is inflammable. The explosibility ranges from 5 % to 15 % while highly explosive mixture is one containing about 10 % methane.

b) Detection

A variety of approved instruments are available to detect and measure methane concentrations in the mines. These include:-

i) The oil flame safety lamp.
ii) Methano meters.
iii) Automatic firedamp detectors.
iv) Interferometers.
v) Infrared Analysers.
vi) Digital Detectors.

c) Permissible Limit

i) Mixtures of firedamp in air within the range, 0 to 4 percent are not explosive. The approximate percentage can be determined by a safety lamp.
ii) Mixtures within the range 5 to15 % are inflammable. The most explosive mixture is at 10 % and the most easily ignited mixture is at 7.5 %. Mixtures above 15% are not explosive. They do not support combustion but will burn if mixed with air.
iii) Percentage of CH_4 in mine air should be kept less than 1%.

d) Physiological Properties

As long as there is sufficient Oxygen in the atmosphere, it is not poisonous. But if a large percentage of methane is present, an equivalent percentage of air with its contained Oxygen is displaced, and a person breathing in such a mixture would suffer from the deficiency of Oxygen. Thus if there be 25 % of Methane (CH_4) in the atmosphere, the remaining 75 % would be air and one-fifth i.e. 15 % would be oxygen. Such an atmosphere would be dangerous from the point of view of respiration. But if there be 60% Methane (CH_4), there would be only 40 % of air containing about 8% of Oxygen and this atmosphere would be extremely dangerous.

5) BLACK DAMP

This is sometimes called chokedamp or stythe and is defined as mechanical mixture of carbon dioxide and nitrogen in excess of usual percentages of these gases found in pure atmospheric air. Analysis of large number of samples indicates an average composition of about 11% to 13% of Carbon dioxide and 87% to 89% of Nitrogen.

a) Properties

Because of its variable composition it is impossible to fix specific gravity. Blackdamp containing 5% of carbon dioxide has the same density as air. If less than 5% of Carbon dioxide is present in the blackdamp, the mixture is lighter than air whilst if more than 5% of Carbon dioxide is present, the mixture is heavier than air.

b) Detection

The presence of blackdamp makes itself evident by its effect on the flame of an oil safety lamp, the light being dimmed to an extent which depends on the percentage of Oxygen deficiency.

For every 5% of blackdamp present results 1% reduction in the percentage of oxygen, the luminosity is decreased by about 30%. The light is extinguished altogether when the oxygen is reduced to 17.00 or 17.5% which corresponds to about 15% blackdamp.

c) Occurrence

It is always mixed with air quite frequently, with firedamp and occasionally with carbon monoxide.

d) Physiological Effects

Its action on human body is primarily due to deficiency of oxygen and also carbon dioxide poisoning.

It may be noted that if the composition of blackdamp is 12% CO_2, 88% N_2 , then;

- i) 25% blackdamp (75% air; 15% oxygen, 3% CO_2) Rate of breathing becomes doubled.
- ii) 50% blackdamp (50% air;10% oxygen, 6% CO_2) Violent headache, distress, face turning blue
- iii) 60% blackdamp (40% air, 8% Oxygen, 7% CO_2) Imminent danger of collapse and death due to lack of oxygen.

It will be seen from the foregoing that heavier blackdamp in the air increases the percentage of Carbon dioxide. A victim, thus, has plenty of time to retreat safely before it is too late.
On breathing fresh air again, a victim of blackdamp usually recovers fairly rapidly and no lasting ill effects normally occur.

Example

Calculate the percentage composition of blackdamp in an air sample containing.

O_2	19.54 %
CO_2	0.70 %
CH_4	1.62 %
N_2	78.14 %

Find the percentages of Nitrogen and Carbon dioxide.

Solution

Normal air contains.

O_2	20.93%
N2	78.11%
CO_2	0.03%
Argon & Inert Gases	0.93%

In normal air, the ratio of nitrogen to oxygen = 78.11/20.93 = 3.732

And the ratio of carbon dioxide to oxygen = $\frac{0.03}{20.93} = \frac{1.0}{698}$

In the given sample, the fresh air equivalent of the oxygen present has the following composition.

Oxygen	19.54 %
Nitrogen	19.54 x 3.732 = 72.92%
Carbon dioxide	19.54 x 1/698 = 0.03%
Total air	19.54 + 72.92 + 0.03 = 92.49%
Hence the excess Nitrogen	78.14 – 72.92 = 5.22%
And excess Carbon dioxide	0.70 – 0.03 = 0.67%
Total blackdamp	5.22 + 0.67 = 5.89%

Thus sample contains 92.49% of ordinary air, 1.62% of CH_4 and 5.89% blackdamp making a total of 100%.

The percentage composition of blackdamp is: -

Nitrogen (N_2) =	5.22/5.89 x 100 = 88.6%
Carbon dioxide (CO_2)	0.67/5.89 x 100 = 11.37%
Total =	88.6 + 11.4 = 100 %

6). WHITE DAMP

The chief sources of white damp or carbon monoxide in mines are:-

i) Oxidation of coal.
ii) Use of explosives.
iii) Spontaneous combustion of coal.
iv) Explosions of firedamp or coal dust.
v) Air compressors.
vi) Diesel locomotives.

a) Oxidation of Coal

It produces small percentages of carbon monoxide which contaminate the return air of nearly all deep mines exceeding about 500 meters deep. This is quite a normal condition and does not imply the existence of self heating. The percentage present is usually less than 0.001 % and is quite harmless.

b) Explosives

Combustion is seldom perfect in explosives while blasting them and CO is liable to be present in the blasting fumes. Men should not be allowed to return to the place until the ventilation has cleared the fumes.

c) Spontaneous Combustion

This gives rise to dangerous percentages of CO, great care is necessary in the neighborhood of a heating or in the return air from a gob fire or when sealing off a mine or a part of it.

d) Explosions of Firedamp and Coal Dust

They also produce dangerous percentages of Carbon monoxide in the resulting afterdamp. Many valuable lives have been lost so far. It has been noticed that the victims who have escaped the violence of explosion usually die due to inhalation of this gas.

e) Air Compressors

They also produce dangerous quantities of CO owing to the slow combustion of carbonaceous deposits. Carbon monoxide is circulated through the transmission system, possibly with fatal results. The remedies include.

a) Use a high-grade lubricant having a flash-point of not less than 260 ^{o}C
b) Filter the inlet air to exclude coal dust;
c) Clean out the cylinders and air passages periodically;
d) Stop the compressor at once if any abnormality in running is noticed.

f) Diesel Locomotives

These produce little CO (less than 0.02% in the exhaust). Danger from this gas may arise if the engine is not properly worked and efficiently maintained or if the locomotive is running where adequate ventilating current is not flowing. The general air in a road must normally contain less than 0.005% of CO and the use of locomotives must be dis-continued if the percentage of CO exceeds 0.01%. Further points of interest relating to carbon monoxide include;

a) Carbon monoxide forms from 5% to 1`5% of ordinary coal gas. It is supplied through pipes for domestic lighting and heating.

b) When steam is passed over red-hot coke the hydrogen and oxygen in the steam are set free and the oxygen combines with the carbon in the coke. The result of mixture of hydrogen and carbon monoxide is known as water gas.

a) Properties

This is also carbonic oxide and is produced whenever carbon is burnt with an insufficient supply of oxygen.

It is a colourless and odorless gas with a metallic taste. Its specific gravity is 0.967 (i.e. lighter than air). It does not support combustion but itself is a combustible gas.

b) Detection of Carbon Monoxide

i) In mine the normal method of testing for CO is by means of a small warm blooded creature such as canary, linnet or mouse. These creatures are much more quickly affected by CO than man and thus give warning symptoms before a man is in danger. A bird is preferred to a mouse because it is more sensitive and gives a clearer indication of distress.

ii) Digital carbon monoxide monitor can record carbon monoxide from 1 PPM to 1000 PPM.

iii) Multi-gas tubes are used to detect carbon monoxide, methane and deficiency of oxygen.

c) Permissible Limits

The effects corresponding to different percentages of white damp or carbon monoxide and the time required for them to take place cannot be stated with exactness but are approximately as follows according to the most recent determinations. Maximum permissible limit for carbon monoxide is 0.005% or 50 PPM.

Explosive Effects of Carbon Monoxide

% of CO	Maximum Saturation	Time required		Result
		At rest	Working	
0.02	20%	4 hour	2 hours	Slight headache
0.04	33%	2 hours	45 mins	Headache nausea and possible collapse.
0.12	60%	3 hours	1 hour	Collapse.
0.20	65%	1 hour	10 mins	Death possible.
0.30	70%	45 mins	5 mins	Death possible.
1.00	75 to 80%	30 mins	1 min	Death certain.

It will be seen that anything over 0.02% may cause discomfort and distress; 0.12% rapidly causes dangerous symptoms with possibly fatal consequences if exposure is prolonged; anything over 0.2% is extremely dangerous; whilst 1% of CO may be regarded as very "high percentage in which death may very quickly ensue.

d) Physiological Effects of Carbon Monoxide

White damp is a deadly poisonous gas because its chemical affinity for the haemoglobin of the blood is about 300 times as strong as that of oxygen. Normally, oxygen combines with haemoglobin to form an unstable compound called oxyhaemoglobin. This passes to the tissues where the oxygen is abstracted for use in vital processes. If the smallest quantity of CO enters the lungs, the oxygen is out–paced and the CO immediately combines the haemoglobin to form a more stable compound called carboxyhaemoglobin. If this continues breath after breath, the blood is no longer capable of taking up the life giving oxygen and the blood becomes more or less "saturated" with carbon monoxide. Ultimately death may occur for want of oxygen. However if death does not occur, the lung cells are liable to be permanently damaged.

Guiding Principles when using Birds to Test for Carbon Monoxide

i) Use two or more birds, if possible, because they vary in their sensitivity.

ii) Use fresh birds for each determination because, like men, they may develop a tolerance for small percentages of CO and exhibit no signs.

iii) Withdraw to the fresh-air base when a bird shows the first sign of distress or the bird may be lost.

iv) Birds do not test for deficiency of oxygen as they can live in a lower percentage of oxygen than is required by a man.

v) Do not take birds into an atmosphere known to be irrespirable because of carbon monoxide.

Calculation of Degree of Saturation of Carbon Monoxide

As a guide the following formula may be applied.

$$b = \frac{4\,a\,t\,e}{100}$$

Where

b = Blood saturation by carboxyhaemgolobin as a percentage.
a = Concentration of carbon monoxide in air in parts per million.
t = Time of exposure in hours
e = Factor to allow for nature of activity taken as

1 = At rest
2 = Walking
3 = Moderate work

Example:- A man walks for fifteen minutes in a carbon monoxide level of 400 parts per million. What blood saturation will eventuate?

Solution:- We use the formula

$$b = \frac{4\,a\,t\,e}{100}$$

Where

a = 400 Parts per million

t = 15 Minutes = 0.25 hours

e = 2 (as the man walking)

$$b = \frac{4 \times 400 \times 0.25 \times 2}{100} = \mathbf{8\%}$$

7) STINK DAMP

a) Properties

It is also known as hydrogen sulphide, sulpharetted hydrogen or rotten egg gas. It has no colour but a powerful and unpleasant odour resembling that of rotten eggs. It has a specific gravity of 1.19 and burns in air with a bright blue flame producing sulphur dioxide and water vapour.

Occurrence

It is produced by the decomposition of animal or vegetable matter containing sulphur. It is also produced when gob fires occur in mines, in seams containing high sulphur coal. It is also a component of afterdamp of coal dust explosions. Small amounts may also be evolved from stagnant water containing rotten vegetation.

b) Detection

It has rotten egg like smell. Tube Detectors detect the percentage of hydrogen sulphide. White blotting paper saturated with lead acetate is turned black in the presence of this gas. Silver coins are also discoloured by the presence of hydrogen sulphide.

c) Permissible Limits

It forms flammable mixture in air in the range of 4.5 to 45 per cent. Permissible limit is 0.001%.

d) Physiological Effects:

Hydrogen sulphide is an extremely toxic gas, it irritates the lungs and respiratory tract but in particular it has a narcotic effect on the nervous system.

Percentage	Effects
0.0005	The gas is not poisonous. Does not cause any discomfort.
0.01	Irritation to the eyes and respiratory tract.
0.02	Within 10 minutes intense irritation of the eyes and throat.
0.05	It is the highest percentage that can be breathed without causing death. This amount causes palpitation, muscular weakness, fainting and cold sweats within half an hour.
0.06	Serious symptoms within a few minutes. Pains in the chest.
0.07	Highly dangerous to human life. Depression, unconsciousness and death.
0.10	Very dangerous, death occurs almost immediately due to asphyxiation.

8) AFTERDAMP

This is a mixture of gases of greatly variable composition found in a mine after an explosion of methane or coal dust. Afterdamp is composed of nitrogen, a little oxygen, carbon dioxide, carbon monoxide and water vapour, the products of combustion and in some cases methane and hydrogen from the distillation of coal.

The water vapour usually renders the afterdamp very humid and in general, the atmosphere is irrespirable due to the lack of oxygen and often toxic due to the carbon monoxide. Carbon monoxide is perhaps the most important constituent and usually renders the afterdamp lethal to breathe.

9) OXIDES OF NITROGEN

The oxides of nitrogen include nitric oxide (NO), nitrogen tetra oxide (N_2O_4), and nitrogen dioxide (NO_2). Nitric oxide converts to nitrogen dioxide in air so the properties of the oxides of nitrogen may be related to those of nitrogen dioxide.

Occurrence

The oxides of nitrogen or nitrous fumes are produced as a component of diesel exhausts, or by explosives of the nitroglycerine type especially when they are incompletely detonated.

a) Properties

Nitrogen dioxide has reddish brown colour, an acrid smell and an acid taste. It has a specific gravity of 1.6. It is very soluble in water and forms nitric acid and nitrous acid. Although incombustible and non-flammable it will support combustion.

c) Permissible Limits

It is 5 parts per million (0.0005 per cent). The recommended First Aid treatment is oxygen administration, complete rest, keep the body warm and then provide medical aid.

d) Physiological Effect

Nitrogen dioxide is extremely poisonous. In the early stage, a man will feel ill and cough violently.

Percentage	Effects
0.004	Can be detected by smell and tolerated for several hours.
0.01	Causes coughing, will seriously irritate the respiratory passages.
0.015	Produces great discomfort if breathed for a few hours.
0.02	Can cause dangerous illness if breathed for a few minutes.

10) SULPHER DIOXIDE

a) Properties

Sulphur Dioxide has no colour but possess a pungent, suffocating, sulphurous odour and almost intolerable acidic taste. It has a specific gravity of 2.26 and is soluble in water forming sulphurous acid.

It is incombustible and also non-flammable.

Occurrence

It is generally found in mines when a heating or fire occurs in coal containing sulphur or occasionally when rubber is burnt and in diesel exhausts.

b) Detection

It can be identified and determined with detector tubes. Its typical odour can be detected by smell at 3 parts per million.

c) Permissible Limits

It is 5 parts per million (0.0005 per cent). The recommended First Aid treatment is oxygen administration, complete rest, keep the body warm and then provide medical treatment.

d) Physiological Effects

Sulphur dioxide is extremely poisonous but owing to irritating effect on the eyes and respiratory passages, it is intolerable to breathe for any length of time in dangerous concentrations. The physiological effects corresponding to percentage concentrations are given below:-

Percentage	Physiological Effect
0.0003 — 0.001	Detectable by taste (acidic)
0.003	Least quantity detectable by its odour
0.01	Very uncomfortable to breathe with an irritating effect on the eyes and respiratory passages
0.05	Dangerous to life for short exposures

11) HYDROGEN

a) Properties

Hydrogen is a colourless, odourles sand tasteless gas. It has specific gravity of 0.07. It is non-poisonous but does not support life. It is a combustible gas and will burn with a bluish flame in air or oxygen forming water vapour.

b) Detection

There is no available method for detecting and measuring hydrogen underground in the presence of other flammable gases. Detector tubes are not approved for use because of their high heat of reaction and poor accuracy.

c) Permissible Limit (Flammability)

Hydrogen forms flammable mixture with air in the range of 4-74 per cent hydrogen. It is considered to be the most dangerous of all flammable gases because of its large flammable range, the almost complete absence of lag of ignition, the immediate attaining maximum pressure, the low energy of ignition (about half that of methane) and its relatively low ignition temperature (580-590 Celsius degrees).

Occurrence

Hydrogen is present in the normal atmosphere in trace amounts only. In a mine, it may be found in the atmosphere during or after a fire but does not appear in the combustion until a temperature of 250 Celsius degrees is reached. After a methane or coal dust explosion, hydrogen is present in similar quantities as carbon monoxide. Two-thirds of the gas evolved during battery charging is hydrogen. It is also a constituent of water gas.

1.4 Mine Dusts

In each category, dusts are listed in the order of decreasing harm.

1. Fibro genic dusts (harmful to respiratory system).

i. Silica (quartz, chert)
ii. Silicates (asbestos, talc, mica etc).
iii. Metal fumes (nearly all)
iv. Beryllium ore
v. Tin Ore.
vi. Iron Ores.
vii. Carborundum
viii. Coal (anthracite, bituminous)

2. Carcinogenic Dusts.

a) Radon Daughters.
b) Asbestos
c) Arsenic

3. Toxic dusts (poisonous to body organs, tissue, etc)

a) Ores of beryllium, arsenic lead etc.

4. Radioactive dusts (injurious because of α and β radiation)

a) Ores of uranium, radium, thorium

5. Explosive Dusts

a) Metallic dusts (magnesium, aluminium, zinc)
b) Coal (bituminous lignite).
c) Sulfide Ores.
d) Organic Dusts.

6. Nuisance dusts (little adverse effect on humans)

a) Gypsum, Kaolin, Limestone.

7. Inert Dusts (no harmful effect in lung)

a) none

CHAPTER 02

DETECTION OF MINE GASES

Several instruments are used for detection of mine gases, we will discuss only the following which are commonly employed for this purpose:-

i. Oil Safety Lamp.
ii. The Drager Universal Gas Detector

2.1 Oil Safety Lamp

The main purpose of the flame safety lamp is to detect:-

i. Methane.
ii. Oxygen Deficiency.

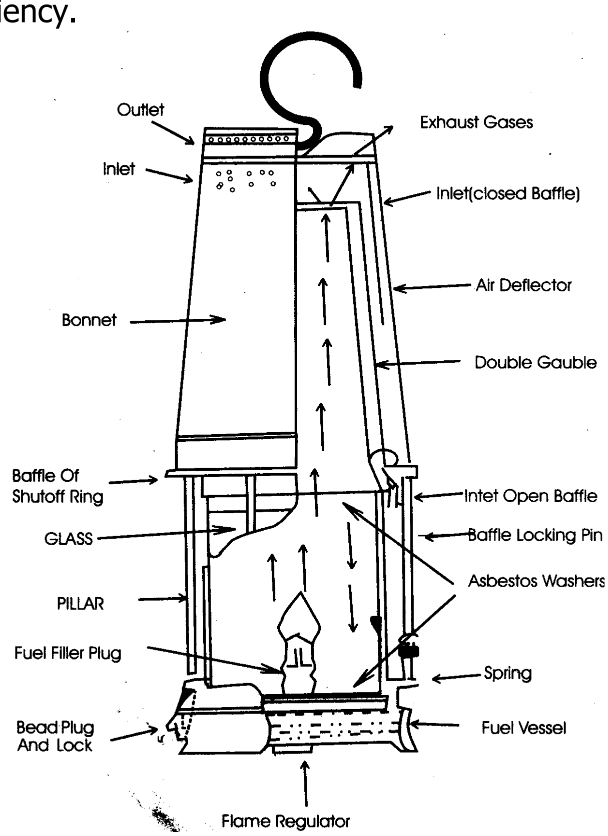


Fig 2.1. Oil Flame Safety Lamp

2.1.1 The Principle of the Flame Safety Lamp

As a gas detector, the lamp is rapidly becoming obsolete in most of the mining countries of the world and is being replaced by electronic detectors with a high order of accuracy, reliability and electrical safety.

The flame safety lamp will always remain a potentially dangerous appliance when used in gassy mines. The safety of the lamp in a flammable firedamp/air mixture depends on the wire gauze and this still remains the essential safety feature in modern lamps. The purpose of the gauze is to prevent the passage of flame from the interior to the exterior of the lamp so that, even if gas be ignited within the gauze, no external ignition will occur. This holds good as long as the gauze itself does not become white hot or flame is not forced through the apertures by high air velocities. A single unprotected gauze (as in the Old Davy Lamp) was ineffective in preventing the passage of flame under the above condition. Modern lamps, with their double gauzes and protective outer bonnet, successfully resist the passage of flame in all conditions likely to be met with underground.

The gauze prevents the passage of flame by splitting it up into a large number of small tongues which are rapidly cooled by conduction as they try to pass through the gauze apertures. The gauze itself is cooled by radiation and the uprising current of air. If the gauze becomes coated with soot, its power of dissipating heat will be diminished.

The gauzes recommended for use in safety lamps are of steel or charcoal annealed iron wire and of 28 mesh. The 28 mesh gauze has 28 meshes to the linear inch (784 to the square inch), and is made of wire 0.0148 inch diameter (28 standard wire gauge).

2.1.2 The Use of the Oil Flame Safety Lamp

As a gas detector the lamp has two major uses:-

2.1.2.1 Detection of Oxygen Deficiency

The normal carrying flame of a lamp is 2 centimeters high, for oxygen detection this height is reduced to 1 centimeter. A reduction in oxygen concentration of 1 percent will cause an approximate reduction in flame height and luminosity of 30 percent until at 16-17 percent oxygen the flame will extinguish.

When entering any place suspected of having blackdamp, bottom gas, or being unventilated, the lamp should be held at head height and then gradually lowered to floor level carefully watching the flame.

It is important that lamp is only a rough indicator of oxygen deficiency. Any estimation of oxygen content depends entirely on the memory of operator as to the flame height and luminosity in fresh air. Furthermore the presence of methane will alter the reaction of the flame to oxygen content. It is important to note the common assumption, that if an oil flame safety lamp is alight there is sufficient oxygen for breathing, is not always correct.

2.1.2.2 Detection of Methane

The safety lamp provides the readiest and simplest means for the detection of firedamp in the air and for estimating the percentage present.

The first essential is to examine the lamp and make sure that it is properly assembled and safe in all respects. The observer should also be familiar with the appearance of the flame when burning in pure air.

There are two ways of examining for gas with a safety lamp namely (1) The Accumulation Test, using a nearly normal wick flame, and (2) The Percentage Test, using the lowered testing flame.

Any type of flame safety lamp can be used for gas testing, but one of the most favoured types is a Marsaut lamp with round wick burning a light petroleum spirit (naphtha). The lamp may additionally be fitted with an internal relighting device, and it may also be adjustable by the user to admit air at the top of the lamp only. The latter arrangement is specially desirable to enable the observer to test for gas near the roof.

2.1.2.2.1 The Accumulation Test

The purpose of this test is to detect the presence of an accumulation of gas (but not the exact percentage) in any such places as a hole in the roof; the edge of the goaf; the face of a rise heading; any blind end, or unventilated place. In such places only the presence of accumulation of gas should be detected, because percentage may increase rapidly. Therefore, it is used less to ascertain the percentage of gas.

To carry out the accumulation test, the observer should raise the lamp cautiously, with a flame of normal size, or only slightly reduced, and note the behaviour of the flame. If the flame becomes elongated, it may be taken that 3% (or more) of gas is present and the lamp must be immediately withdrawn, steadily and without jerking. No attempt should be made to raise the lamp any higher than is necessary to detect the presence of an accumulation of firedamp. The only result would be to place the lamp in a still richer gas mixture, with the result that the light would be extinguished although the firedamp may continue to burn inside the gauzes.

If however, the accumulation test shows that no accumulation of gas exists, i.e. if the lamp flame behaves in a normal way, then the more sensitive percentage test may be safety applied.

2.1.2.2.2 The Percentage Test

The purpose of this more sensitive test is to ascertain, within the limits of about 1% to 5% of gas, if any, is mixed with the air, either in the general body of air, or in places where a previous accumulation test has shown that no accumulation of gas exists.

The percentage test is obviously the one to apply in all ventilated places—in the main and branch airways, haulage and travelling roads, longwall faces and other working places—where men have to work or pass and where the quality of the ventilation must reach a certain specified standard. It must also be applied before shot firing.

Testing for gas by this method depends on the fact that, if the lamp flame is lowered in an atmosphere containing up to about 5% of firedamp so that glaring white light disappears, a pale blue gas cap can be seen above the flame. The height, shape and general appearance of this 'cap' form, to an experienced observer, a fair index of the percentage of gas present. Actually, these small percentages also form a gas cap above the normal full wick flame, but the cap is so nearly non-luminous that it is obscured by the greater brilliance of the wick flame, just as a match flame is dimmed or obscured by bright sun light.

When the percentage of gas exceeds 5% there is enough gas to cause the flame to spread throughout the gas and air mixture inside the lamp. In other words, at this percentage, the atmosphere is just bordering on the lower limit of inflammability i.e. it will propagate a flame away from and independently of the source of ignition. Above this percentage, a minor explosion takes place within the lamp and the wick flame is extinguished, although the firedamp may continue to burn. Below this percentage, combustion of the gas takes place only at the wick flame where sufficient heat is generated to cause the firedamp to burn.

The methane gas cap produced is slightly lighter in colour than a fuel cap.

The height of the cap for given percentages varies somewhat with:-

i. Type of lamp.
ii. Shape and width of wick.
iii. The oil burned.

The ability to detect and read accurately gas caps varies from individual to individual, and each person who uses a lamp should first have practice in reading caps in a gas test station with known concentrations of methane.

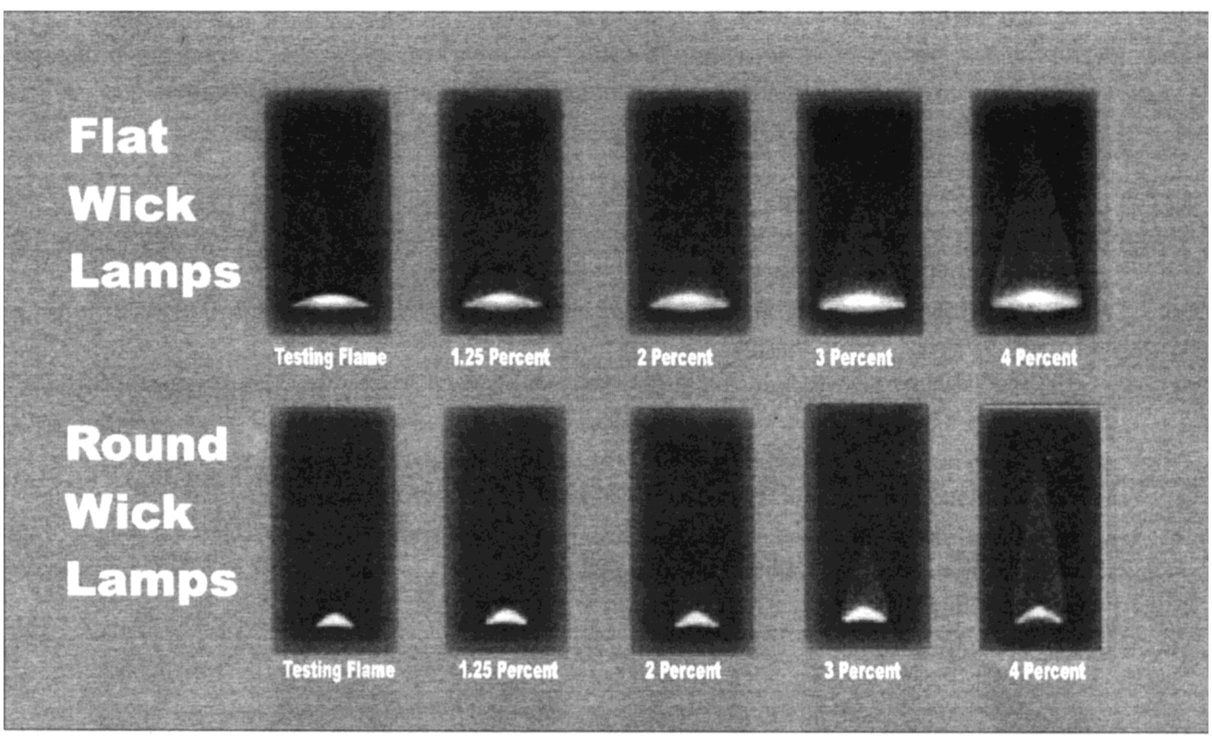


Fig 2.2. General Body Gas Caps

For general guide regarding size of caps the following could be adopted:-

1.5 percent - small cap, faint and incomplete in shape of truncated cone
2.5 percent - complete well defined triangular cap.
4 percent - high triangular cap
5 percent - burning gas fills the lamp and extinguishes the flame.

2.2 The Drager Universal Gas Detector

The Drager Universal Gas detector (Fig 2.3) is designed to enable a wide range of gas types and concentrations to be estimated. These gases include carbon monoxide, carbon dioxide, nitrogen dioxide, hydrogen sulphide and sulphur dioxide. The instrument consists of a spring loaded rubber bellows type pump and a range of replaceable glass indicating tubes containing chemicals specific to a particular gas. The pump has a capacity of 100 cubic centimeters and can be operated by one hand. This enables sample gas of this volume to be drawn through an indicating tube before passing to the bellows:-

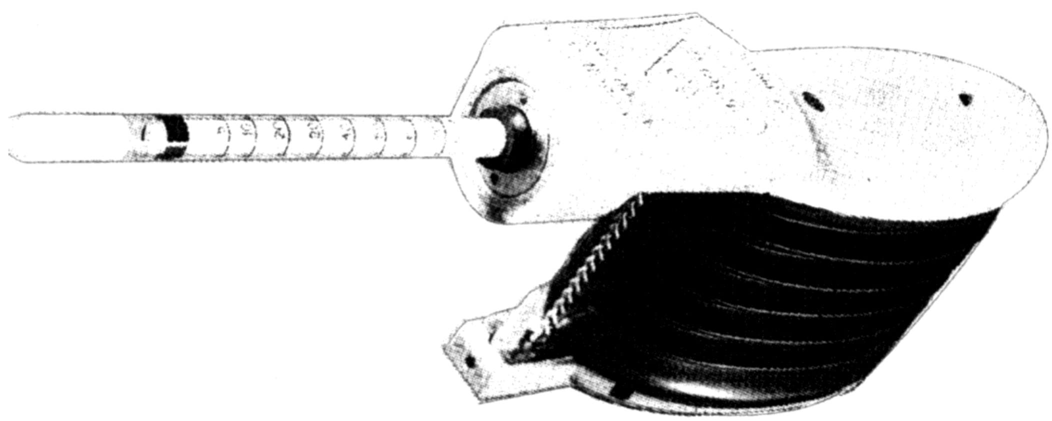


Fig .2.3. The Drager Universal Gas Detector

2.2.1 a) Operation

i. The bellows should be squeezed once or twice to be sure the outlet valve is operating.
ii. The bellows should be leak tested. This may be performed by placing a finger over the inlet of the bellows or alternatively placing a new unbroken tube in the inlet. The bellows once squeezed should remain collapsed. If a leak is evident the valve plate may be removed and the valve seat inspected or cleaned.
iii. An indicator tube of suitable range is then selected for the particular gas to be analyzed. The tube is inspected to confirm it is within the expiry date and then the sealed ends are broken using the 'breaker' attached to one end of the drag chain.
iv. The tube is inserted firmly into the rubber inlet of the bellows so that the direction for the sample flow will be according to the arrow on the tube.
v. Squeeze the bellows to fully expel the residual air and then allow the bellows to draw the gas sample through the tube until the bellows are compeltely full. The time required for this is approximately forty seconds. Allow a further two to three seconds to equalize the pressure.
vi. If no discolouration occurs, repeat the procedure (v) nine more times.

vii. The gas concentration is the graduated mark corresponding to the lowest level of general discolouration not the deepest point of colour penetration (Fig. 2.4).

viii. Note the time, date and place on the rough end of the tube.

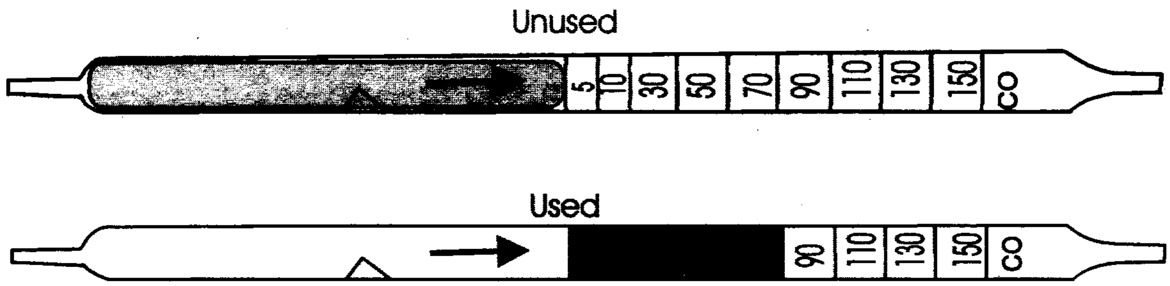


Fig. 2.4. The COIOB Tube

Note:

a. Indicator tubes have a shelf life of two years.

b. One indicator tube may be re-used ten times provided there has been no discolouration.

c. The general accuracy of each determination is usually within · 20%.

d. Hydrogen tubes are not approved for use underground because of the intense heat developed.

e. A pre-tube, filled with activated charcoal is required when estimating low levels of carbon monoxide in the presence of diesel exhausts or higher hydrocarbons as found in afterdamp or in seam gases.

f. Exhaust gas should be passed through a cooling device to make sure the temperature is below 40 °C before passing through an indicator tube.

g. Oxygen tubes are not approved for use underground because of lack of accuracy.

CHAPTER 03

OXIDATION OF COAL AND SPONTANEOUS COMBUSTION

3.1 Oxidation

Oxidation of coal is defined as the depletion of oxygen and the increase of carbon dioxide in the mine air.

In oxidation some of the oxygen combines chemically with the carbon of the coal to form carbon dioxide, and some combines with the hydrogen to form water. In some cases small quantities of carbon monoxide may also be produced. These are purely chemical reactions.

3.2 GENERAL CONDITIONS FAVOURING OXIDATION

3.2.1. Low Carbon Content

Coals containing upto 85% of carbon is liable to oxidation. Anthracite coals have less chances of oxidation.

3.2.2. Bright Coals

The bright constituents of coal e.g. vitrain and clarain are more oxidisiable than the dull constituent of coal e.g. durain and fusain.

3.2.3. Presence of Iron Pyrites

The sulphide of iron when undergoes the process of oxidation, swells up and disintegrates the coal so the coal becomes permeable by air and helps in oxidation, by exposing a greater area.

3.2.4. Presence of Moisture

Moisture does not assist in oxidation of coal. Its presence is essential for the oxidation of pyrites and it has an accelerating effect on the disintegration of the coal.

3.2.5. Friable Coal

A friable coal which easily breaks into small pieces is more likely to self heat than a hard coal.

3.2.6. High Temperature

Increase of temperature helps in oxidation. First the coal is ignited and then it starts burning.

3.3 Spontaneous Combustion

Spontaneous combustion may be defined as the self heating of coal or other carbonaceous material resulting eventually in its ignition without the application of any external source of heat.

3.4 Situations Liable to Spontaneous Combustion

They are:-

3.4.1 Thick Seams

Seams exceeding one meter in thickness are more liable to self heat than thinner seams because coal is a bad conductor of heat as compared with shale and sandstone.

3.4.2 Deep Seams

Seams lying at great depths are more liable to self heating. The strata temperature increases due to depth and the process of oxidation is accelerated.

3.4.3 Seams Containing Bands of Inferior Coal

Thin layers of dirt in coal and possibly having a roof of carbonaceous shale, are more liable to self heating. The inferior coal bands and dirt are often left underground, and shale is also oxidised after falling in the wastes.

3.4.4 Loosely Packed Goaf Containing Small Coal and Other Carbonaceous Refuse

This forms perhaps the most usual site for self heating to occur. The air percolates through the coal to cause oxidation, which is most likely to occur near the face where the packs have not become consolidated.

3.4.5 Sites of Old Falls

The easiest way to start a gob fire is to leave a small pillar of coal, with a few pieces of roof supports, in the goaf, behind the advancing face. Such stooks of coal and roof supports should always be removed.

3.4.6 Edges of Solid Coal Pillars and Ribs

These are also liable to self heating when crushed and fractured.

3.4.7 Faults

These also cause self heating because inferior coal is some times left next to the line of faults which agitates the self heating.

3.5 Symptoms of Self Heating

The development of self heating is accompanied progressively by "Haze", "Sweating", "Stink", "Smoke" and finally "Fire".

3.5.1 Haze

It is due to the moisture given off during oxidation. It is condensed as small globules in the cooler air away from the heating.

3.5.2 Sweating

It is due to the condensation of moisture and its deposition as beads on the cooler surfaces e.g. roof, sides, timbers and metal surfaces.

3.5.3 Stink

Faint odour, known as "gob-stink", slightly oily, sometimes sweet, and sometimes like the smell of decaying timber are symptoms of self heating.

3.5.4 Hot Surfaces

A large variety of modes of ignition can be included under this heading:-

i) Over Heated Lamp Gauzes

If firedamp becomes ignited within a safety lamp gauze it my continue to burn there indefinitely, even though the oil flame be extinguished. With bonneted lamps having two gauzes, there is a high margin of safety and the possibility of an external inflammable atmosphere becoming ignited is limited.

ii) Electrically Heated Wires

The tungsten filament of an incandescent electric lamp is quite capable of igniting a firedamp-air mixture if the enclosed bulb should become accidentally broken.

iii) Heated Rock Surfaces

Continued friction between certain kinds of sandstone can generate sufficient heat to ignite firedamp. Under practical conditions such friction may occur when a large mass of rock falls some distance and glides along the sharp edges of another piece. It has also been found that the friction of rock upon rock is more likely to cause ignition than that of metal upon rock. It is quite possible to ignite firedamp by the striking of a pick on quartizitic sandstone.

iv) Incandescent Coal

Danger of ignition from this cause is only liable to occur in those mines where the coal is subject to self heating or spontaneous combustion. Ignition of fire damp may occur before the coal actually fires i.e. at the stage where the exposed surfaces of the coal become incandescent.

v) General

Several other causes of ignition under the heading of heated surfaces e.g. over heated brake blocks, timber and steel props heated by moving conveyor troughs, un-lubricated haulage rollers heated by rope friction and so on, may be added.

3.5.5 Smoke

Smoke coming out from any underground working may not be a symptom of self heating.

3.5.6 Concentration of Carbon Monoxide

In the application of gas analysis to the detection of a heating it is first essential to ascertain the CO/O_2 ratio. This may vary from about 0.1% in some cases to as much as 1% or slightly more in others. Any increase in the ratio indicates the development of heating. Broadly, a ratio exceeding 1% demands careful watching; a ratio of 2% indicates distinctly dangerous conditions; whilst a ratio of 3% or more is a generally definite indication that fire exists.

3.6 Precautions to Prevent Spontaneous Combustion

All precautions must be focused on:-

a) Reducing the quantity of crushed coal that is available for oxidation and
b) Preventing the access of air to the crushed material.

They may be listed as follows:-

1. Where practicable, completely extract all coal by the longwall system either advancing or retreating. Maintain a straight line of face.
2. Advance the face rapidly and continuously allowing the goaf to be packed effectively.
3. Form large pillars in room and pillar method of working and extract them rapidly.
4. Avoid leaving stooks of coal in the goaf. If a fall occurs at the face, all the coal should be removed and the place packed with inert material.
5. Build wide road side and rib-side packs with inert material.
6. Withdraw all props, whether of steel or wood from the goaf.
7. Keep intakes and returns as far apart as possible and seal off all leakage paths between them.
8. Drive straight roomy airways so as to allow an adequate amount of air current to flow at a low water gauge.

9. Build all doors, stoppings, air crossings and regulators in strong, unbroken ground in order to prevent leakage of air around them.
10. Avoid "bottle necks" in roadways, for smooth airflow.
11. Tightly pack all disused roadways and seal off worked out panels properly.
12. No time should be lost as and when first signs of incipient heating appear.

Factors of Pollution of Mine Atmosphere

Modern mining has become a source of pollution. All the different sections of biosphere are polluted by mining and in various ways. They are:-

i. Strata.
ii. Humidity and Temperature.
iii. Geothermic Gradient.
iv. Oxidation of Coal or other Carbonaceous Materials.
v. Exhalation, Exhaust from Machinery.
vi. Dust.

i) Strata

The movement of ground due to subsidence is a sources of producing pollution in the mine atmosphere. Other factors include fall of roof and sides; caving or collapse of waste; drilling and blasting and conduction of heat from the strata.

ii) Humidity and Temperature

These both play a vital role in polluting the mine atmosphere. The underground mine air is heated/polluted due to conduction of heat from the strata, compression of air due to depth, burning of lamps, exhalation of men and animals, use of booster fans, power operated machinery, friction of air current against surfaces of roadways.

The health of the workmen is affected by heavy perspiration in high temperatures, this causing loss of salt from the blood and gradual weakening. The air that is humid contains more heat and moisture than normal.

iii) Geothermic Gradient

The temperature of mine atmosphere increases with the increase of depth. Usually the surface temperature remains unchanged upto a depth of 50 feet. The rate of increase of temperature with depth is called geothermic gradient. This varies greatly in different localities and is of the order of $1^{o}c$ per 30 meters of depth in U.K.

iv) Oxidation of Coal or other Carbonaceous Materials

Oxidation of coal or other materials give rise to polluting the mine atmosphere. Harmful gases like carbon monoxide, firedamp, hydrogen sulphide, nitrous fumes are evolved in oxidation process of coal and other carbonaceous material which adds to the pollution in the mine atmosphere, immediate treatment should be under taken to bring the mine atmosphere within the safe limits otherwise valuable lives may be lost.

v) Exhalation, Exhaust from Machinery

In the exhaust of diesel engines carbon monoxide and oxides of nitrogen are evolved which pollute the mine atmosphere.

vi) Dusts (Already discussed in Chapter No.1)

CHAPTER 04

VENTILATION

(The Atmosphere)

4.1 Definition

Circulation of air is called ventilation. It is the control of air movement, its amount and direction. It controls the quality, quantity, temperature and humidity of the air in mines.

4.2 Purpose

The main purposes of mine ventilation are:-

i) To provide an adequate amount of fresh (clean) air currents in the roadways and in the working places where persons are to pass or work so as to maintain their health, safety and comfort.
ii) To dilute and remove noxious and inflammable gases to such an extent that men and animals working in the mines do not feel any discomfort during work.
iii) To cool the working places in deep mines.
iv) To remove and dilute dust produced in cutting and transportation of coal.

4.3 Atmospheric Pressure

It is defined as that pressure which supports a column of mercury 760 millimeters (30.00 inches) high at sea level when the temperature is 0 ^{0}C (32 ^{0}F).

The standard atmospheric pressure is equivalent to 29.922 x 0.4908 = 14.7 lbs per sq. inch for one atmosphere. It becomes 1470 lbs per sq. inch at 100 atmosphere.

As specific gravity of mercury is 13.6 and the atmospheric pressure supports a column up to 30. inches, so the equivalent column of water is 30 x 13.6 = 408 inches = 34 feet high.

Example 4.1

Assuming that the "mean atmospheric pressure" is stated as 30 inches of mercury. What is the equivalent pressure in (a) lbs. per sq. inch, (b) lbs. per sq. ft. and (c) feet of water column.

Solution

One inch of mercury exerts a pressure of 0.4908 lbs. per sq. inch and specific gravity of mercury is 13.6.

a) in lbs. per sq. inch = 30 in. mercury x 0.4908 lbs. per sq. inch = 14.7 lbs. per sq. inch.
b) in lb.s per sq. ft. = 14.7 x 144 sq. inch in one sq. ft = 2116.8 lbs. per sq. ft.
c) in feet of water column = 30 in. of mercury x 13.6 = 408 in. = 34 ft. water column.

4.4 Barometer

Barometer is an instrument used for accurate measurement of the atmospheric pressure.

4.4.1 Construction

It consists of a vertical glass tube about 36 inches long and about 0.3 to 0.4 inches inside diameter. The upper end of tube is sealed and the lower end kept open. The open end is dipped into a small wooden box, cistern of mercury and which has a small chamois leather base.

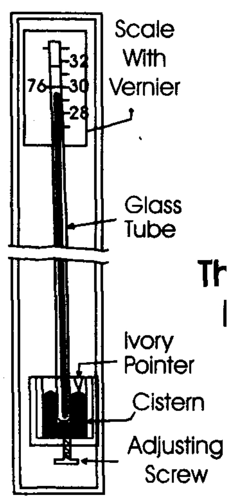


Fig. 4.1. A mercury barometer

Before any reading is taken, the level of the mercury is adjusted so that the surface of the mercury just touches the tip of an ivory pointer. This represents the level from which the height of the mercury column must be measured. Near the top of the tube a scale and a vernier is mounted which enables a reading to be made to the nearest hundredth of an inch.

It will be seen that at sea level, mercury stands at about 30 inches which means the atmospheric pressure at that place is 14.7 lbs. per square inch.

4.4.2 Variation of Barometric Pressure with Height

The reading of barometer depends on the height above or depth below sea level and density of the air column above that place.

Various complex formulae have been designed to take account of all the factors involved but a simple statement is that a difference of one inch in the barometer represents about 900 feet difference of level.

Thus at the top of a mountain 2700 feet high, the barometer will read about 3 inches less than at sea level. Conversely, at the bottom of a shaft, 1800 feet in depth, the barometer will read about 2 inches more than at sea level.

It is important that two instruments are used and read simultaneously to record correct pressure at that place.

Example 4.2

When the Barometer at the surface is 28.50 inches, what will be its approximate reading at the bottom of shaft 500 yards deep?

Solution

One inch difference represents 900 feet and the barometer reading decreases as we ascend and increases as we descend. So

at the bottom of 500 yards deep or 1500 feet = $\frac{1500}{900}$ = 1.67 inches.

Reading at depth of 500 yards = 28.50 + 1.67 = 30.17 inches.

4.4.3 Height of the Atmosphere

The atmosphere is known to extend many miles above the earth. Record shows that at 3.5 miles above sea level, the barometer reads about 15 inches, at 7.0 miles only 7 inches at 10 miles, 3 inches and at 20 miles about 0.6 inches.

4.4.4 Barometric Changes and their Effects in a Mine

It should be noted that sudden rise and fall in the atmospheric pressure may considerably affect conditions in the mine workings, especially if there are large areas of goaf or old workings underground which are unventilated and filled with noxious gases.

If a barometer starts falling rapidly, the gases in goaf or old workings expand and overflow into the mine roadways.

The danger is least when the barometer is steady or rising for then no overflow takes place and the gases remain confined in their place.

The normal ventilation usually controls the emission of gas from the coal and strata. It is, therefore, advisable that ventilation of a mine should have careful attention at the whole mine and at all times, no matter whether the barometer is rising or falling.

4.5 Thermometer

It is an instrument used to measure the temperature of a body and a place where it is fixed.

4.5.1 Construction

It consists of a short sealed glass tube with a capillary (i.e. hair-like) bore running through the centre and has a small glass bulb at the lower end.

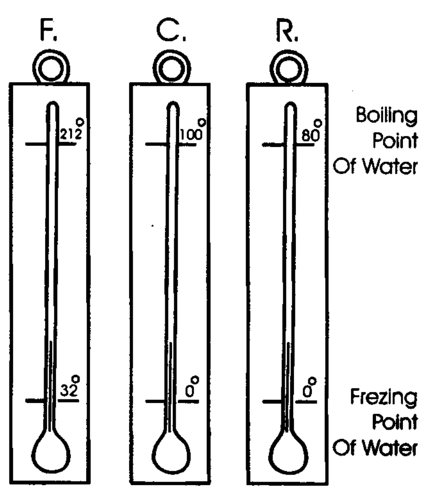
The bulb and tube are filled with mercury (or sometime with alcohol which has a lower freezing point). The tube is placed in a certain known high temperature so that the mercury fills both tube and bulb and the end is then fused and sealed. As the mercury cools, it contracts and moves towards the bulb. When the thermometer is used, the mercury in the tube expands or contracts according to the onsite temperature. A scale is marked on the tube to enable the temperature to be read.

4.5.2 Thermometer Scales

There are three scales, known respectively as Fahrenheit, Celsius and Reaumur. The construction and principle is the same in each case.

The Fahrenheit scale is commonly used in Britain, Celsius scale is of universal application and Reaumur is chiefly used in Russia. In each thermometer, two definite points are taken as standard, namely the freezing and boiling points of water.

The freezing point of water is marked as 32 degrees on the F scale, 0º (zero degrees) on the C scale and R scale as shown in Figure 4.2 below.



The boiling point of water is marked as 212 degrees on F scale, 100 degrees on C scale and 80 degrees on R scale.

Temperatures below 32 degrees in F scale and below 0 degrees in C and R scales are denoted by the minus sign. Thus –6 ^{0}F means 6 degrees below zero on F scale or 38 ^{0}F below the freezing point of water.

4.5.3 Rules for Conversion of Different Scales

It is here necessary to consider the conversion of degrees F to degrees C and vice versa.

The rules to be applied are based on the fact that in degree Celsius the difference between freezing point and boiling point is 100 (0^0 to 100^0) as compared with 180^0 in Fahrenheit (32^0 to 212^0). Hence, each Celsius degree is 9/5 times a Fahrenheit degree and the following equation is true ^{0}F – 32/^{0}C = 9/5 where ^{0}F and ^{0}C are thermometer readings.

Thus to convert ^{0}F to ^{0}C, we have ^{0}C = (^{0}F – 32) x 5/9 and to convert ^{0}C to ^{0}F, we have ^{0}F = (^{0}C x 9/5) + 32.

Example 4.3

a) Convert 200 ^{0}F, 98.4 ^{0}F and 0 ^{0}F to degree Celsius.
b) Convert 200 ^{0}C, 158 ^{0}C and −10 ^{0}C to degree Fahrenheit.

Solution

a) Fahrenheit to Celsius = (F – 32) x 5/9

$$\text{Hence } 200\,^{0}F = (200 - 32) \times \frac{5}{9} = \frac{168 \times 5}{9} = \frac{840}{9} = 933\,^{o}c$$

$$98.4\,^{0}F = (98.4 - 32) \times \frac{5}{9} = \frac{66.4 \times 5}{9} = \frac{332}{9} = 36.89\,^{o}C$$

$$^{0}F\ (98.4 - 32) \times \frac{5}{9} = \frac{-32 \times 5}{9} = \frac{-160}{9} = -17.78\,^{o}C$$

b) Celsius to Fahrenheit = (C x 9/5) + 32

$$\text{Hence } 200\,^{0}C = 158 \times \frac{9}{5} + 32 = (40 \times 9) + 32 = 360 + 32 = 392\,^{0}F$$

$$158\,^{0}C = 158 \times \frac{9}{5} + 32 = 284.4 + 32 = 316.4\,^{0}F$$

$$-10\,^{0}C = -10 \times \frac{9}{5} + 32 = -18 + 32 = 14\,^{0}F$$

4.5.4 Uses of Thermometer in Mining

Temperature readings are required in mining to measure the temperature of the air in connection with ventilation, spontaneous combustion, steam plant and machinery.

1) To Measure the Temperature of the Air

In ventilation, the temperature of the air must be known before we calculate the density of air. This is a factor which is involved in many ventilation problems, especially those connected with natural ventilation. The temperature of the intake air also has a close bearing on the drying power of the air current whilst the temperature in the work places, in conjunction with humidity of the air has a great effect on the efficiency and comfort of the workmen.

2) To Help in the Detection of Spontaneous Combustion

In mines liable to spontaneous combustion, any undue rise of air temperature above the normal, may indicate self-heating of coal or other carbonaceous material in the vicinity.

3) Efficient Running of Electrical Apparatus

Thermometers may be used to detect over heating of bearings and electrical apparatus such as transformers etc.

4) Efficient Running of Steam Plant

The thermometer has also important uses when efficiency tests of boilers are being made, and in particular for measuring the temperature of the feed water, and of the flue and chimney gases.

5) To Measure the Temperature of the Strata

It helps to measure the rock temperature to determine geometric gradient with increase of depth.

4.5.5 The Absolute Zero of Temperature

This is theoretically the lowest possible temperature and is the point at which all heat would be extracted from a substance if we could cool it sufficiently.

The absolute zero is – 273.13 ^{0}C or – 459.63 ^{0}F. The figure most usually used in calculation is – 459 ^{0}F and if we add 459 to any Fahrenheit temperature, the corresponding absolute temperature on the F scale is obtained.

4.6 Hygrometer

It is used to determine the temperature and relative humidity of the mine air which affect the comfort and efficiency of workmen.

1. Construction

It consists of two thermometers mounted on a frame, one of them is dry and the other is wet, having its bulb covered with a piece of muslin, which dips into a small vessel filled with water as shown in Fig 4.3 below.

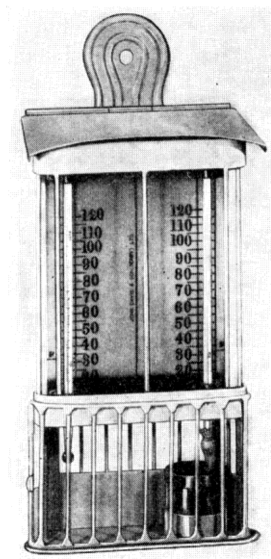


Fig. 4.3. Whirling Hygrometer

The operation of the instrument depends on the fact that evaporation of moisture produces a cooling effect and lowers the temperature of the wet-bulb.

When the air is fully saturated, both indicate the same temperature and when the air is somewhat dry i.e. unsaturated, the wet bulb indicates a lower temperature than the dry bulb. In short, the greater the difference between the two readings, the drier the air and less shall be the relative humidity in the atmosphere.

4.6.2 Calculation of Relative Humidity

Following rules may be applied.

a) For dry-bulb reading upto 65 ^{0}F, deduct 6% from 100% for every degree difference.
b) For dry bulb reading above 65 ^{0}F, deduct 5% from 100% for every degree difference.

Thus if readings are 63 ^{0}F and 60 ^{0}F, the difference in reading is 3^0, so the relative humidity = 3 x 6 = 18% less than 100% = 82% and if readings are 80 ^{0}F and 76 ^{0}F, the relative humidity is 4 x 5 = 20% less than 100% = 80%.

4.6.3 Uses of Hygrometer in Mining

The conditions may be considered satisfactory where the wet bulb temperature is below 78 ^{0}F and the velocity of air is reasonable i.e. within the range of 150 to 600 ft per min. At higher temperature, conditions progressively deteriorate until, at wet bulb temperatures 85 ^{0}F to 88 ^{0}F, efficient work becomes virtually impossible.

4.6.4 Precaution against High Temperature and Humidity

1. Large quantities of air must be circulated in the travelling roads and working places.
2. Inbye splits should be reasonably short and air velocities reasonably high.
3. The shafts and intake roadways must be kept as dry as possible.
4. Where practicable, main roads should be driven in rock to prevent excessive oxidation and to prevent rise in temperature.
5. The packs should be built as close as possible to the face.
6. Coal face operations should be mechanized.
7. In special cases, refrigerating plants may be installed to cool the intake air.

4.7 Boyle's Law

This law describes the relationship between volume and pressure of a gas and states:

"The volume of a given mass of a gas varies inversely as the absolute pressure if the temperature remains constant".

In other words, if the pressure be increased, the volume will be decreased in the same ratio, and vice versa. If the pressure be doubled, the volume will be halved. In all cases:-

The product of pressure x volume is constant

$P_1V_1 = P_2V_2 = a$ (constant)

where P_1 and V_1 = Initial absolute pressure and volume

P_2 and V_2 = Final absolute pressure and volume.

Example 4.4

An air compressor has a capacity of 1000 cubic ft. of free air per minute. What volumes will be delivered per minute to an air receiver, the final pressure being 85 lbs. per sq. inch by gauge and the temperature being assumed constant throughout.

Solution

In this case, the initial absolute pressure = P_1 = 15 lbs. per sq. inch absolute

the final absolute pressure = P_2 = 85 + 15 = 100 lbs. per sq. inch abs.

the initial volume = V_1 = 1000 cubic ft. per min.

Final volume = V_2 = ?

Temperature = constant

We use the equation.

$$P1V1 = P2V2$$

$$V2 = \frac{P1V1}{P2}$$

$$= \frac{15}{100} \text{ x } 1000 = 150 \text{ cubic feet per minute.}$$

Corollary of Boyle's Law

The density, or weight per cubic foot of a gas, is directly proportional to absolute pressure, if the temperature remains constant.

Example 4.5

If the weight of a cubic foot of air at 30 inches barometer is 0.0807 lbs. What is its weight at 28 inches, the temperature remains constant.

Solution

$$\text{At 30 inches barometer, the weight of air} = 0.0807 \text{ lb.}$$

$$\text{At 28 inches} = \frac{0.0807}{30} \text{ x } 28$$

$$= 0.0753 \text{ lb.}$$

4.8 Charle's Law

This law describes the relationship between volume and temperature of gas and states:

"The volume of a given mass of a gas is directly proportional to its absolute temperature when the pressure remains constant"

In other words, every gas expands with increase of absolute temperature and vice versa. It is expressed as:-

$$\frac{\text{Final Volume}}{\text{Initial Volume}} = \frac{\text{Final absolute temperature}}{\text{Initial absolute temperature}}$$

$$\frac{V_2}{V_1} = \frac{459 + t_2}{459 + t_1} = \frac{T_2}{T_1}$$

$$\frac{V_2}{T_2} = \frac{V_1}{T_1} = \text{a constant, where T1 and T2 are absolute temperatures}$$

Example 4.6

A certain weight of gas has a volume of 1000 cubic feet when the temperature is 50 ^{0}F. What will be its volume at 75 ^{0}F assuming the pressure to be constant.

Solution

As pressure is constant, we employ Charles Law which is as under

$$\frac{V_2}{T_2} = \frac{V_1}{T_1}$$

Values given are:-

$$V_1 = 1000 \text{ cub. ft.}$$

$$T_1 = 459 + 50 = 509^O\text{R}$$

$$T_2 = 459 + 75 = 534^O\text{R}$$

$$V_2 = ?$$

$$V_2 = \frac{V_1 \text{x}\, T_2}{T_1}$$

putting the values, we have

$$V_2 = 1000 \text{ x } 534/509 = 1049 \text{ cub. ft.}$$

Corollary of Charle's Law

The density, or weight per cubic foot of a gas, is inversely proportional to the absolute temperature when the pressure is constant.

Example 4.7

If a cubic foot of air at 32 ^{0}F weighs 0.0807 lb. What will be its weight at 50 ^{0}F, assuming pressure as constant.

Solution

The initial absolute temperature	$= T_1 = 459^0 + 32^0 = 491^0$R
and the Final absolute temperature	$= T_2 = 459^0 + 50 = 509\ ^0$R
density	$= W_1 =$ 0.0807 lbs. per cubic ft.

$$\text{Weight at 50 0F} = W_1 \text{x} \frac{T_1}{T_2}$$

$$= 0.0807 \text{ x} \frac{491}{509} = 0.0778 lbs$$

4.9 Combination of Boyle's and Charle's Laws

$$\text{By Boyles Law } P_2 V_2 = P_1 V_1 \text{ or } V_2 = V_1 \text{x} \frac{P_1}{P_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(a)}$$

$$\text{By Charles Law } \frac{V_2}{T_2} = \frac{V_1}{T_1} \text{ or } V_2 = V_1 \text{x} \frac{T_2}{T_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(b)}$$

Combining (a)& (b)

$$V_2 = \frac{P_1}{P_2} \text{x} \frac{T_2}{T_1} \text{x } V_1$$

$$\text{Hence} \frac{P_1 V_1}{T_1} \text{x} \frac{P_2 V_2}{T_2} = \text{a constant}$$

Example 4.8

A given weight of gas occupies 400 cubic feet at 52 ^{0}F and 30.5 inches barometer. Find its volume at 64 ^{0}F and 29.6 inches barometer.

Solution

V_1 = 400 cubic tt.
P_1 = 30.5 ins. Hg.
P_2 = 29.6 ins. Hg.
T_1 = 459 + 52 = 511 ^{0}R
T_2 = 459 + 64 = 523 ^{0}R
V_2 = ?

Using formula

$$V_2 = \frac{P_1}{P_2} \text{x} \frac{T_2}{T_1} \text{x} V_1 = \frac{30.5}{29.6} \text{x} \frac{523}{511} \text{x} 400 = 422 \text{ cubic ft}$$

Weight of Air

The formula to find

$$\text{Weight per cubic foot of dry air } = \text{ W} = \frac{1.3253}{459 + \text{F}} \, Blb$$

where B = reading of Barometer in inches of mercury
F = air temperature in ^{0}F

Example 4.9

alculate the weight of a cubic foot of dry air at 50 ^{0}F and 30 inches barometer.

Solution

$$\text{w} = \frac{1.3253 \text{ X } 30}{29.6} \text{x} \frac{39.759}{509} = 0.0781 \text{ lb}$$

CHAPTER 05

NATURAL VENTILATION

5.1 Natural Ventilation

Natural ventilation means the current of air that flows through a mine by purely natural means i.e. without the aid of a fan or other mechanical contrivances.

Air will flow naturally through a mine when there is a natural difference of its density between two, vertical or inclined columns of air contained between the same two horizontal planes.

As a result of the difference of density, the heavier or downcast column overbalances the lighter or upcast column, and a continuous flow of air takes place so long as the difference of density is maintained.

In general, the cause of the difference of density is a naturally existing difference of temperature but it may also sometimes be partly due to the lighter column containing more firedamp, or more water vapour, than the other.

5.2 How it is Produced

Let BC and FD in Fig.5.1 represent two mine shafts at different surface levels, the mine working being level and shown by a single roadway CD.

At A and F, the air pressures and temperatures are equal as both the points are in the open air and have the same altitude. Any difference of pressure causing a current of air to flow must have its birth below AF.

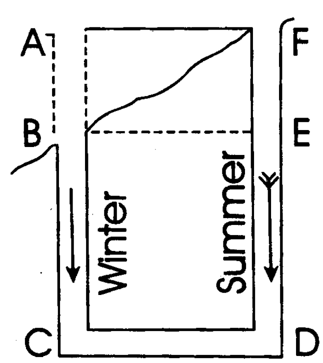


Fig. 5.1

Let us assume that the rock temperature in the mine is about 35^0C, while the surface temperature in winter is 25^0C and in summer 45^0C. Now the direction of flow of air current in cold weather, mild weather and hot weather shall be, to some extent, as under:

1. In cold weather: the air column AB is in the open and is colder and heavier than the column FE and the column BC is also cooler and heavier than ED. The whole column AC is thus heavier and cooler than the column FD and so air will flow naturally down AC, through CD and up DF.
2. In mild weather, the air in AC may reach the same mean temperature as the air in DF, so the flow of air may cease altogether.
3. In hot weather, the conditions are reversed. The mean temperature in FD, owing to the cooling effect of the strata becomes less than AC and thus the air flows down FD and up CA.

So to maintain a purely natural ventilation, two conditions must normally be satisfied.

1. The inlet and outlet of a mine must be at different surface levels.
2. There must be a difference of temperature and therefore of density, between the two air columns.

5.3 Natural Ventilating Pressure, Water Gauge, Motive column and Weight of ir.

a) Natural Ventilating Pressure

Ventilating pressure is not a single pressure, but a difference between two pressures. If an air current is caused to flow along an airway, a pressure difference must be set up between its two ends. In mines, fans are used to set up a difference of pressure between the air in the fan drift and the air outside. Ventilating pressure is always a difference between two absolute pressures.

Natural Ventilating Pressure = P = w x h
w = Weight of a cubic foot of air in lbs.
H = Motive Column in ft.

b) Water Gauge

The pressure per sq ft at the base of a column of water (or any other fluid) depends only on the vertical height of the column and the density of the fluid. It is independent of the shape, size and section of the containing vessel. One cubic ft. of water weighs 62.4 lbs. Hence, a column of water 1 inch high and 1 sq. ft. in sectional area weighs 62.4/12 = 5.2 lbs. Therefore

1 inch w.g.= a ventilating pressure of 5.21bs per sq. ft.
Natural water gauge = P/5.2 inches of w.g.
P = Ventilating pressure.

c) Motive Column

Motive column is that portion of downcast column that has the same weight as the difference of weight between the two columns. It is the effective part of the down cast column that causes a flow of air to take place.

The height of the motive column in feet depends on the difference of temperature and the depth of the columns and is given by the formula.

$$\text{Motive Column} = \text{H} = \frac{F_u - F_d}{459 - F_u} \text{ x D}$$

Where

F_u = Mean temperature in F in upcast column.
F_d = Mean temperature in F in downcast column.
D =The depth in feet of downcast column.

d) Weight of Air

Weight of one cubic foot of air in each column is calculated from the Formula:-

$$\text{W} = \frac{1.3253}{459 + \text{F}}$$

Where

B = Atmospheric pressure in inches of mercury

F = Temperature in downcast shaft.

So

Natural ventilation pressure = P= w x H and

Natural water gauge = $\frac{P}{5.2}$

5.4 Calculation of Natural Ventilation Pressure

It can be understood by the following examples.

Examples

The mean temperature of the air in a certain DC shaft is 50^{0}F, and in the UC shaft 70^{0}F. Both shafts are 2,000 feet deep. Calculate (a).the natural ventilating pressure in lbs. per sq. ft.; and (b) the height of the motive column. Assume a mean barometer 30 ins. at half the depth of the downcast.

Answer

a) First calculate the weight of a cubic foot of air in each column from the formula w = 1.3253 B/459 + F lb. (where B is the barometer in inches and F is the temperature of the air) and so find the total weight of each column, one square foot in section. Then:-

$$\text{weight of DC air column} = \frac{1.3253 \text{ X } 30}{459 + 50} \text{x } 2000 = 007811 \text{ x } 2000 = 156.22 \text{ lbs}$$

$$\text{weight of DC air column} = \frac{1.3253 \text{ X } 30}{459 + 70} \text{x } 2000 = 007516 \text{ x } 2000 = 150.32 \text{ lbs}$$

$$\text{Natural ventilating pressure} = \text{p} = 5.90 \text{ lbs. per sq. ft.} = 5.9 \div 5.2 = 1.14 \text{ ins. w. g}$$

b) Now convert this pressure to feet of motive column from the expression:-

$$\text{Motive column in feet} = \text{or H} = = \frac{\text{n. v. p. in lbs. per sq. ft}}{\text{wt. per cub. ft. of DC}} = \frac{\text{P}}{\text{W}}$$

$$\text{Motive column} = 5.9 \div 0.07811 = 75.6 \text{ feet.}$$

Note carefully that, in all such calculations, we must take the mean temperatures in the DC and UC shafts, and also the barometric reading at half of the depth.

Alternative Method

The height of the motive column in feet may be calculated directly from the temperatures and depth, without reference to the weights of the columns, by applying the following formula:-

$$\text{Motive Column} = \text{H} = \frac{F_u - F_d}{459 - F_u} \text{x D} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

where

H = height in feet of air column having the same density as the DC air.
F_u = the mean temperature of the upcast column in ^{0}F
F_d = the mean temperature of the downcast column in ^{0}F
D = the vertical depth in feet of the whole DC column.

Applying formula (1) to the figures in Example 1, we have:-

$$\text{Motive Column} = \text{H} = \frac{70 - 50}{459 + 70} \text{x } 2000 = \frac{20}{529} \text{ x } 2000 = 75.6 \text{ ft}$$

It will thus be seen that the motive column in feet depends only on the difference of temperature and the depth of the shafts and not at all on the barometric pressure. The latter, however, does affect the density of the air and therefore also the natural ventilating pressure in lbs. per sq. ft. or in ins. w-g.

Example

a) If the mean UC temp. is 80 ^{0}F and that of the DC 59 ^{0}F what is the height of he motive column of air at the temperature of the DC, if the mine be 2,400 feet deep? What is the equivalent natural ventilating pressure in (b) lbs. per sq. ft. and (c) ins. of w.g.? Assume an atmospheric pressure of 30 ins. at half the depth of the downcast shaft.

CALCULATION OF NATURAL VENTILATING PRESSURE

$$\text{(a)} \quad \text{Motive Column} = \text{H} = \frac{80 - 59}{459 + 80} \text{x } 2400 = \frac{21X2400}{539} = \frac{50400}{539} = 93.5 \text{ ft}$$

$$\text{(b)} \quad \text{Weight of 1 cub. ft. of DC air} = \text{w} = \frac{1.3253 \text{ x } 30}{459 + 59} = \frac{39.759}{518} = 0.07675 \text{ lbs}$$

$$\text{Natural ventilating pressure} = \text{P} = \text{wH} = 0.07675 \text{ x } 93.5 = 7.18 \text{ lbs. per sq. ft}$$

$$\text{(c)} \quad \text{Natural water gauge} = \text{Pressure in lbs. per sq. ft./ } 5.2 = 7.18/\ 5.2 = 1.38 \text{ ins. w. g.}$$

Alternative solution

$$\text{weight of DC column of air} = \frac{1.3253 \text{ X } 30}{518} \text{x } 2400 = 0.07675 \text{ x } 2400 = 184.2 \text{ lbs} = W_1$$

$$\text{weight of UC column of air} = \frac{1.3253 \text{ X } 30}{539} \text{x } 2400 = 0.07376 \text{ x } 2400 = 177.02 \text{ lbs} = W_2$$

$$\text{Excess weight} = 7.18 \text{ lbs.} = (W_1 - W_2)$$

$$\text{Natural ventilating pressure} = \text{P} = 7.18 \text{ lbs. per sq. ft.} = 1.38 \text{ inch w. g.}$$
$$\text{Height of motive column} = \text{P /w} = 7.18/\ 0.07675 = 93.5 \text{ ft.}$$

5. Causes of Changes in Mine Air Temperature

a) Heating Effects

1. Conduction of Heat from the Strata

The temperature of the rocks increases with the depth below the surface at a rate known as the geothermic gradient. This varies greatly in different localities but is of the order of'**1ºF per 60 ft.** of depth in Great Britain. As a result, the rock temperature in Great Britain nearly always exceeds the surface temperature and the air is heated as it passes through a mine until eventually it may reach the rock temperature. On very hot days, however, the entering air may exceed the rock temperature and then the air gives up heat to the strata being thereby cooled as it passes through the mine.

2) Compression of the Air due to Depth

As the air passes down the DC shaft and along dipping roadways, it is compressed by the increasing weight of the air above it and there is an automatic increase of temperature at a rate of 5·5 ^{0}F per 1,000 feet of depth, except in so far as this increase is counteracted by other causes.

3) Oxidation of Carbonaceous Material

Heat is produced by the oxidation of coal in the goaf and at the working face. It is not susceptible to precise computation but it sometimes causes the air temperature at the face to exceed the rock temperature and heat transfer to take place from the air to the strata.

4) Subsidiary Causes

These include the burning of lamps, heat given out by men, machines, and subsiding strata. Their effect is relatively small, except possibly in confined spaces.

b) Cooling Effects

1. Evaporation of Moisture

The conversion of water into water vapour involves the absorption of heat by the water and this heat is abstracted from the air as it passes along wet shafts or roadways. The cooling effect so produced on the air tends to counteract the foregoing heating effects and resulting air temperature is therefore lower than it would be under dry conditions. Conversely condensation and the resulting deposition of moisture (which is much less frequent in a mine) is accompanied by an increase in the air temperature.

2) Expansion of Air

This is the converse of compression and occurs whenever the air ascends from a lower to a higher level, as in the UC shaft or along rising roadways.

3) Exhaust of Compressed Air Motors

The expansion of the air exhausted from compressed air motors has a cooling effect, which is sometimes evidenced by the formation of ice around the exhaust, due to the freezing of the moisture in the compressed air. Considerable local cooling of the air in the working places may result from this cooling effect due to expansion.

CHAPTER 06

MECHANICAL VENTILATION

In mines where the natural ventilation pressure is insufficient, mechanical ventilation is used.

6.1 Types of Fans

It involves the use of some mechanical devices to cause airflow in the mine by creating a pressure difference. Fans are the most important and most common mechanical devices.

There are two types of fans.

1. The centrifugal or radial flow fan.
2. The air screw or axial flow fan.

6.2 Principle and Working of a Centrifugal Fan

The principle of centrifugal fan is that the air is entered in the centre and is discharged more or less tangentially from the circumference.

It consist of a wheel, rotor or runner carrying vanes or blades as shown in Fig. 6.1 below. The wheel revolves on a shaft at a speed which depends on the size of the wheel and on the pressure difference to be set up between the centre of wheel and the periphery. Its action depends upon the fact that the air possesses inertia which once set in motion, continues to move in a straight line unless it is compelled by an impressed force to change its direction.

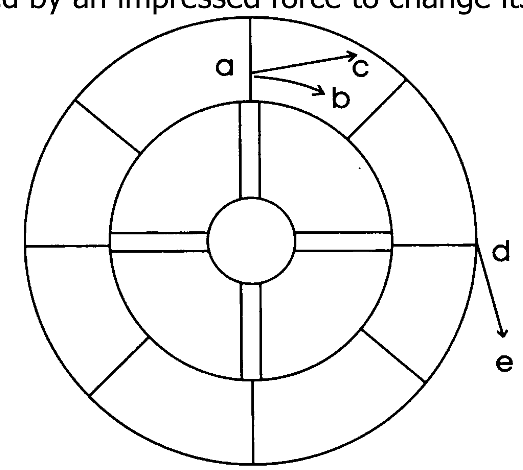


Fig. 6.1

Consider a particle of air at a as shown in Fig 6.1. It is acted upon by the blade which is rotating in a circular path towards b, but due to its inertia, it tends to move in a straight line in the direction ac. The resultant of these two simultaneous movements is that the particle actually follows the spiral path i.e., tangential to the circumference along arrow 'de' as shown in the figure. Strictly speaking the air is said to fly off because of centrifugal force. The continuous movement of air from inlet to periphery sets up a difference of pressure or water gauge as a result of which mine is ventilated by mechanical means.

The centrifugal fan has spiral casing and expanding chimney or evasee.

The purpose of spiral casing is to enclose the fan wheel and to prevent re-entry of the discharged air. Its cross-sectional area increases to accommodate more and more quantity of discharged air from the wheel.

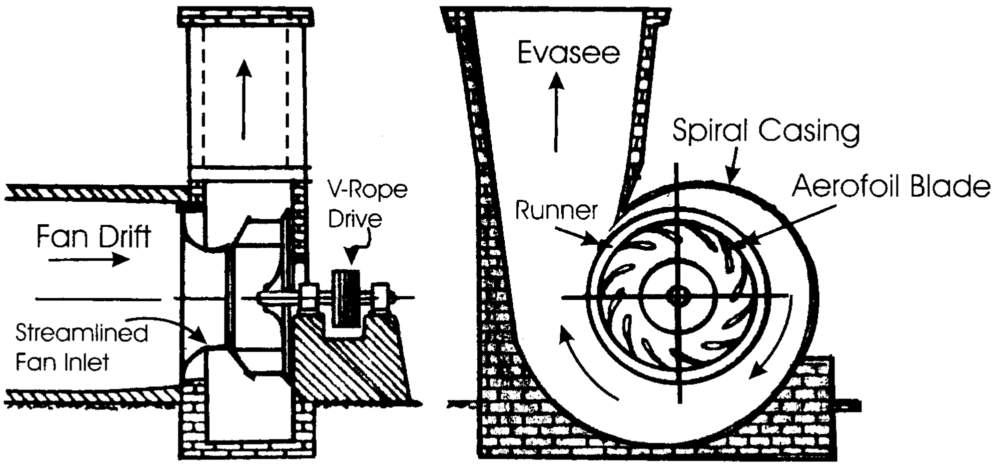


Fig. 6.2.

The purpose of evasee chimney is to reduce the final velocity of discharge to a minimum and to promote smooth flow of air, without turbulence and eddy currents. By this, the efficiency of the fan is increased and the required w.g. is developed with a smaller expenditure of power.

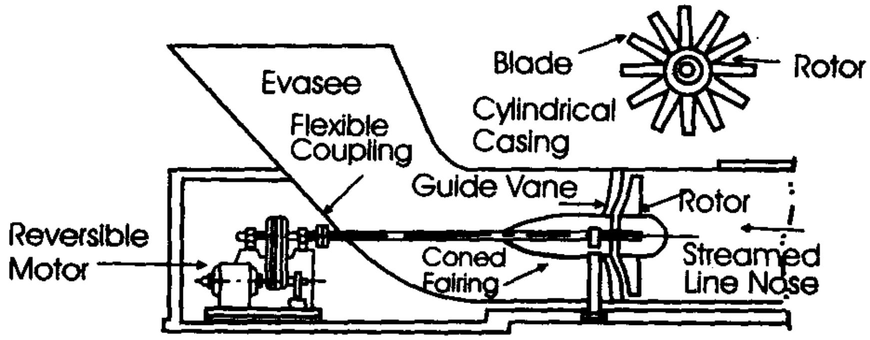
6.3 The Air Screw or Axial Flow Fans

The principle of air screw fan is that it propels the air forward axially i.e. straight through the fan in line with the shaft. It is diverted later into evasee chimney.

The action of an air screw fan depends on the principles of aerodynamics. In an aeroplane, the machine is driven forward through the air when the propeller revolves but in a fan, the machine itself remains fixed to its foundation and the air is driven forward.

In an axial flow fan, much higher peripheral speed is needed to develop a given water gauge than in the case of a centrifugal fan.

The figure below shows a sketch of a fixed pitch, single stage air screw fan.



It consists of multi bladed rotor or runner. When the rotor revolves, it discharges its air through stationary guide vanes towards nose shaped head. This streamlines the flow of air. The cone or nose shaped head extends to the perimeter of the air drift and designed to maintain streamline flow at the outlet also. The rotor and guide vanes are mounted within a cylindrical casing with a small clearance between blades and casing. The casing is fitted with an expanding chimney.

The air screw fans are made in all sizes from 18 inches diameter to 12 feet diameter. It is essentially a high speed machine running at from 180 to 3000 r.p.m.(revolutions per minute). It may be driven by an electric motor. Two or more rotors each with a set of guide vanes can be made to produce high w.g.

6.3.1 Comparison between Centrifugal Fans and Air Screw Fans

1. The efficiency of centrifugal fan ranges from 70 to 75% whereas air screw fan ranges from 80 to 85%.
2. The centrifugal fan becomes overloaded whereas the driving motor of an air screw fan does not become overloaded, no matter how the resistance or equivalent orifice of the mine may change.
3. The air screw fans have smaller weight for a given duty as compared to centrifugal fan.
4. The air screw fans are more suitable for auxiliary ventilation.
5. The centrifugal fans are more suitable for the development of high water gauges (pressure difference) where otherwise a more costly 3-stages air screw fan would be required.
6. The air screw fans have high speed of rotation and for this reason it necessitates careful construction of the rotor with its shaft and bearing.
7. The air screw fans have high noise of operation. This can be avoided by providing two or three stage construction which enables the required w.g. to be obtained with a lower tip speed.

6.3.2 Reversing of Air

Reversal of air with an air screw fan may be obtained simply by reversing the driving motor and fan runner. It should be noted that volume of air flowing is much reduced on reversal. Sometimes it is reduced to 30% of normal volume and w.g. also reduces to on-tenth of normal. However, these figures can be improved upon by modification in design.

Reversal of air with centrifugal fans is done by fitting doors in the opposite direction of flow of air.

Laws relating to Quantity, Pressure and Power in Relation to Fan Speed

When a fan is running in a mine with constant resistance it obeys the following laws:

Let Q = Quantity of air, in cubic feet per min.; N = Revolutions of fan, per min.

and V = Peripheral speed of blade tips, in feet per min.

Law No. 1 The quantity of air flowing varies directly as the speed of the fan. Thus if the speed is increased by 20% i.e. 1.2 times the original speed, it will pass 1.2 times the original quantity of air, and so on or Q Varies as N or V.

Law No. 2 The effective w.g. developed by a fan varies as the square of the speed of the fan. Thus if the speed be increased to 1.2 times of the original speed, the fan will develop $(1.2)^2 = 1.44$ times the original w.g. or w.g. varies as N^2 or V^2 or Q^2.

Law No. 3 The horsepower required to drive a fan varies as the cube of the speed. Thus, if the speed (and quantity) be increased to 1.2 times the original, the power required will be $(1.2)^3 = 1.728$ time the original power or H.P Varies as N^3 or V^3 or Q^3**.**

Example 6.1

A fan running at 200 r.p.m. produces 150,000 cub. ft. per min. at a water gauge of 4 in. (a) What quantity of air, and (b) What water gauge will be produced when the speed is increased to 250 r.p.m., assuming the conditions of the mine to remain unaltered ?

Solution

(a) The quantity of air produced by a fan varies directly as the speed. Hence, at 250 r. p. m.

$$\text{Quantity of air} = 150{,}000 \text{ x} \frac{250}{200} = 150{,}000 \text{ x} \frac{5}{4} = 187{,}500 \text{ cub. ft. per min.}$$

(b) The water gauge produced varies directly as the square of the speed. Hence, at 250 r. p. m.

$$\text{Water gauge} = 4 \text{ x} \left[\frac{250}{200}\right]^2 = 4 \text{ x} \left[\frac{5}{4}\right]^2 = 4 \text{ x} \frac{25}{16} = 6.25 \text{ inch. w. g}$$

Example 6.2

If a fan which is developing 216 H.P in the air causes 150,000 cub. ft. of air per min. through a mine (a) what power will the fan develop when passing 200,000 cub. ft. of air per min. and (b) what quantity would the same fan produce in the same mine when developing 144 H.P ?

Solution

(a) In a mine of given resistance, the power varies as the CUBE of the quantity.

$$\text{Hence, when the quantity is increased} = \frac{200{,}000}{150{,}000} = \frac{5}{4} = \text{ required will be}$$

$$\left(\frac{4}{3}\right)^3 \text{ times the original power.}$$

$$\text{H. P required} = 216 \text{ x } \left(\frac{4}{3}\right)^3 = 216 \text{ x} \frac{64}{27} = 512 \text{ H. P}$$

(b) In a mine of given resistance, the quantity varies as the CUBE ROOT of the power. Hence, when the power is reduced in the ratio 144/216, the quantity of air will be reduced in the ratio $\sqrt[3]{\frac{144}{216}} = \sqrt[3]{\frac{2}{3}} = \sqrt[3]{0.667} = 0.874$

$$final\ quantity = (150{,}000)\ X \sqrt[3]{\frac{2}{3}} = 150{,}000\ X\ 0.874 = 131{,}000\ cub\ ft\ per\ min.$$

Example 6.3

A fan running at 100 r.p.m. develops a w.g. of 3 in. and delivers 220,000 cub. ft. per min. It is driven by a motor developing 160 H.P. What will be the quantity, the w.g., and the HP, when the fan speed is reduced to 85 r.p.m.?

Solution

(a) The quantity will be reduced in the ratio of the two speeds (85/100)

New quantity = Q = 220,000 x 85/100 = 187,000 cub ft. per min.

(b) The w.g. will be reduced in the ratio of the squares of the two speeds, namely $(85/100)^2$

New w.g. = 3 x $(85/100)^2$ = 3 x 0.7225 = 2.17 in. w.g.

(c) Similarly, the HP will be reduced in the ratio of $(\text{speeds})^3$ namely $(85/100)^3$

New HP = 160 x $(85/100)^3$ = 160 x 0.6141 = 98.26 HP.

Some formulae relating to fan calculations

1. H.P. of Ventilation

$$\text{H. P. in the air} = \frac{\text{PQ}}{33{,}000} = \frac{\text{Q x w. g. x 5.2}}{33{,}000}$$

$\text{P} =$ effective ventilating pressure in lbs. per sq. foot $=$ w. g. in inches x 5.2

2.

$$\text{Indicated H. P} = \frac{\text{PLAN}}{33{,}000} \text{ x 2 cysles}$$

where

P = pressure in lbs. per sq inch
L = stroke length
A = Area
N = No. of r. p. m

---

3. Overall mechanical efficiency $= \frac{\text{Air H.P.}}{\text{Ind H.P}}$

4. With a 3 − phase a. c. motor, H. P. Input $= \frac{\sqrt{3} \text{ x Volts x amperes x power factor}}{746}$

5. Brake H. P. = H. P. Input x efficiency.

6. Mechanical Efficiency of a fan $= \frac{\text{Air H.P.}}{\text{H.P input to motor}}$

7. Overall efficiency = fan efficiency x motor

Example 6.4

(a) What is the HP of ventilation produced in a mine which has 90,000 cub. ft. per min. circulated by a w.g. of 2 ins. ? What would be (b) the w.g. and (c) the HP if the quantity were increased to 120,000 cub. ft. per min. ?

Solution

(a)

$$\text{H. P. of ventilation } = \frac{\text{Q x w . g x 5.2}}{33{,}000}$$

$$= \frac{90{,}000 \text{ x } 2 \text{ x } 5.2}{33{,}000} = 28.36\ HP$$

(b) The w. g. would be greater in the ratio of the $(\text{quantity})^2$

$$\text{New w. g.} = 2 \text{ x} \frac{120^2}{90^2} = 2 \text{ x} \left(\frac{4}{3}\right)^2 = 2 \text{ x} \frac{16}{9} = \frac{32}{9} = 3.5 \text{ inches w. g}$$

(c) The HP will be greater in the ratio of the $(\text{quantity})^3$

$$\text{New HP} = 28.36 \text{ x} \left(\frac{120}{90}\right)^3 = 28.36 \text{ x} \left(\frac{4}{3}\right)^3 = 28.36 \text{ x} \frac{64}{27} = 67.22 \text{ HP}$$

Example 6.5

A fan is driven by a double horizontal steam engine, 15" cyls., 3 ft. stroke, mean effective pressure 40 lbs. per sq. inch, speed 50 r.p.m. the w.g. is 4.5 ins., and the quantity of air 100,000 cub. ft. per min. What is the overall efficiency ?

Solution

$$\text{Ind. HP} = \frac{\text{PLAN}}{33{,}000} \text{ x 2 cyls} = \frac{\text{40x3 x152x0.7854x50 r. p. m. x2x2 cyls}}{33{,}000} = 128.5 \text{ Ind HP}$$

$$\text{Air HP} = \frac{\text{Q x w. g x 5.2}}{33{,}000} = \frac{100{,}000 \text{ x } 4.5 \text{ x } 5.2}{33{,}000} = 70.9 \text{ HP}$$

$$\text{Overall mechanical efficiency } = \frac{\text{Air HP}}{\text{Ind. HP}} = \frac{10070.9{,}000 \text{ x } 4.5 \text{ x } 5.2}{128.5} = 0.552 = 55.2\%$$

Example 6.6

If the fan in example 6.5 had been driven by a d.c. motor taking a current of 150 amps. at a voltage of 550, what would then be the overall efficiency ?

Solution

$$\text{With a d.c. motor, HP input} = \frac{\text{volts x amps}}{746} = \frac{550\text{x}150}{746} = 100.6\text{ HP}$$

$$\text{Overall mechanical efficiency} = \frac{\text{Air HPvolts x amps}}{\text{HP Input to motor}} = \frac{70.9}{110.6} = 0.641 = 64.1\%$$

Example 6.7

If the fan in example 9.6 had been driven by a 3-phase a.c. motor taking a current of 19 amps. at a voltage of 3,000, the power factor being 0.8, what would then be the overall efficiency? And what would be the efficiency of the fan alone if the motor had an efficiency of 90%?

Solution

$$\text{With a 3} - \text{phase a.c. motor, HP Input} = \frac{\sqrt{3}\text{ x volts x amps x power factor}}{746}$$

$$= \frac{1.732\text{ x }3{,}000\text{ x }19\text{ x }0.8}{746} = 105.9\ HP$$

and Brake HP = 105.9 x 0.9 = 95.3 HP

Overall mechanical efficiency =Air HP/HP input to motor = 70.9/105.9= 67%

Mechanical efficiency of fan = Air HP/Brake HP of motor = 70.9/95.3= 0.744 = 74.4%

(Also overall efficiency = fan efficiency x motor efficiency = 0.744 x 0.9 = 0.67 = 67%)

Example 6.8

What quantity of air per minute is passing through a mine when the overall efficiency is 70%, the HP input to the motor is 90 HP and the w.g. is 4 inches?

Solution

$$\text{First find the HP in the air} = 70\%\text{ of }90\text{ HP} = 63\text{ HP}$$

$$\text{Then HP in the Air} = 63 = \text{Q x wg. x }\frac{5.2}{3300} = \text{Q x 4 x }\frac{5.2}{3300}$$

$$\text{By transposition, Quantity of air} = \text{Q} = \frac{63\text{x}33{,}000}{4X5.2} = 99{,}952\text{ cub. ft. per min.}$$

Theoretical Depression

The theoretical depression is that which is produced by an imaginary perfect fan working in a closed space and suffering no kinetic loss due to velocity of discharge or alternatively by a fan connected to an evasee chimney of infinite height so as to reduce the velocity of discharge to zero. This value is never reached in practice by any fan.

$$\text{Theoretical depression} = \text{T} = \frac{V^2}{g} \text{ ft of air column}$$

$$= \frac{WV^2}{g} \text{ lbs. per sq. ft}$$

V = tangential speed of blade tips in ft/sec
w = wt. of one cubic ft. of air in lbs. and
g = 32.2 ft/sec^2

This formula applies to radial bladed centrifugal fans and also to single stage air screw fans . For a centrifugal fan with curved blade.

$$\text{Theoretical depression} = \text{T} \ \frac{V^2}{g} \pm \frac{\text{Vu cot }\Phi}{g} \text{ft of air column}$$

Where
u =radial velocity of the air in ft. per second
cot = quantity in cub. ft. per sec / peripheral area of fan outlet in sq. ft.
Φ = the angle made by the blade tips with the tangential direction.

The peripheral area of fan outlet = circ. of fan x its width = πD x W

If the blades are curved forward positive sign is used and if the blades are curved backward the negative sign is used.

Example 6.9
What is the theoretical w.g. of a 14 ft. fan running at 210 r.p.m. on a closed fan drift? Assume w = 0.075 lb.

Solution

$$\text{Circumference of fan} = \pi \text{ D} = \frac{22}{7} \text{ x } 14 = 44 \text{ ft}$$

$$\text{tip speed} = 44 \text{ x } \frac{210}{60} = 154 \text{ ft. per sec}$$

$$\text{Theoretical depression} = \frac{\text{wV}^2}{g} = \frac{0.075 \text{ x } 154^2}{32.2} = 55.2 \text{ lbs per sq. ft} = 10.6 \text{ in w. g.}$$

Example 6.10

What is the w.g. wasted in imparting a velocity of 1,000 ft. per min. to air leaving the outlet of fan. Assume the weight of a cub. ft. of air to be 0.075 lb.

Solution

$$\text{Velocity head} \;=\; \text{h} = \frac{\text{V}^2}{2g} = \left(\frac{100}{60}\right)^2 \text{ x } \frac{1}{2X32.2} = \; 4.31 \text{ ft}$$

$$\text{Velocity pressure} \;=\; \text{p} \;=\; \text{wh} \;=\; 0.075 \text{ x } 4.31 \;=\; 0.323 \text{ lb. per sq. ft}$$

$$\text{Water gauge wasted} \;=\; \frac{0.323}{5.2} = \; 0.062 \text{ inch. w. g.}$$

Example 6.11

The evasee chimney of a fan has an area of 25 sq. ft. at the base and 100 sq. ft. at the outlet. Calculate the saving of w.g. and of HP due to the evasee when the output of the fan is 60,000 cub. ft. per min., assuming the density of the air to be 0.08 lb. per cub. ft.

Solution

$$\text{Airvelocity at base} \;=\; \frac{\text{Quantity}}{\text{Area}} = \frac{1000}{25} = \; 40 \text{ ft. per second}$$

$$\text{Airvelocity at outlet} \;=\; \frac{1000}{100} = \; 10 \text{ ft. per second}$$

$$\text{Airvelocity at outlet} \;=\; \frac{40^2 \; - \; 10^2}{2X \; 32.2} == \; 23.3 \text{ feet of motive column}$$

$$= \; 23.3 \text{ x } 0.08 \;=\; 1.864 \text{ lb. per sq. ft} \;=\; \frac{1.864}{5.2} = \; 0.36 \text{ inch w. g.}$$

$$\text{Gain of horsepower} \;=\frac{\text{PQ}}{33{,}000} = \frac{1.864 \text{ x } 60{,}000}{33{,}000} = \; 3.4 \text{ HP}$$

Equivalent Orifice of a Mine

The equivalent orifice of a mine is the area of an imaginary opening in a thin plate which offers the same resistance to the passage of air as is offered by the mine itself. It is the area of opening through which passes the same quantity of air as passes through the mine under the same pressure difference across this opening.

The theoretical volume of air that flows through an orifice depends upon the area, a, of opening in square feet and the velocity of air flow in feet per second. Friction being neglected, the velocity resulting from a head of h feet is given by the expression.

$$\text{Velocity} = \sqrt{2\text{gh}} \text{ feet per second}$$

$$\text{Q} = \text{Actual quantity flowing} = 0.65 \text{ x a} \sqrt{2\text{gh}} \text{ cubic feet per second}$$

$$\text{or Equivalent orifice in square feet} = \text{a} = \text{Q}$$

$$= \frac{\text{in cubic feet per sec}}{0.65 \text{ x} \sqrt{2\text{gh}}} \; 0.65 \text{ x a cubic feet per second}$$

$$\text{where } 0.65 = \text{coefficient of vena contracta}$$

$$\textit{and} \;\; \text{g} = \frac{32.2 \text{ ft}}{\text{sec}2.65}$$

Example 6.12

At a certain colliery, the volume of air is 325,000 cub. ft. per min. and the fan drift w.g. is 4 inches. What is the equivalent orifice of this mine? Assume w = 0.078 lb.

Solution

$$\text{h} = 4 \text{ x } 5.2 \text{ lbs. per sq. ft}$$

$$= \frac{4 \text{ x } 5.2}{0.078} = 267 \text{ ft of air column}$$

$$\text{Q} = 325{,}000 \text{ cub. ft. per} = \frac{325{,}000}{60} \text{ cub. ft. per sec.}$$

$$\text{Equivalent Orifice} = \text{a} = \frac{\text{Quantity in cub. ft. per sec}}{600.65 \text{ x} \sqrt{2\text{gh}}}$$

$$= \frac{325{,}000}{600.65 \text{ x} \sqrt{232.2\text{x}267}} = \frac{325{,}000}{39\text{x}131} = 63.6 \; sqft$$

CHAPTER 07

LAWS OF MINE AIR FRICTION

The laws of mine air friction are important because they show us how variations in the shape and size of airways affect the ventilation of a mine.

The ventilating pressure which is the difference of pressure between two ends of an airway is in fact a measure of the frictional resistance. The greater the resistance the greater must be the ventilating pressure (or water gauge) to overcome it.

Laws of Mine Air Friction

The laws of mine air friction were first enunciated by J.J. Atkinson in 1854. He embodied them in the shape of an equation known as Atkinsonian equation.

Mine air friction has four laws.

Law No. 1

The pressure P required to overcome friction is directly proportional to the area of the rubbing surface or

$$P \propto S,$$

where S = perimeter of airway x length.

Law No. 2

The pressure P required to overcome friction is directly proportional to the square of velocity or

$$P \propto V^2,$$

where V = Air velocity

Law No. 3

The pressure P required to overcome friction is inversely proportional to the sectional area of the airway or

$P \propto 1/a$,

where a = sectional area of airway in sq. feet.

Law No. 4

The pressure P required to overcome friction varies as the nature of rubbing surface, or, in other words, as the coefficient of friction or

$P \propto K$,

where

K is the coefficient of friction.

The Atkinsonian Equation

If we combine all the four laws, the equation becomes as

$$\text{Pressure overcoming friction} = P = \frac{KSV^2}{a}$$

where

P = ventilating pressure in lbs. per sq. foot or in inches of water gauge.
a = sectional area of airway in sq. feet.
S = area of rubbing surface in square feet = perimeter x length

V = velocity of air current in thousands of feet per min.

or

$$V = \frac{Q}{a} = \frac{\text{Quantity in thousands of cubic feet per min}}{\text{Sectional area}}$$

K = coefficient of friction expressed in the same unit as P in the equation

Example 7.1

What water gauge is required to pass 9000 cubic feet per min through an airway 6ft. x 6ft. and 4000 feet long, assuming K = 0.0012 inches w.g.

Solution

We have

$$\begin{aligned} K &= 0.0012 \text{ inches w.g} \\ S &= \text{Perimeter x length} \\ &= (6 + 6) \text{ x } 2 \text{ x } 4000 \text{ sq. ft.} \\ &= 24 \text{ x } 4000 \text{ sq. ft.} \\ a &= 6 \text{ x } 6 = 36 \text{ sq. ft.} \end{aligned}$$

$$V = \frac{Q}{a} = \frac{9000/1000}{6 \text{ x } 6} = \frac{9}{36} = \frac{1}{4} = 0.25 \text{ thousand of ft. per min.}$$

$$P = \frac{KSV^2}{a} = \frac{0.0012 \text{ x } 24 \text{ x } 4000 \text{ x } (0.25)^2}{36} = \frac{0.0012 \text{ x } 96000 \text{ x} 0.0625}{36}$$

$$= 0.2 \text{ inch w.g}$$

The Coefficient of Friction

The coefficient of friction is a "proportionality factor" K introduced in the Atkinsonian equation. It is defined as the ventilating pressure which is required to overcome the frictional resistance of one square foot of rubbing surface when the velocity of air is 1000 ft. per minute. Its equivalent numerical value may be calculated from the expression:

$$K = \frac{Pa}{SV^2}$$

when the numerical values of P, a, S and V are known,

where P = ventilating pressure in lbs. per square foot or in inches of w.g.
a = cross section area of airway in sq. feet
S = area of rubbing surface in sq. feet = perimeter x length
V = velocity of air in thousands of feet per minute.
= Q/a

Factors Affecting the Coefficient of Friction

These are:-

1. The nature of rubbing surface, whether rough or smooth.
2. The existence of sharp bends, sudden changes in sectional area, obstructing tubs and timbers, jagged surfaces, manholes, road crossings, etc., resulting in the production of eddy currents and turbulent motion of the air.

How to Reduce the Coefficient of Friction

1. **Shaft**, inclines and tunnels should be of large diameter, smooth lined and fitted with rope guides to eliminate obstructing buntons.

2. **The fan drift** should be of ample area and arranged to give stream-lined flow from the high level to the fan drift.

3. **Main underground** roadways should be large, straight and of uniform area, with smooth lining.

4. **Timbered Roadways** should have packed walls between the timber sets to give conditions approximately of a smooth surface roadway.

5. **All bends** should be of large radius. The rounding of a right angle elbow approximately halves the resistance of the bend.

Typical Values of Coefficient of Friction

The numerical value of coefficient of friction varies from about 0.002 lb. per sq. ft. for smooth lined roadway upto about 0.01 lb. per sq. ft. for timbered roadways. The value of K for steel arches lining may range from 0.004 lb. per sq. ft. when bricked and lined all round to 0.0085 lb. per sq. ft. when poorly lined and unbricked.

Example 7.2

A quantity of air 300,000 cub ft. per minute is passing though two shafts (down cast and upcast) 18 feet diameter and 600 yards deep, the coefficient of friction being 0.003 lb. per sq. ft. What w.g. is expended on overcoming shaft friction?

Solution

We apply the formula

$$\mathrm{P} = \frac{KSV^2}{\mathrm{a}}$$

where

$$\mathrm{K} = 0.003\ \mathrm{lb.\ Per\ sq.ft}$$

$$\mathrm{a} = \mathrm{area\ of\ shaft} = \frac{\pi}{4}\ X\ d^2$$

$$\mathrm{V} = \frac{\mathrm{Q}}{\mathrm{a}} = \frac{\frac{300{,}000}{1000}}{254.5} = \frac{300}{254.5} = 1.179$$

$$\begin{aligned} \mathrm{S} &= \mathrm{perimeter\ x\ length} \\ &= (\pi\ \mathrm{x\ d})\mathrm{x\ length\ x\ 2\ shafts} \\ &= (3.1416\ \mathrm{x}\ 18)\ \mathrm{x}\ 1800\ \mathrm{x}\ 2 \\ &= 56.55\ \mathrm{x}\ 3600 = 203{,}580\ \mathrm{sq.ft} \end{aligned}$$

Putting the values,

$$\mathrm{P} = \frac{0.003\ \mathrm{x}\ 203{,}580\ \mathrm{x}\ (1.179)^2}{254.5}$$

$$= \frac{0.003\ \mathrm{x}\ 203{,}580\ \mathrm{x}\ 1.39}{254.5} = 3.34\ \mathrm{lbs.\ per\ sq.ft}$$

$$= \frac{3.34}{5.2} = 0.64\ \mathrm{inches\ w.g}$$

Example 7.3

A main intake is half a mile long, 7.5 ft. high and 12 ft. wide. The air velocity is 15 ft. per second. The parallel main return is of similar length, height and width and an equal quantity of air travels therein. The w.g. on the main separation doors is 2.80 inches and another w.g. connecting the main intake and return is 1.48 inches. What is the coefficient of friction.

Solution

We apply the formula

$$K = \frac{Pa}{SV^2}$$

P = difference of pressure between main separation door and main intake and return
= $2.80 - 1.48 = 1.32$ inches w.g
= $1.32 \times 5.2 = 6.864$ lbs. per sq. ft

a = $7.5 \times 12 = 90.0$ sq. ft

S = perimeter x length
= $(7.5 + 12) \times 2 \times 5280$
= 39×5280 sq. ft.

$$V = 15 \text{ ft. per second} = 15 \times 60 = 900 \text{ ft. per} = \frac{900}{1000} = 0.9\ thousand$$

Putting the values,

$$K = \frac{6.864 \times 90}{39 \times 5280 \times 0.9 \times 0.9} = 0.0037 \text{ lbs sq. ft}$$

Variation of Pressure with Rubbing Surface

The first law of friction states that the pressure is directly proportional to the rubbing surface (perimeter x length). Thus, if one airway is twice as long as another (other things being equal), it will offer twice as much frictional resistance and require twice as much ventilating pressure for a given quantity of air.

Example 7.4

If one airway is 6 ft. x 6 ft. and 4000 ft. long and another airway is 8 ft. x 4.5 ft. and 6000 ft. long, what water gauge would be required to pass 9000 cubic ft. of air per minute. The original w.g. being 0.2 inches.

Solution

$$\frac{\text{Final w.g}}{\text{Original w.g}} = \frac{\text{Rubbing surface of rectangular airwayFinal w.g}}{\text{rubbing surface of square airway}}$$

$$\text{Final w.g.} = \text{Original w.g.} \times \frac{\text{Rubbing surface of rectangular airwayFinal w.g}}{\text{rubbing surface of square airway}}$$

$$= 0.2 \times \frac{(8 + 4.5) \times 2 \times 6000}{(6 + 6) \times 2 \times 400} = 0.2 \times \frac{25 \times 6000}{25 \times 400} = 0.3125\ inches\ \ w.g.$$

Variation of Pressure with Velocity

The second law of friction states that the pressure is directly proportional to the square of the velocity. For example if the quantity is doubled, its velocity is doubled and the friction is doubled twice, i.e., it is multiplied by 2 x 2 = 4. Similarly if the velocity is trebled, the friction is trebled twice i.e. it is multiplied by 3 x 3 = 9.

Example 7.5

If 4 inches w.g. is required to pass a certain quantity of air through a mine. What water gauge will be required if the quantity of air is (a) increased by 40% ((b) reduced by 40% without any change in the airway?

Solution

In this case K, S and a are constant and so may be ignored, the only change being in the velocity of air.

$$P \propto V^2$$

a) Quantity increased by 40%. Here the two values of V^2 are relatively 140^2 and 100^2

$$\frac{\text{Final w.g}}{\text{Original w.g}} = \frac{(\text{Final velocity})^2}{(\text{Original velocity})^2}$$

$$\text{Final w.g.} = \text{Original w.g. x } \frac{(\text{Final velocity})^2}{(\text{Original velocity})^2}$$

$$= 4 \text{ x } \frac{(140)^2}{(100)^2} = 4 \text{ x } \frac{49}{25} = \frac{196}{25} = 7.84 \ inches \ w.g.$$

b) If quantity is reduced by 40%

$$\frac{\text{Final w.g}}{\text{Original w.g}} = \frac{(\text{Final velocity})^2}{(\text{Original velocity})^2}$$

$$\text{Final w.g.} = \text{Original w.g. x } \frac{(\text{Final velocity})^2}{(\text{Original velocity})^2}$$

$$= 4 \text{ x } \frac{(60)^2}{(100)^2} = 4 \text{ x } \frac{(3)^2}{(5)^2} = 4 \text{ x } (0.6)^2 = 4 \text{ x } 0.33 = 1.44 \ inches \ w.g.$$

The Quantity Laws

The quantity law may be derived from the formula:-

$$P = \frac{KSV^2}{a}$$

$$\text{or} \quad Pa = KSV^2$$

Multiplying both sides by a^2

$$Pa^3 = KSa^2V^2$$

$$As \quad aV = Q$$

$$So \quad Pa^3 = KSQ$$

$$or \quad Q = \sqrt{\frac{Pa^3}{KS}}$$

Example 7.6

Calculate the quantity of air that will pass through an airway 10 ft. x 8 ft. and 2,000 ft. long with a w.g. of 2 ins. Assume K = 0.01 lb. per sq. ft.

Solution

We use formula

$$Q = \sqrt{\frac{Pa^3}{KS}}$$

$$P = 2 \text{ x } 5.2 \text{ lbs. per sq. ft.}$$

$$a = 10 \text{ x } 8 = 80 \text{ sq. ft.}$$

$$K = 0.01 \text{ lb. per sq. ft.}$$

$$S = (10 + 8) \text{x } 2 \text{ x } 2000 \text{ sq. ft.}$$

$$= 36 \text{ x } 2000$$

$$Q = \sqrt{\frac{Pa^3}{KS}} = \frac{\sqrt{(2 \text{ x } 5.2 \text{ x } 80 \text{ x } 80 \text{ x } 80)}}{\sqrt{(0.01 \text{ x } 36 \text{ x } 2{,}000)}} = \sqrt{7{,}396} = 86 \; thousand$$

$$= 86 \text{ x } 1000$$

$$= 86{,}000 \text{ cub. ft. per min.}$$

Example 7.7

A quantity of 130,000 cub. ft. per min. is passing with a w.g. of 3.3 ins. What quantity would pass if the w.g. be reduced to 2.5 ins. with the same conditions underground?

Solution

Here, Q is the unknown factor and above formula should again be employed. But a, K and S remain constant and may be ignored. Hence Q ∝ P

$$\frac{\text{Final Quantity}}{\text{Original Quantity}} = \frac{\sqrt{(\text{Final Quantity})}}{\sqrt{\text{Original Quantity}}} = \frac{\sqrt{P_2}}{\sqrt{P_1}} = \frac{\sqrt{2.5}}{\sqrt{3.3}} = \sqrt{0.7575} = 0.87$$

$$\text{Final Quantity} = \text{Original Quantity x } 0.87 = 113{,}100 \text{ cub. ft. per min.}$$

Example 7.8

here are two exactly similar airways except that one is double the length of the other. If both are subject to the same pressure, in what proportion will the quantity of air passing through the shorter airway exceed that passing through the longer one?

Solution

In this case, P, a, and K are constant

$$Q \propto \sqrt{\frac{1}{S}}$$

Let the value of S in short airway = 1, then value of S in long airway = 2

$$\frac{\text{Q in short airway}}{\text{Q in long airway}} = \frac{\sqrt{(1)}}{\sqrt{\frac{1}{2}}} = \frac{1}{0.7071} = \frac{1.4142}{1}$$

$$\text{Q in short airway} = \text{Q in long airway x } 1.4142$$

In other words, there is 1.4142 times as much air in the shorter airway as in the longer one, or 41.42% more.

Example 7.9

If a pressure of 2 ins. w.g. will cause 20,000 cub. ft. per min. to pass through an airway 6 ft. x 6 ft., what water gauge will be required to pass the same quantity of air if the airway is enlarged to 9 ft. wide x 8
ft. high ?

Solution

Here, P is the unknown factor and Quantity formula should be considered. The factors K and Q are constant and may be neglected.

The changes produced are in the sectional area and rubbing surface, and so $P \propto S/a^3$ so we find the relative value of S/a^3 for each airway, this will give us the ratio of the pressures.

$$\text{In the first airway, the relative value of } \frac{S}{a^3} = \frac{(6+6)\text{x } 2}{(6 \text{ x } 6)^3} = \frac{24}{(36)^3} = (X)$$

$$\text{In the first airway, the relative value of } \frac{S}{a^3} = \frac{(9+8)\text{x } 2}{(9 \text{ x } 8)^3} = \frac{34}{(72)^3} = (Y)$$

$$\text{Final w. g.} = \text{ Original w. g. x } \frac{(Y)}{(X)} = \frac{34 \text{ x } 36^3}{72^3 \text{ x } 24} = \frac{2 \text{ x } 34}{2^3 \text{ x } 24} = \frac{17}{48} == 0.35 \text{ ins. w. g.}$$

The Power Laws

The power in the air, in foot pounds per minute, is equal to the total force (Pa) in lbs. multiplied by the velocity of the air in feet per minute (V).

$$\text{Hence power } = \text{ P a V ft. lbs. per minute.}$$

$$\text{HP } = \frac{\text{PaV}}{33{,}000} = \frac{\text{PQ}}{33{,}000} = \frac{\text{Qx w. g. x } 5.2}{33{,}000}$$

Where

$$\text{P } = \text{ Ventilating pressure in lbs. per sq. ft.}$$

From the formula, it follows that: –

a) $\text{HP} \propto \text{Q}$ if the airways are so altered that the pressure remains constant.
b) $\text{HP} \propto \text{P}$ if the airways are so altered that the quantity remains constant

Variation of Power with Quantity in a given Mine

Now we already know that

$$P = \frac{KSQ^2}{a^3} \text{lbs. per sq. ft}$$

Hence, taking Q in thousands of cu. ft. per min.

$$\text{Power} = P \times Q = P = \frac{KSQ^2}{a^3} \times Q = \frac{KSQ^3}{a^3} \dots\dots\dots\dots (6)$$

From the formula, it follows that: –

When K, S and a are constant, i. e. when the airways remain the same,

$HP \propto Q^3$, or the HP varies as the cube of the quantity of air.

Example 7.10

If 40 HP will pass 20,000 cub. ft. per minute through a mine, what power will be required to pass 30,000 cub. ft. per minute through the same mine ?

Solution

$$\frac{\text{Final Power}}{\text{Initial Power}} = \frac{(\text{Final Quantity})^3}{(\text{Initial Quantity})^3} = \frac{{Q_2}^3}{{Q_1}^3} = \frac{30^3}{20^3} = \frac{3^3}{2^3} = \frac{27}{8}$$

$$\text{Final Power} = 40 \times \frac{27}{8} = = 135 \text{ HP.}$$

Problems Related to Splitting

In practice air is never arranged to pass around the underground workings in one continuous current, but is divided up into a number of "splits" or districts, each ventilated by an independent current of air. The main splits should separate as soon as possible after leaving the downcast shaft, and should be brought as near as possible to the upcast before being reunited. This reduces to a minimum the length of trunk airways, in which, as in the shafts, the velocity is high and the friction excessive.

The advantages of splitting are as follows:-

1. A much larger total quantity of air is circulated through the mine for the same expenditure of pressure and of power.
2. Purer air is supplied to each district and the district haulage roads can be ventilated by intake air.
3. The percentage of firedamp in the air at the face is reduced, for firedamp given off in one split does not pass to another and so vitiate the air cumulatively.

4. An explosion is more likely to be limited to one district, unless extended by coal dust.
5. Air velocities are reduced, both in the roadways and at the face, so reducing the frictional resistance and also helping to prevent dust being raised in the air.
6. One or more splits may be regulated, where necessary to secure a proper apportionment of the air to the various districts.
7. Neighbouring splits are not adversely affected by a derangement of the ventilation, (e.g. a fall of roof) in another split.

Example 7.11

A total quantity of 70,000 cubic feet per minute passes into four splits, as follows:-

Split A, 6 ft. x 5 ft., 500 yds. long ; Split C, 6 ft. x 4 ft., 350 yds. long;
Split B, 6 ft. x 6 ft., 400 yds long; Split D, 5 ft. x 4 ft., 300 yds. long;

Calculate the quantity going into each split.

Solution

All problems of this kind are governed by formula,

$$Q = \sqrt{\frac{Pa^3}{KS}}$$

But as all the splits are subject to the same common pressure P; and as it is usually assumed that the coefficient of friction K is the same for all the splits; and as the relative quantities passing depend only on factors which differ; we may say:-

Relative quantity $= \sqrt{\frac{a^3}{S}}$

If, now, we calculate the numerical value of the relative quantity for each split, a series of four relative values will be obtained which bear the same ratio to one another as are borne by the actual quantities of air flowing. The actual quantities may then be obtained by simple proportion.

In split A, the area a is 6 x 5 = 30 sq. ft; the perimeter is (6 + 5) x 2 = 22 ft; and the length is 500 yds. = 1,500 ft.

$$\text{Then relative quantity } = \frac{\sqrt{30^3}}{\sqrt{22\text{x } 1{,}500}} = \frac{\sqrt{9}}{\sqrt{11}}\ 0.905$$

$$\text{In split B,: relative quantity } = \frac{\sqrt{36^3}}{\sqrt{24\text{x } 1{,}200}} = \sqrt{1.62} = 1.273$$

In split C, : relative quantity $= \frac{\sqrt{24^3}}{\sqrt{20\text{x } 1{,}050}} = \sqrt{0.658} = 0.811$

In split D, : relative quantity $= \frac{\sqrt{20^3}}{\sqrt{18\text{x } 900}} = \sqrt{0.494} = 0.703$

Sum of relative quantity $= \mathbf{3.692}$

But sum of actual quantities $=$ 70,000 cub. ft. per min.

To find actual quantities in each split

In split A, Q $= \frac{70{,}000}{3.692} = \text{ x } 0.905 = 18{,}960 \text{ x } 0.905 = 17{,}159$ cub. ft. per min.

In split B, Q $= \frac{70{,}000}{3.692} \text{ x } 1.273 = 18{,}960 \text{ x } 1.273 = 24{,}136$ cub. ft. per min.

In split C , Q $= \frac{70{,}000}{3.692} \text{ x } 0.811 = 18{,}960 \text{ x } 0.811 = 15{,}377$ cub. ft. per min.

In split D, Q $= \frac{70{,}000}{3.692} \text{ x } 0.703 = 18{,}960 \text{ x } 0.703 = 13{,}329$ cub. ft. per min.

Total $= \mathbf{70{,}001}$ cub. ft. per min

CHAPTER 08

AIR MEASUREMENT

8.1 INTRODUCTION

The ventilating system of a mine may be considered under three headings: -

(i) Qualitative Surveying

It involves:-

a) the determination of the firedamp content of the mine air by means of safety lamp or by some forms of special firedamp detector; and

b) the systematic sampling and chemical analysis of the air at strategic points in the roadways and at working faces.

(ii) Pressure Surveying

It involves: -

a) the determination of the pressure drop or water gauge expended from point to point, and

b) the determination of the horsepower absorbed in each section of the mine.

(iii) Quantity Surveying

It involves: -

a) the measurement of air velocity and

b) the determination of the quantity of air flowing in various parts of the mine.

In this chapter, we shall confine ourselves to the quantity surveying only. Measurement of the quantity of air is required for these reasons:-

a) To ascertain the distribution of the air throughout the mine – in main roads and splits, and more particularly, in the working faces of each part of a mine.

b) To locate leakages between intakes and returns and to enable steps to be taken for their elimination.
c) In fan tests and pressure surveys to enable calculation of horsepower, efficiency, resistance, and velocity corrections to be made.

In general, its purpose is to assist the management in providing adequate ventilation and ensuring that the proper quantity of air is reaching the places where it is needed. Periodical air measurement at specified places is laid down in the regulation of Mining Labour Code which should be observed strictly.

To calculate the quantity of air flowing, it is necessary to:-

1. Ascertain the cross-sectional area of the passage in square feet = a.
2. Measure the velocity of the air-current in feet per minute = V.

Then quantity of air = area x velocity = a x V cubic feet per minute.

8.2 Measurement of Velocity

The velocity of an air current may be measured by means of:-

1. Smoke or dust cloud;
2. Anemometer;
3. Velometer;
4. Pitot tube.

8.2.1 Smoke or Dust Method

The procedure briefly is as follows:-

1. Select a length of road AB, say, 100 feet long and of uniform area as shown in Fig. 8.1
2. Observe the time in seconds required for a smoke to traverse the measured distance. Two men are required, one at the windward end to produce the cloud and the other on the other end to note the time period.
3. Calculate the velocity of air V in feet per minute.

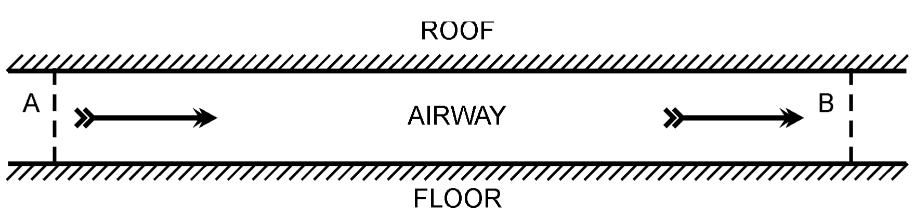


Fig. 8.1

In a naked light mine, smoke may be most easily produced by igniting a fuse or a pinch of gunpowder, but this is not permissible in a safety lamp mine. In the later case, a cloud of fine dust may be thrown into the air, or the simple apparatus as shown in Fig. 8.2 may be used.

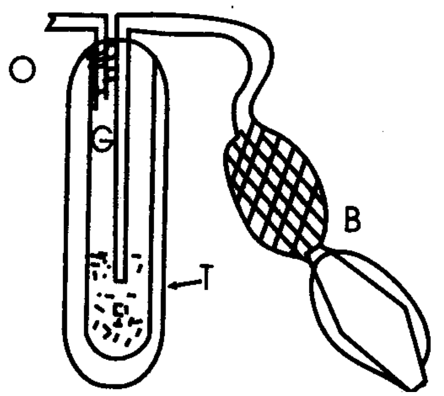


Fig. 8.2

It consists of a glass test tube T containing broken pieces of porous pot, in which titanium tetrachloride (a liquid) is absorbed. The test tube T is fitted with glass tubing G, connected to the rubber bulbs at B. When the lower bulb is squeezed or pumped, air charged with tetrachloride vapour issues from the tube O, immediately forming a white vapour by interaction with the moisture of the atmosphere. The cloud consists of fine particles which are suspended in the atmosphere longer than ordinary dust and are readily carried along by the air current.

The smoke method may be adopted

a) where no instrument is available or

b) when it is desired to estimate very low velocities of air current, below the range of an anemometer.

Example 8.1

A smoke cloud takes 6 seconds to travel a distance of 54 feet in an airway 9 ft. wide and 5 ft. 9 inches high. What quantity of air is passing per minute?

Solution

$$\text{Area of airway} = 9 \text{ x } 5.75 = 51.75 \text{ sq. ft.}$$

$$\text{Velocity of air} = \frac{54}{6} = 9 \text{ ft. per second} = 540 \text{ ft. per minute}$$

$$\text{Quantity of air} = 51.75 \text{ x } 540 = 27{,}945 \text{ cubic ft per minute.}$$

8.2.2 Anemometer

An anemometer consists of a small fan, the vanes of which are set at an angle of 40^0 to 45^0 to the direction of air-flow. The vanes revolve when the instrument is placed in the air current. The shaft or spindle actuates through gearing, a series of pointers on the dial face of meter, so indicating the distance in feet traveled by the air in a given time. A clutch or disconnector is fitted to enable the dial pointers to be put in or out of gear as required. The instrument is fitted with handle rod of required length to enable the operator to hold the instrument well away from himself. The Figure 8.3 shows a simple type of an anemometer.

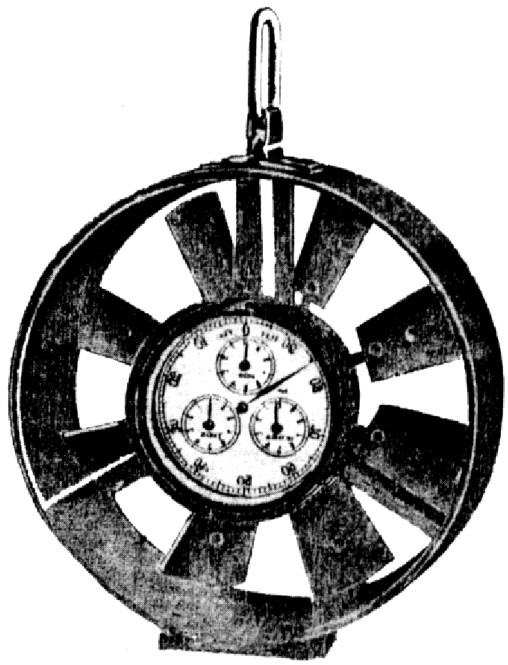


Fig. 8.3

An anemometer usually has one large dial and three, four, or five smaller inner dials as shown in Figures 8.4 and 8.5. Large dial is marked off into 100 divisions each representing one foot of air-travel. The smaller dials are each marked off into 10 divisions. The first dial, E reading in hundreds, the second D reading in thousands, the third C, in tens of thousands, the fourth B, in hundreds of thousands and the fifth A, in millions.

Reading the anemometer

Always start with the dial of highest denomination (A) and note the last figure passed by the pointer. Then proceed similarly with the other dials in proper descending sequence. On this basis, the reading of the instruments in Fig. 8.4 is as under:-

Dial A =1	Dial C = 8	Dial E = 9
Dial B = 6	Dial D = 9	Large Dial = 86

It follows that in this case instrument reading is 1,689,986. It may be noted that it is initial reading which was taken before the instrument was taken into the air for the measurement of air velocity.

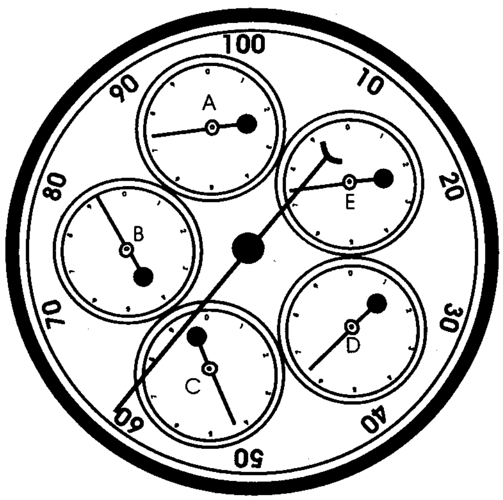


Fig. 8.5. Final Reading

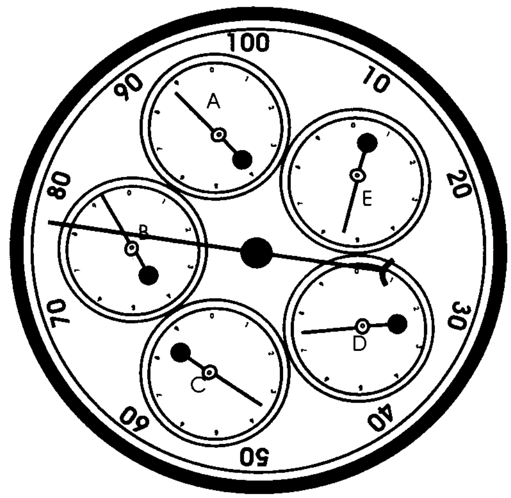


Fig. 8.4. Initial Reading

Suppose then, the instrument is taken into the air stream for ten minutes and final reading as indicated in Fig. 8.5 is recorded as under:-

Dial A = 1	Dial C = 9	Dial E = 8
Dial B = 6	Dial D = 3	Large Dial = 13

It follows that in this case final reading of the instrument is 1,693,813.

So Final reading	= 1,693,813 ft
Initial reading	= 1,689,985 ft
Distance in 10 minutes	= 1,693,813 – 1,689,985 = 3,828ft
Apparent Velocity	= 3,828 ÷ 10 = 3,82.8 ft. per minute

Example 8.2

An anemometer has four dials. The long pointer on the big dial reads between 94 and 95. Of the three inner dials, one is marked 'HDS' and the pointer is between 1 and 2, another is marked 'THDS' and the pointer is between 4 and 5 and the third is marked 'T. THDS' and the pointer is between 8 and 9. What is the reading of the instrument?

Solution

The pointer last passed on ten thousands dial = 8

Thousand	= 4
Hundreds	= 1
Units	= 94
Reading of the instrument	= 84,194

8.2.3 Velometer

The velometer is an air measuring instrument which directly indicates air velocities in feet per minute without the necessity of timing or mathematical calculations. No conversion tables or stopwatches are needed as the pointer directly indicates the air speed. It is usually fitted with the two scales, the lower range reading from 30 to 300 ft. per min. and the high range from 300 to 3,000 ft. per min. Fig 8.6 shows a sketch of a velometer.

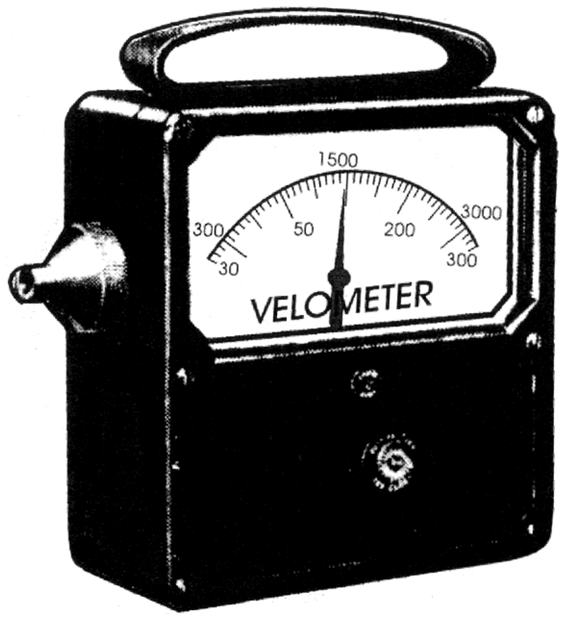


Fig. 8.6.

By suitable design however the instrument may be made to read as low as 10 ft. per min. while high range may also be increased to 6,000 ft. per min. The velometer thus has a wider range than the anemometer and in particular can be used for accurately measuring very low velocities.

Advantages of the Velometer

Compared with the anemometer, the velometer possesses the following advantages:-

1. Instantaneous readings of velocity can be made where a number of spot readings are required. As such velometer readings can be taken on main haulage roads in a short time between successive trains of tubs.
2. Errors due to all angles of deviation (yaw) form the normal upto about 30 degrees are negligible.
3. The instrument is sensitive to low velocities, below the range of anemometer. It can thus be used for measurements near coal face and in the detection of leakage currents.

8.2.4 The Pitot Tube

The pitot tube is a pressure measuring instrument whose readings must be converted by calculation to equivalent velocity measurements. Like the velometer, the pitot tube gives "spot" readings only and the average velocity over an airway must be found by taking a number of equally spaced readings and averaging them. In a normal way, it is not recommended for velocity less than abut 1,000 ft per min.

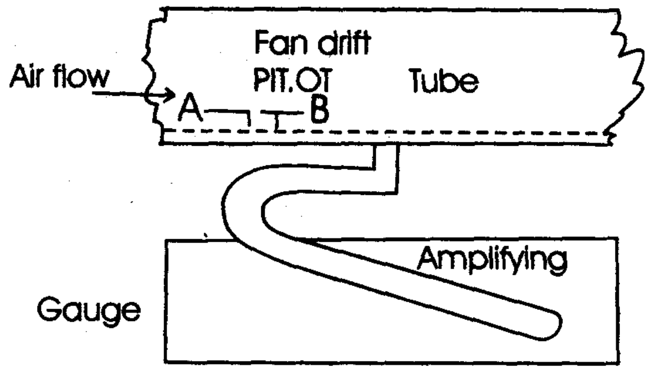


Fig. 8.7

The principle of the pitot tube is shown in Fig.8.7. It consists essentially of two tubes A & B connected by means of rubber tubing to the two limbs of a water gauge or manometer. One tube, A has its end drawn out to form an elongated cone and it is arranged to point up-stream, facing the air current. It records the total pressure of the air (i.e. static pressure plus velocity pressure). The other tube B, is cut off square and is fitted with a plain disc having a hole in the centre. It is arranged at right angles to the air-stream and records only static pressure of the air. It follows that the difference of level of the liquid in the two limbs of the manometer is proportional to the velocity of the air.

Calculation of Velocity from Pitot Tube Readings:-

The relation between the observed water gauge and the velocity of the air is given by the expression:-

$$\text{Velocity pressure} = P_V = \frac{wV^2}{2g} = \frac{wV^2}{232.2}\text{Lbs. per sq. ft.}$$

$$\text{Where w} = \text{weight of a cubic foot of air} = \frac{1.325}{459 + F}$$

V = air velocity in feet per second.
B = barometer in inches of mercury.
F = air temperature in degrees F.

$$\text{Hence, velocity in feet per second} = V = \frac{\sqrt{64.4\,P_v}}{\sqrt{W}} = 8.02\frac{\sqrt{P_V}}{\sqrt{W}}$$

$$\text{And velocity in feet per minute} = V = 8.02 \text{ x } 60\frac{\sqrt{P_V}}{\sqrt{W}} = 481\frac{\sqrt{P_V}}{\sqrt{W}} = 481\frac{\sqrt{5.2\,w.g}}{\sqrt{W}}$$

$$= 1098\frac{\sqrt{w.g}}{\sqrt{W}}$$

Example 8.3

It is observed that the velocity pressure indicated by a pitot tube is 0.027 inch w.g. The barometric pressure is 30 ins. of mercury and the air temperature 71^0 F. What is the velocity of the air?

Solution

$$\text{Density of the air} = \frac{1.325 \times 30}{459 + 71} = \frac{39.75}{530} = 0.075 \text{ lb per cubic ft}$$

$$\text{Air Velocity} = 1{,}098 \times \frac{\sqrt{0.027}}{\sqrt{0.075}} = 1{,}098 \times \sqrt{0.36} = 1{,}098 \times 0.6 = 658.8 \text{ ft. per min.}$$

MEASUREMENT OF AREAS

1. Squareor Rectangular

If the airway is square or rectangular in section, its area is easily found by measuring the height and width and multiplying the two dimensions together. In other cases the following formulae are used:-

Fig. 8.7 (a, b, c, d, e, f) shows the sketches of different shapes of roadways. The areas can be calculated as follows:-

a) Circular Shafts or Airways Fig. 8.8(a)

Area = $(\text{diameter})^2$ x 0.7854

b) Elliptical Shafts Fig. 8.8(b)

Area = (D x d) x 0.7854

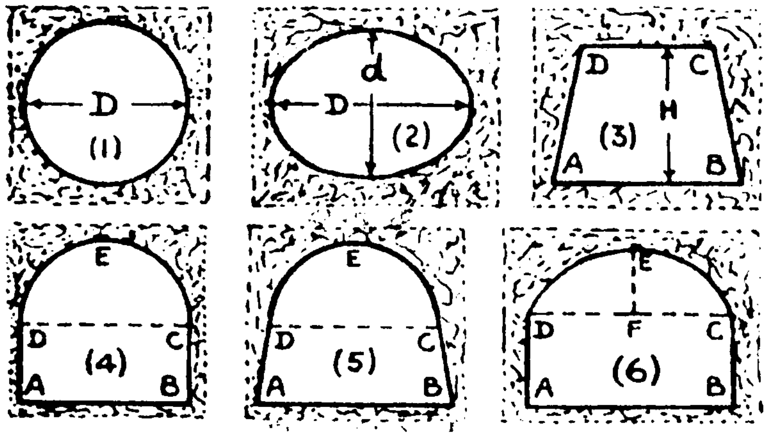
c) Trapezoidal Airways Fig 8.8(c)

A trapezoid is a four sided figure having two sides parallel.

$$\text{Area} = \frac{\text{sum of parallel sides}}{2} \times \text{ perp. height.}$$

$$= \frac{AB + CD}{2} \times H$$

a b c



d e f

Fig. 8.8

d) Arched Airways Fig. 8.8 (d,e)

Always make a neat and fully dimensioned sketch, based on the data given and calculate the area in two portions namely:-

a) The area of the upper semi circle, EDC.
b) The area of the lower rectangle ABCD Fig. 8.8(d) or trapezoid Fig. 8.8(e).

Note that point E is the crown of the arch, whilst C and D are called the springing points. Fig. 8.8(d) shows a straight legged arch, whilst Fig. 8.8((e) shows a splayed arch.

e) Segmental Airway (f)

Fig. 8.8(f). In this case, the lower portion is a rectangle, the upper portion being a segment less than a semi circle and

Segmental area = $1.33\ h \times (0.625h)^2 + (0.5c)^2$
Where h = EF = height of arc, c = CD = chord of arc.

f) Irregular Airways

The general principle to follow is to make a dimensioned sketch and to divide the irregular area into a number of parts, each of which is easily measurable. Thus:

Fig. 8.9(a) Area = trapezoid ABCD + trapezoid CDEF.
Fig. 8.9(b) Area = rectangle ABCD + triangle AGB + trapezoid EFGH.

Fig. 8.9(c) In this case, AB and CD are almost parallel, but the sides are irregular. The figure may be divided by horizontal lines into a number of trapezoids, the area of each of which may be readily calculated.

Fig. 8.9(d) In this case, the roof has practically arched itself and the area may be divided vertically into a number of trapezoids MNOL, the separate areas being added together.

Fig. 8.9(e) Here, the road is of very irregular outline. By lines at right-angles, divide the area into a number of equal squares of known area. Count the number of whole squares and, for the broken squares, neglect each which is less than half a square and count each which is greater than half a square. This is called measuring on the "give and take" principle.

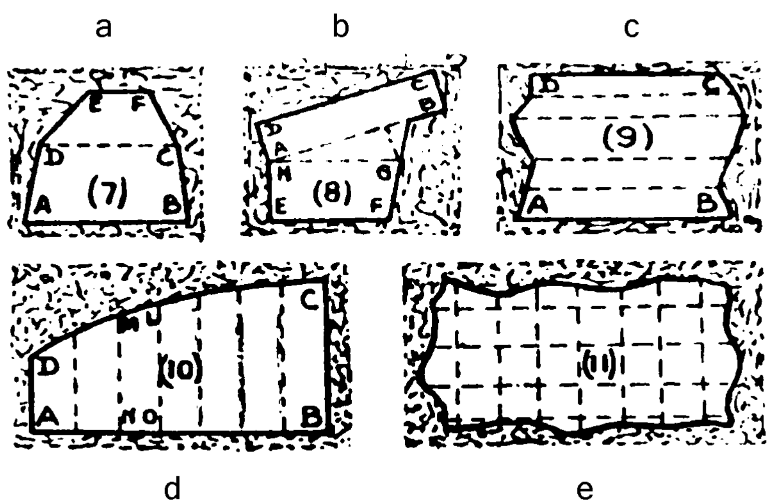


Fig. 8.9

8.4 NUMERICALS

Example 8.4.1

An airway is 7 ft. high, 10 ft. at the top and 12 ft. wide at the bottom. The air velocity is 450 ft. per minute. What is the quantity?

TRAPEZOIDAL AIRWAY

$$\text{Area of airway} = \frac{(10 + 12)}{2} \text{x } 7 = 11 \text{ x } 7 = 77 \text{ square feet.}$$

$$\text{Quantity of air} = \text{a x V} = 77 \text{ x } 450 = 34{,}650 \text{ cubic feet per minute.}$$

Example 8.4.2

In an airway of 50 sq. ft. area, the initial reading of an anemometer was 4,684, and the final reading at the end of a 2 minutes' run was 5,438. The correction required is +25 ft. per minute. Calculate the volume of air flowing.

VELOCITY AND QUANTITY

Apparent velocity of air = (5,438 – 4,684) ÷ 2 = 754 ÷ 2 = 377 feet per minute.

True velocity of air = 377 + 25 = 402 feet per minute.

Quantity of air = a x V = 50 x 402 = 20,100 cubic feet per minute.

Example 8.4.3

(a) A fan drift is 17 ft. high to the crown of the semi-circular arch, and 22 ft. wide between the vertical side walls. Calculate its area.

(b) The initial and final readings in an anemometer measurement extending over 2 minutes were 7,346 and 10,578, the correction being –88 ft. per min. Calculate the volume of air flowing.

QUANTITY IN FAN DRIFT

a) $\text{Diameter of semi} - \text{circle} = 22 \text{ ft.}$

$\text{Radius of semi} - \text{circle} = 11 \text{ ft.}$

$\text{Height of rectangle} = 17 \text{ ft.} - \text{radius} = 17 - 11 = 6 \text{ ft}$

$\text{Area of rectangle} = 22 \text{ x } 6 = 132 \text{ sq. ft.}$

$$\text{Area of semi} - \text{circle} \quad \frac{22 \text{ x } 22 \text{ x } 0.785}{2} = 190 \text{ sq. ft.}$$

$\text{Total area} = \mathbf{322\ sq.ft}.$

b) $\text{Difference of anemometer readings} = 10{,}578 - 7{,}346 = 3{,}232 \text{ ft.}$

$\text{Apparent velocity of air} = 3{,}232 \div 2 = 1{,}616 \text{ ft. per minute.}$

$\text{True velocity} = 1{,}616 - 88 = 1{,}528 \text{ feet per minute.}$

$\text{Quantity} = \text{a x V} = 322 \text{ x } 1{,}528 = 492{,}016 \text{ cubic feet per minute.}$

Example 8.4.4

A roadway, lined with splayed steel arches, is 9 ft. 6 ins. high in the clear, 12 ft. wide at springings, and 13 ft. wide at floor. What is the quantity of air passing when the average velocity is 450 ft. per minute?

SPLAYED ARCH ROADWAY

The semi-circle stands on a diameter of 12 ft. and its radius is 6 ft. The height of the trapezoid is thus, 9.5 – 6 = 3.5 ft.

$$\text{Then area of trapezoid} = \frac{12 + 13}{2} \text{x } 3.5 = 43.75 \text{ sq. ft.}$$

$$\text{Area of semi} - \text{circle} = \frac{12 \text{ x } 12 \text{ x } 0.7854}{2} = 56.55 \text{ sq. ft.}$$

$$\text{Total area} = \mathbf{100.30\ sq.ft}.$$

$$\text{Quantity of air} = \text{a x V} = 100.3 \text{ x } 450 = 45{,}135 \text{ cubic ft per min.}$$

{**Note**. Actually, the top portion of a splayed arch does not form an exact semi-circle, but the error is of no practical consequence in such problems}.

Example 8.4.5

If the quantity of firedamp produced in a mine be 1,500 cub. ft. per min., calculate the minimum quantity of air necessary to ensure that the percentage of gas in the main return shall not exceed 0.5%.

DILUTION OF FIREDAMP

To ensure only 1.0% of firedamp in the air, the total quantity of air flowing (including the firedamp) would be 1,500 x 100 = 150,000 cub. ft. per min. To reduce the percentage to 0.5% double the quantity of air would be needed, namely 300,000 cub. ft. per minute, and this would be the quantity as measured in the main return. Of this total quantity, 1,500 cub. ft. would be firedamp.

Hence, Quantity of air required = 300,000 – 1,500 = 298,500 cub. feet per minute.

[Alternatively, if there is 0.5% of firedamp in the return, the air will form 99.5% of the "atmosphere"; i.e. there will be 199 times as much air as firedamp.]

Quantity of air = 1,500 x 199 = 298,500 cubic feet per minute (excluding the firedamp).

= 300,000 cubic feet per minute (including the firedamp)

Example 8.4.6

The percentage of CH_4 in a certain district is found to be 1.25, and the quantity of air circulating is 15,000 cub. ft. per min. How much more air will be required to reduce the percentage of CH_4 to 0.5%?

REDUCING PERCENTAGE OF CH_4

The CH_4 is to be reduced in the ratio of 1.25 to 0.5, or 2.5 to 1. Hence, the volume of air must be increased in the same ratio.

Final volume of air = 15,000 x 2.5 = 37,500 cubic feet per minute.
Additional air required = 37,500 – 15,000 = 22,500 cubic feet per minute.

[Alternatively, quantity of CH_4 = 1.25% of 15,000 = 187.5cubic feet per minute.

If this CH_4 is to form only 0.5% of the atmosphere,

Then final volume of air flowing = 187.5 x 200 = 37,500 cubic feet per minute.
And additional volume = 22,500 cubic feet per minute]

Example 8.4.7

Calculate the (a) area, (b) perimeter, and (c) rubbing surface of an airway 1,200 yds. long, and lined with splayed arches 8 ft. high, 8 ft. wide at springings, and 9 ft. wide at floor. Calculate (d) the ventilating pressure, and (e) the air horse-power required to cause 30,000 cub. ft. per min. to flow, assuming K = 0.001 inch w.g.

ARCHED AIRWAY PROBLEM

a) $\text{Area} = \text{semi} - \text{circle} + \text{trapezoid}$

$$= \frac{8 \text{ x } 8 \text{ x } 0.7854}{2} + \frac{(9+8)}{2} \text{ x } 4$$

$$= 25.13 + 34 = 59.13 \text{ sq. ft.}$$

b) $\text{Perimeter of semi circle} = \pi R = 3.1416 \text{ x } 4 = 12.57 \text{ ft.}$

$\text{Base} = 9.00 \text{ ft.}$

$\text{Two sides} = 2 \text{ x} \sqrt{(4^2 + 0.5^2)} = 2 \text{ x} \sqrt{16.25} = 8.06 \text{ ft.}$b)

$\text{Perimeter} = \mathbf{29.63 \text{ ft}}.$

c) $\text{Rubbing surface} = 29.63 \text{ x } 1{,}200 \text{ x } 3 = 106{,}668 \text{ sq. ft.}$

d) Ventilating pressure $= P = \frac{KSQ^2}{a} = \frac{KSQ^2}{a^3}$

$$= \frac{0.001 \text{ x } 106{,}668 \text{ x } 30 \text{ x } 30}{59 \text{ x } 59 \text{ x } 59} == 0.46 \text{ inch w.g.}$$

e) Air horse power $= \frac{Q \text{ x w.g. x } 5.2}{33{,}000} = \frac{30 \text{ x } 0.46 \text{ x } 5.2}{33} == 2.17 \text{ HP.}$

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5. Ventilation Standards base on:-

i) Labour employed.
ii) Production requirement.
iii) Special prevalent condition

The quantity of air circulating in the various workings of a mine must be such as to comply with the requirements of prescribed Coal Mines Regulations paying special regard to:-

a) keeping the percentage of firedamp and carbon dioxide in the air below specified limits.

b) maintaining an adequate amount of oxygen.

c) reducing the temperature and humidity to such an extent that persons can work comfortably.

d) keeping all travelling roads and working places fit and safe for working.

The adequacy of ventilation in the various parts of mines may be determined.

a) by systematic sampling and analysis of mine air.

b) by regular use of oil flame safety lamp or other means of detecting the percentages of noxious and inflammable gases.

c) by regular measurement of quantity of air flowing by any instrument as described above.

Immediate steps may then be taken to rectify any deficiency that may be found.

Ventilation standard based on:-

1. Labour Employed

Due regard should be paid to the air velocity flowing at the face. It should be between 150 and 500 feet per minute. Usually a man needs 200 cubic ft. per minute and a mule 400 cubic ft. per minute. The oxygen in the air should not be less than 19 percent.

2. Production Requirement

It is estimated that daily output of each ton of coal needs about 55 cubic feet per minute.

3. Special Prevalent Conditions

The quantity of air required on each face, based on expected gas emission and maximum permissible methane percentage (say 0.5%) should then be calculated. Where locomotives (Diesel) are in use in any roadway or part thereof due regard should also be paid to the flow of air velocity.

It is a saying that mere quantity of air is not the only criteria of the adequacy of the ventilation. It is the quality of the ventilation that is the ultimate deciding factor. The only way to determine this is the systematic sampling and analysis of the air at strategic points in the mine.

CHAPTER 09

DISTRIBUTION OF THE AIR

9.0 Distribution of air to the various portions of a mine is done by using:-

1. Brattice Cloth,
2. Stoppings,
3. Doors,
4. Air-crossings,
5. Regulators.

These appliances must be kept in good order so that these may be used as and when required in ordinary conditions and in emergencies. Let us describe each one by one.

9.1 Brattice Cloth

This is simply a sheet or sheets of canvas hung from props and planks either (a) as a screen across an airway to prevent or reduce the flow of air along it, or (b) as a partition along an airway to divide it into two parts, intake and return. Canvas screens are suitable only in the inbye workings where the ventilation pressure is small. Fig. 9.1 shows the manner in which brattice cloth is hung.

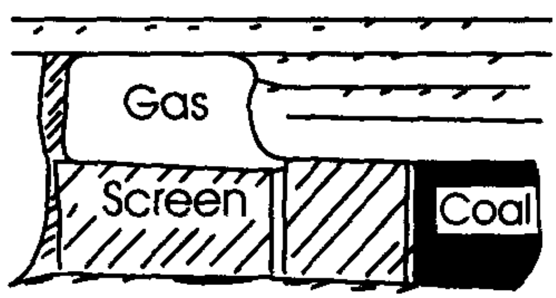

Fig. 9.1

A hurdle screen is a canvas cloth which does not reach right to the roof. It is used to divert an air-current upwards into a roof cavity in order to keep it clear of gas. Fig. 10.2 shows an arrangement where such a screen is used to divert the air from a long longwall face to the edge of a ripping so as to clear away an accumulation of gas.

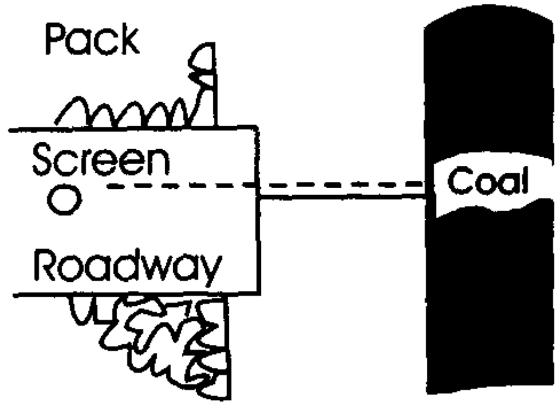

Fig. 9.2

Brattice partitions are used to ventilate narrow places driven in advance of the general ventilation e.g. in board and pillar workings. Fig. 9.3 shows faces A and B are ventilated by hanging canvas in the manner shown. The air travels in the direction as shown by the arrows. When the two places have been driven a proper distance, they are generally interconnected at hand then the brattices can be removed and a door is hung at D. The air then travels along one heading then across H and then comes back along the other heading. Brattices are used for limited distances.

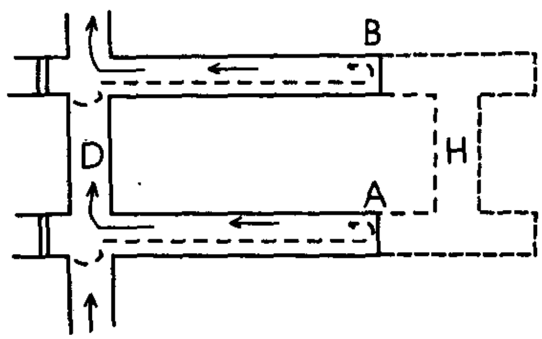

Fig. 9.3

9.2 Stoppings

These are used to block off any old roadway not required for travelling, haulage or ventilation. Between main intakes and returns, these must be explosion proof and constructed to comply with legal requirements laid down in the Regulations. In general, they are built of stone, sand or rubbish packing with a well built wall of brick work or concrete at one end (the intake) or at both ends. The intake side road must be kept clear.

9.3 Doors

These are placed on roadways used as haulage or travelling roads. Normally two doors are used so that one is always closed when the other is open. Fig. 9.4 shows one type of door. Dimensions of the door depend upon the place where it is to be erected but care should be taken that it is made of well seasoned wood. The door frame consists of two side pieces, a crown piece and a sole piece and is built into a brick wall which closes the rest of the roadway. The space below the door is made air-tight as far as possible. The door must be arranged to close automatically.

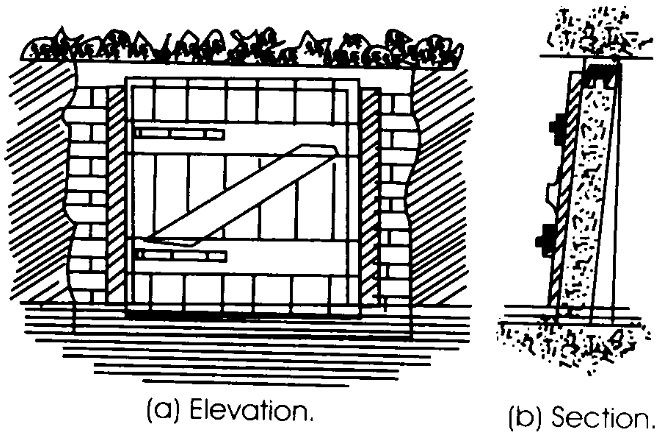

Fig. 9.4. Ventilation Door

9.4 Air Crossings

These are required whenever the return air-current has to cross the intake air current without mixing with it. When airway rises over the other, the crossing is called an overcast and when dips under the other it is called undercast. The latter has the disadvantage that water may accumulate in it, and so an overcast should be preferred. An air crossing may be either temporary or permanent in character.

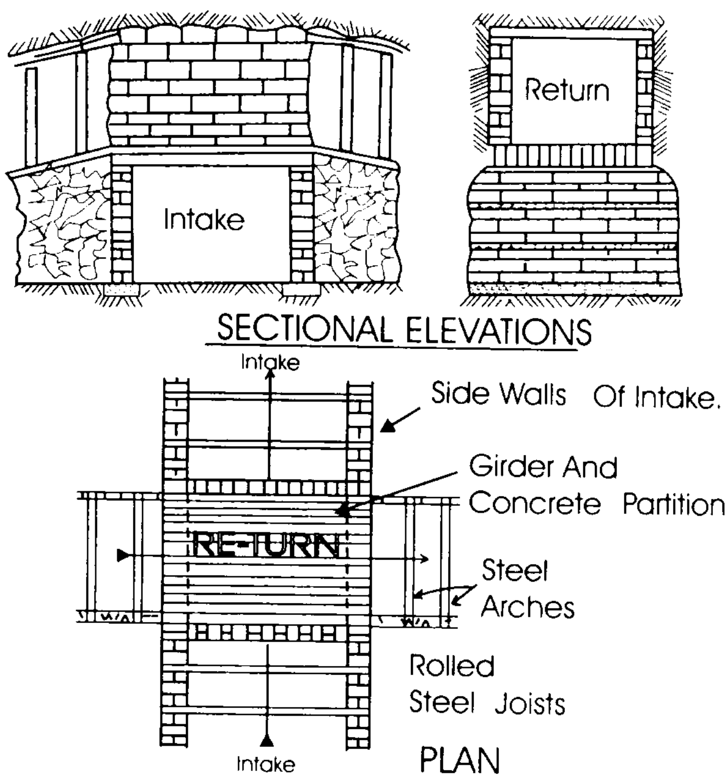

Fig. 9.5

9.4.1 Temporary Air Crossing

Temporary air crossing is made where the partition between the intake air and return may be of timber or of air-tubes. These may be used:

i) Near the working face where the strata have not settled down.
ii) In connection with narrow headings which are advancing and require independent ventilation.
iii) In restoring workings after an explosion before the erection of permanent crossings.

9.4.2 Permanent Air Crossings

These are used where strata have settled down and the crossing is likely to be required for a long period. The chief features of such a crossing are that:-

i) The structure must be airtight so as to prevent leakage from intake to return;
ii) It must be explosion proof;
iii) It must be of ample size to permit the free flow of air.

9.5 Regulators

Fig. 9.6 shows a common form of a regulator. It consists of sliding wooden shutter fitted into a brick stopping or in a ventilation door. The area of opening may be adjusted usually by trial until only the required amount of air passes through. The shutter is then locked in position to prevent unauthorised interference.

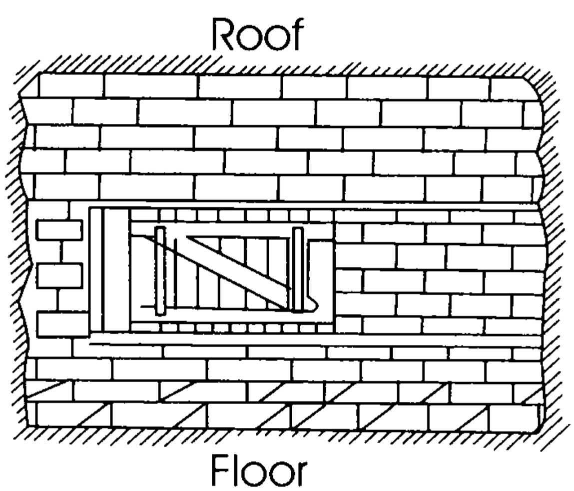

Fig. 9.6

It will be obvious that the smaller the opening of the regulator, the greater will be the resistance offered by it, the greater will be pressure or w.g. absorbed in forcing air through it and the smaller will be the volume of air flowing through.

In practice a regulator is placed in a low resistance split, possibly near the shaft which is taking too large a proportion of the total air. It has the effect of reducing the air flowing in that split and increasing flow of air in an unregulated parallel split of high resistance. It is thus a convenient means of controlling the relative flow of air to each district according to the requirements of the district.

It should be understood that a regulator is an added artificial resistance which increases the total resistance of the mine and reduces the volume of air flowing for a given fan drift water gauge.

9.6 Ascensional & Descensional Ventilation

Ascensional Ventilation

Ascensional ventilation occurs when the air travels uphill along the face as shown in the right hand split A as shown in Fig. 9.6. To bring this about the intake air is first taken direct to the lowest point of the district, namely X and, after travelling up the face leaves by the return airway at the top end of the face.

Descensional Ventilation

Descnsioanl ventilation occurs when the air enters at a higher level, descends along the face and leaves at a lower level as in split B.

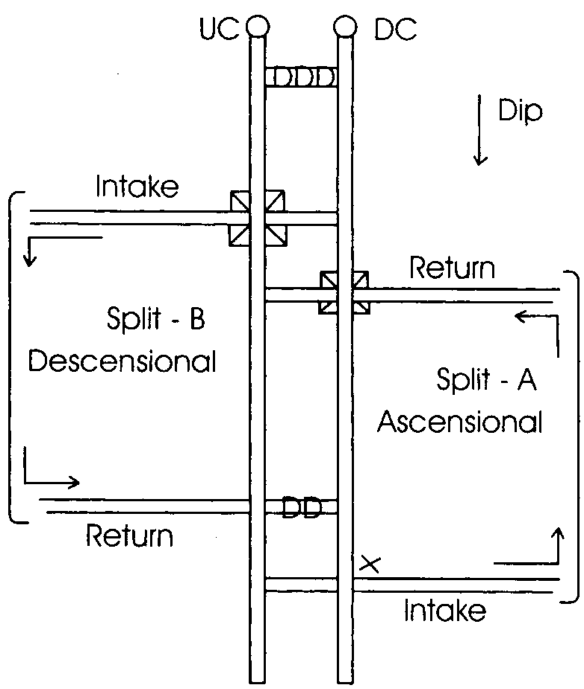

Fig 9.7 Ascensional & Descnsioanl Ventilation

It may be said that in general, ascensional ventilation is normally to be preferred because:-

a) The natural ventilation pressure (n.v.p) developed in the workings assists the fan ventilation.

b) The quantity of air flowing is increased more especially where the w.g. developed by the fan is low.

c) Firedamp, being lighter than air is readily carried uphill towards the return.

d) If the fan should stop, the air will continue to flow in the same direction, although at a reduced rate. <u>These are all very important considserations, especially in a gassy mine.</u>

On the other hand, with descensional ventilation,

a) The n.v.p. opposes the fan and if the fan is stopped, the airflow will be greatly reduced, and may even be reversed.

b) Firedamp newly given off may migrate to the rise, in a thin layer next to the roof and in the opposite direction to the air current and so find its way into the top (intake) roadway.

c) A brisk current of air (produced by the fan at relatively high w.g.) is essential if safe conditions as to firedamp are to be maintained at the face.

d) If a fire occurs on a descensionally ventilated face, the hot gases may reverse the ventilation and so put the fire fighters in a dangerous position, whilst tending to limit the spread of the fire.

It may nevertheless be argued that especially in deep hot mines, it may be better to take the intake air into the mine via an upper horizon and ventilate the faces descensionally. The chief advantage of this is that the air reaches the faces in a cooler and drier condition and the climatic conditions on the face are thereby improved, possibly postponing the need for the installation of special air conditioning plant. It is important that the w.g. developed by the fan shall be sufficient to counteract the n.v.p. and the buoyancy of methane in the goaf and that adequate standby ventilating plant shall be installed to ensure continuity of the ventilation at all times. Other advantages arise on a descensionally ventilated face where the lower road is used both as a return airway and as a coal transport road, but this is more suitably dealt with under the next heading.

9.7 Homotropal & Antitropal Ventilation

Homotropal Ventilation

Homotropal ventilation occurs when the air and coal flow in the same direction. This applies to the descensional split B as shown in Fig. above. The return airway is used as the coal transport road, to the upcast shaft.

Antitropal Ventilation

Antitropal ventilation occurs when the air and coal flow in opposite directions. This applies to the ascensional split A as shown in fig. above.

9.8 Booster Fan

A booster fan is a more or less permanent installation designed to pass the whole of the air circulating in the district or districts.

9.8.1 Purposes to use Booster Fan

a) To increase the quantity of air at the place of high resistance far inbye.

b) To improve the working conditions in deep hot mines by speeding up the air.

c) To reduce the excessive leakage between intakes and returns.

d) To reduce or adjust the pressure difference between intakes and returns in mines liable to spontaneous combustion.

The installation of a booster fan is considered justifiable where an increased quantity of ventilation is urgently required. Booster fan may be of either centrifugal or the air screw type and may be placed.

a) In the return to act as an exhausting fan or
b) In the intake to act as a forcing fan.

9.8.2 Location of Booster Fan

It is very important that the correct size of booster fan is chosen and that it is correctly placed to avoid the danger of re-circulation of air, or of leakage from return to intake or of undue interference with the ventilation of other districts. It is necessary to conduct the ventilation survey before the installation of booster fan.

9.9 Auxiliary Fan

An auxiliary fan is a more or less temporary installation designed to pass a proportion of the air circulating in the district concerned.

9.9.1 Purposes to use Auxiliary Fan

a) Long headings and cross-measure drifts driven in advance of the workings;
b) Narrow places in mechanized room and pillar workings.
c) Roadways where roof fall has blocked the normal air course.

9.9.2 Type of Auxiliary Fan

a) These are centrifugal fans usually electrically driven. Sizes commonly range up to about 20 in. diameter.

b) Axial flow fans driven by electricity or by compressed air;

c) Static blowers which, though not fans, may be used as auxiliary ventilators.

9.10 Advantages & Disadvantage of Forcing Fans

9.10.1 Advantages

a) A current of cool intake air at high velocity is led to the face so increasing the comfort and efficiency of the men and rapidly dispersing any gas, dust or short firing fumes at the face itself.

b) Any gas made in the heading is carried outbye away from the face.

c) The fan handles clean intake air;

d) Flexible ducting can be used and need not be kept very close up to the face.

Disadvantage

The main disadvantage of forcing is that only a slow ventilating return current traverses the roadway and it may take a long time for dust to be entirely removed therefrom.

9.10.2 Advantage and Disadvantages of Exhaust Fan

Advantages

The main advantage of exhausting is that firedamp, dust and blasting fumes at the face are drawn direct into the air tubes and the working place is kept clear for persons working and travelling therein.

1. The intake airway does not get fresh air.
2. The faces get inadequate air current and gases may accumulate in them.

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