CHAPTER 4

Airborne Pollutants

This chapter describes and classifies the various airborne pollutants. The hazards posed by these pollutants and their occurrence and origins are discussed together with sampling and monitoring techniques and strategies. The legal limits of exposure to airborne pollutants are set out and control methods applicable to these pollutants are described.

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Glossary

ACGIH: American Conference of Governmental Industrial Hygienists

Aerodynamic size: relating to airborne particles of unit density : a means to facilitate comparison of the behaviour of aerosols

Aerosol: generic name for airborne entities such as dusts, smokes, mists, fumes

Asbestos: collective term for mineral silicates of the serpentine and amphibole groups

Aspect ratio: for fibres, the length to breadth ratio

Gravimetric: relating to weighing e.g. of dust-collecting filters

Halides: compounds of the gases chlorine, bromine, fluorine and iodine

HEG: Homogeneous Exposure Group : a group of persons generally exposed to similar dusty conditions

l/min: litres per minute — a flow rate

mg/m^3: milligrams per cubic metre — a measurement of concentration

Mineral fibres: fibrous materials such as slag and glass wool

NIOSH: (USA) National Institute for Occupational Safety and Health

Noxious: harmful, injurious

Occupational hygienist: an individual trained to anticipate, recognise, evaluate and control health risk factors at the workplace

OEL: Occupational Exposure Limit : a guide to permissible exposure to airborne substances

OHSA: (USA) Occupational Health and Safety Administration

Particulate: referring to particles

Pollutant: contaminant of air, water etc.

ppm: parts per million — a measure of concentration

PNOC: Particles Not Otherwise Classified

Respirable: of such an aerodynamic size (< 7µ in diameter) as to be capable of inhalation into the lung depths

RPE: Respiratory protective equipment

RPM: Respirable particulate matter

SABS: South African Bureau of Standards

Solvent: a substance used to dissolve other substances

SiO_2: Silicon dioxide (silica)

STEL: Short term exposure limit

STP: Standard temperature and pressure (25°C and 101,3 kPa)

TLV: Threshold limit value

TPM: Total particulate matter

TWA: Time weighted average

µm: micrometre (micro = millionth)

µg: microgram

4.1 Introduction

South African mining legislation has existed for many years to protect workers from the adverse health effects of inhaling airborne pollutants such as airborne dust, noxious fumes or harmful gases. Under early mine health and safety regulations Occupational Exposure Limits (OELs) have been published for carbon dioxide, carbon monoxide, oxides of nitrogen and hydrogen sulphide levels in air. In 1992 some fifty particulate airborne pollutants were assigned OELs under the Guidelines for the Gravimetric Sampling of Airborne Particulates for Risk Assessment in Terms of the Occupational Diseases in Mines and Works Act No. 78 of 1973. Recently, all mine OELs have been updated in a schedule to the Occupational Hygiene Regulations (2001) under the Mine Health and Safety Act, 1996. OELs are now prescribed for hundreds of chemical airborne pollutants including particulates, gases and vapours.

4.2 Types of airborne pollutants

Airborne pollutants refer to dusts, smokes, fumes, mists, gases, vapours, fungi, bacteria, algae and viruses. Based on their physical properties airborne pollutants can generally be grouped as:

4.2.1 Dusts

Dusts are generated during the handling, pulverisation, grinding, crushing, rapid impact and decrepitation (crackling through heat exposure) of organic and inorganic substances such as rock, ore, metal, coal and wood.

These particles may be so small, (sub-micrometre) that, because of collisions with air molecules, they do not always move in the expected direction i.e. downwards. The resistance offered by the air hampers the free fall of such bodies. The air resistance depends on the density and viscosity of the air and on the aerodynamic size and speed of the falling body. A one micrometre dust particle liberated two metres above the footwall (floor of a mine) will take about 10 hours to settle on the floor in still air. On the other hand, clearly visible road dust of 100µm diameter will settle in about five seconds.

4.2.2 Fumes

Fumes are solid particles generated by condensation from the gaseous state, generally after volatilisation from molten metals. In the case of metals this process is often coupled with a process of oxidation so that the metallic fumes present in the air are partly in the form of an oxide. Fumes can flocculate or coalesce.

4.2.3 Mists

Mists consist of small liquid droplets generated by condensation from the gaseous state or by the breaking-up of a liquid into a dispersed state by, for example, splashing, foaming or atomising. Mist is formed when a finely divided liquid is suspended in air, for instance during spraying operations.

4.2.4 Gases

Gases are formless, diffusing fluids, which completely fill the containers in which they are kept. They can be transformed to the liquid state only by the combined effect of increased pressure and decreased temperature.

4.2.5 Vapours

Vapours are gaseous forms of substances which can be transformed to the liquid phase either by increasing the pressure or decreasing the temperature alone. Vapours will diffuse in the air or in any other gas.

4.3 Specific Entities

4.3.1 Asbestos

Asbestos (translated from the Greek word: unquenchable) is a collective term for some of the metamorphic, fibrous, mineral silicates of the serpentine and amphibole groups. They have different

physical and chemical properties but share a fibrous form. Mineralogists have generally taken a particle with a length-to-breadth ratio (aspect ratio) of 10:1 or more to be a fibre. In milled asbestos most of the particles have aspect ratios that range from 5:1 to 20:1 or more and, in the case of chrysotile, mostly greater than 50:1. In medical and environmental literature a *regulated* fibre has been defined as a mineral particle with a length which is at least three times greater than its diameter, of length greater than 5 micrometres and diameter less than 3 micrometres. This definition has been the basis of all fibre counting for dose-response studies since 1965.

Amongst the most valuable characteristics of asbestos are its durability, which, unfortunately, also causes it to persist in lung tissue, and its fine diameter, which gives it a very high surface-to-weight ratio but also renders it respirable.

There are essentially two major varieties of asbestos viz. serpentine and amphibole. Serpentine is an hydrous magnesium silicate, which occurs as a plating variety (antigonite), or as a fibrous variety (chrysotile), which in long fibres is *chrysotile asbestos*. Chrysotile is found in both igneous and metamorphic rocks.

Amphiboles typically contain magnesium or calcium and can form fibrous structures due to the ease with which their molecular chains can be separated. The species and varieties are as follows:

Table 4.1 Asbestos

SPECIES	VARIETY
Chrysotile	Serpentine
Anthophyllite	Amphibole
Amosite	Amphibole
Actinolite	Amphibole
Tremolite	Amphibole
Crocidolite	Amphibole

Amphiboles are commonly found as a component of igneous and metamorphic rocks of basic or mafic types and comprise about five percent of the earth's crust. The two commercially significant fibres, crocidolite and amosite, occur in sedimentary strata known as banded ironstones.

Chrysotile is known as white asbestos, crocidolite as blue asbestos and amosite (found only in South Africa) as brown asbestos.

It has been known for some time that inhalation of asbestos fibres increases the risk of lung disease. The three diseases associated with asbestos are:

- Asbestosis, a non-malignant fibrotic condition
- Bronchogenic carcinoma
- Mesothelioma, a rare cancer of the lining of the chest or abdominal cavity

The limit for airborne asbestos concentrations for regulated fibres was set at 2f/ml for many years but in a revision to the regulations this has been lowered to 1 f/ml.

4.3.2 Mineral Fibres (synthetic i.e. man-made)

Synthetic mineral fibres fall into the following main groups:

- Slag or rock wool (mineral wool)
- Glass wool
- Continuous filament glass
- Ceramic fibre

The mineral wools are made from melts of specific argillaceous limestones and smelter slags, sometimes with the addition of wollastonite and kaolin. Glass wool (or fibreglass) is made from different types of silicate glass. They are all glassy minerals, which, unlike asbestos materials, are

amorphous silicates. Diameters of ordinary glass fibres are usually greater than 3µm but may vary down to diameters of less than 1µm. "Melts" at a temperature of 1000 to 1500°C are "fiberised" by drawing, blowing or centrifugal methods. The diameters and lengths of fibres differ according to the use for which they required, and are manufactured to a controlled "nominal" (specified) diameter.

Man-made mineral fibres (MMMF) are commonly coated with a binder, which is usually a biologically inert, fully polymerised , thermosetting resin. They have also been coated with mineral oil to reduce dust emissions and to serve as a lubricant between fibres to improve handling properties. Unlike asbestos fibres, which split longitudinally into numerous fibrils of much smaller diameter, MMMF break transversely with the same diameter.

Even though fibres of "respirable" dimensions have been present in most products since manufacture began in the late 1840's, epidemiological and radiological studies have not revealed any evidence of pneumoconiosis. This holds for both long and short fibres. Nevertheless, rock or slag wool, fibrous glass and ceramic fibres have been classified as a "possible human carcinogen". Continuous glass filaments were found not to be classifiable.

Under mining regulations no limits have been set for the concentration of mineral fibres but the ACGIH has specified a limit of 1f/ml.

4.3.3 Biological agents

- A biological agent is of vegetable or animal origin and can cause illness or disease at the workplace. Such agents include vegetable scraps, micro-organisms, parasites, biological allergens and toxins. However, the presence of these biological agents and the resulting illnesses may not always be recognised. It has been noted that some 193 biological agents are known to produce infectious, allergenic, toxic and carcinogenic reactions at the workplace. Most of the identified agents can be placed into the following groups
- Micro-organisms and their associated toxins (viruses, bacteria, fungi, and their products), infection, exposure, or allergenic reaction
- Arthropods (arachnids, insects and crustaceans): bites and stings, transmission of infectious agents, or allergic reaction
- Allergens and toxins from certain plants: dermatitis from skin contact, rhinitis/asthma from inhalation
- Allergens from certain animals (from urine, faeces, hair or saliva)

Other groups that a pose a potential biohazard include plants other than fungi e.g. lichens, liverworts and ferns and animals other than arthropods viz. parasites such as protozoa, flatworms and roundworms.

Some of the better known diseases caused by biological agents include anthrax, athlete's foot, legionnaires' disease, malaria, psittacosis, rabies, ringworm, sporotricosis, tetanus and tuberculosis.

It must be stressed that only illnesses arising from daily exposure to biological agents at the workplace can be classified as occupational.

4.3.4 Blasting Fumes

Several oxides of nitrogen are usually found together in the same atmosphere and collectively they are known in mining circles as nitrous fumes.

Nitrous fumes are commonly a mixture of NO, NO_2, N_2O_4 with possible some N_2O_3.

They occur in the gases formed by the detonation of nitro-explosives (see Table 4.2). The burning of such explosives produces significantly greater quantities of these gases. They are also present in the exhaust gases of diesel-powered engines and are also produced in small quantities by both oxy-acetylene and arc welding.

Nitrous fumes make up an irritant gas mixture, and if inhaled cause irritation in the nose, throat and windpipe and may lead to delayed pulmonary oedema, a potentially fatal condition in which fluid accumulates in the lungs. In the case of gassing it is important that the employee concerned receives prompt medical attention.

Table 4.2 Gases produced by explosives

Gas	Volume m^3
Carbon monoxide	1,2-4,0
Carbon dioxide	10-27
Nitrous fumes	0,6-4,4
Ammonia	0,03-0,3

4.3.5 Chlorine

Cl_2 is a heavy, greenish-yellow gas, that is irritant with a pungent odour. It is extremely poisonous. As in the case of nitrous fumes, oedema (waterlogging) of the lungs may occur several hours after exposure.

There are simple tests available for the detection of chlorine gas but are usually not necessary since chlorine is not commonly found in underground workings and generally only occurs where chlorine is being used to disinfect water. The gas's distinct smell will usually make its presence known.

4.3.6 Diesel engine exhaust emissions

Where diesel- powered vehicles are deployed in close proximity to each other the potential to superimpose exhaust emissions is high. In addition to dust from the mechanised sections where diesel-powered vehicles are used, the exhaust gases are also emitted into confined spaces of the workings. Included in the exhaust emissions is soot, or as it is also technically known, Respirable Combustible Dust (RCD) or Diesel Particulate Matter (DPM). The concern with diesel soot is the Polynuclear Aromatic Hydrocarbons (PAH). Included amongst the PAH is benzo-a-pyrene, which is one of the most powerful carcinogens known to man. The need to control and dilute diesel soot in the workings and remove it to prevent exposures is thus clear.

Table 4.3. Constituents of diesel exhaust emissions

Emission	**Pollutant**
	Carbon monoxide CO
	Carbon dioxide CO_2
Gaseous	Nitrous fumes NO_x
	Sulphur fumes SO_x
	Formaldehyde HCHO
Particulates	Diesel Particulate Matter DPM
	Sulphur

Note. "Tailpipe" gases are discussed under section 4.3.8

4.3.7 Dust

The largest quantities of airborne dust particles are produced in a mine by blasting operations and mechanical mining systems. Additional dust is produced by other mechanical operations such as drilling, scraping, barring, lashing, tipping and loading.

Some of the fine dust produced during blasting is carried away by the ventilating airstream. To minimise exposure to dust and blasting fumes a re-entry period is specified and applied. Persons are removed from the mine during blasting operations and may not re-enter the mine for a period of four

hours after blasting (general re-entry period). However, a large amount of dust is trapped with the rock broken by blasting. Some of the coarse particles that have become airborne settle out on the footwall and some of the finer particles collide with each other and aggregate to form larger particles, which settle out. However, if precautions are not taken, these settled particles, if disturbed, can become airborne during the shift when persons are present in the workings and thus become available for inhalation.

One cubic millimetre of rock crushed to cubes of one micrometre size would yield 1000 million dust particles. In drilling a 40 mm diameter hole one metre deep the volume of rock removed is 1,2 million cubic millimetres and drilling such a hole takes less than 10 minutes. Assuming an airflow rate of 20 m^3/s in the working place (stope), such a hole could add 100 000 particles of dust per millilitre of air or, in terms of mass, approximately 3 500 milligrams of dust. Fortunately, however, very much less than one per cent of the rock drillings is as small as one micrometre and most is prevented from becoming airborne through engineering intervention.

Most of the dust produced by drilling is captured by water flowing down the drill steel and exits the hole being drilled as sludge. Unfortunately, all the dust is not controlled in this way because some compressed air usually leaks past the piston of the rockdrill and finds its way down the drill steel to the bottom of the hole where it collects some dust before escaping to the atmosphere. Modern sealed-spline rock drills allow less air to escape than the old exposed-spline machines. The front head release ports allow some of the air, which gets past the piston to escape to atmosphere without passing down the hole being drilled.

The dust created and liberated into the atmosphere by scraping, barring, lashing and loading can, to a large extent, be kept out of the ventilating air by ensuring that the rock is kept sufficiently wet.

When a piece of rock covered with fine dust is allowed to fall, as happens when it is transferred from one conveyor belt to another or when it is dropped into a tip or on to a stockpile, it is subject to gravitational acceleration and subsequently to a sudden stop or deceleration. These processes release dust into the air and if the tip is, for example, upcasting this dust is then carried into the ventilating air.

Table 4.4 Sources of airborne dust in a mine

Approx severity	Dust producing operation
1	Blasting
2	Drilling
3	Crushing
4	Grinding
5	Scraping
6	Barring
7	Lashing
8	Tipping
9	Loading

4.3.7.1 Crystalline silica

The most common form of crystalline silica or silicon dioxide (SiO_2) is quartz. Other forms of crystalline silica include tridymite and cristobalite. Quartz itself is given various names such as rock crystal, amethyst, smoky quartz and milky quartz depending on its colour, which is caused by various impurities, and its shape. Silica and silicates, i.e. silica combined with some other base, occur very freely in nature and actually form a very high percentage of the earth's crust. The gold-bearing ore in South African mines can contain up to 100 per cent silicate. One of the problems confronting the occupational hygienist is the fact that the silica content in ore being mined is neither uniform nor homogeneous. This results in variable silica content of airborne dust samples

4.3.8 General mine gases

A summary of common gases encountered in mines, together with relevant properties and places of occurrence is set out in Table 4.5. Knowledge of the specific gravities of the various gases is useful in assisting with testing techniques. For example, a gas with a specific gravity less than unity (i.e. lighter than air) could be expected to be found against the hanging wall (roof), before any mixing takes place. Therefore it would be logical to test for such a gas above one's head and not at floor level.

The Occupational Exposure Limits provided in the table are taken from the Regulations for Occupational Hygiene under the Mine Health and Safety Act.

Table 4.5 Common mine gases and properties

Name	Chemical Symbol	Specific Gravity Relative to Air	OEL: ppm	Sources
Carbon dioxide	CO_2	1,5	5000	Breathing, oxidation, blasting, diesel exhaust, fires
Carbon monoxide	CO	0.97	25	Blasting, diesel exhaust, fires
Hydrogen sulphide	H_2S	1,2	10	Fissures, stagnant water
Nitrogen	N_2	0.97		Normal air
Nitrous fumes	NO, NO_2, etc	1,04 1,6	25 3	Blasting, diesel exhaust, welding, burning of explosives
Methane	CH_4	0,55	Simple asphyxiant Explosive hazard	Fissures, coal seams
Oxygen	O_2	1,0	> 19%	Normal air
Sulphur dioxide	SO_2	2,22	2	Smelting operations, diesel exhaust fumes, sulphur in coal seams
Hydrogen	H_2	0,07	Simple asphyxiant Explosive hazard	Battery charging, sometimes from fissures with methane
Chlorine	Cl_2	2,5	10	Chlorination of water
Aldehydes	HCHO, etc	1,04		Diesel exhaust
Ammonia	NH_3	0,6	25	Cooling plants, blasting
Acetylene	C_2H_2	0,93		Welding and cutting

4.3.8.1 Oxygen

Most gases can, under certain conditions, constitute a danger to life. The first step towards guarding against these dangers is to know their properties in order to understand where to expect a dangerous condition, how to recognise it and what to do about it.

Oxygen is a colourless, odourless and tasteless gas at normal temperatures but the only normal way that oxygen can pose a danger in underground workings is by its absence. Air that has stagnated for a long period may have had much of the oxygen removed by oxidation of metals and minerals and

also by decaying timber. Some or all of the oxygen may have been replaced by CO_2 and such a mixture, which has an oxygen deficiency but is neither poisonous nor explosive, is called *black-damp* in coal mining. It is important to note that if stagnant workings have to be entered, for whatever reason, the atmosphere should be carefully tested for oxygen content as well as for the presence of flammable gas.

4.3.8.2 Nitrogen

Nitrogen is the most common gas in the atmosphere, comprising nearly 80 percent by volume. It is colourless, odourless, and tasteless and is almost insoluble in water. It does not burn nor support combustion and is obviously not poisonous. While nitrogen gas is chemically inactive the element nitrogen occurs in many active compounds such as nitrates, ammonia and others. Nitrogen in the atmosphere dilutes oxygen. This is very important because without this dilution an oxygen-rich atmosphere would result in uncontrollable fires.

Nitrogen combines directly with some metals to form *nitrides* at high temperatures. Examples are aluminium nitride (AlN) and iron nitride (Fe_4N_2). It is also a constituent of nitric acid, HNO_3, which in turn forms nitrates such as sodium nitrate, ($NaNO_3$) and calcium nitrate ($Ca(NO_3)_2$). It is also found in nitrous acid, (HNO_2), which forms nitrites such as sodium nitrite ($NaNO_2$) and calcium nitrite ($Ca(NO_2)_2$).

4.3.8.3 Carbon dioxide

Carbon dioxide, (CO_2), is formed by breathing and by the burning of matter containing carbon such as wood coal and fossilised fuels. It sometimes issues from rock formations and may have methane accompanying it. In collieries it is formed by oxidation of fine coal dust.

Carbon dioxide is odourless and colourless but it does have a slight acid taste. It is approximately one and a half times heavier than air and when stratified will therefore be found low down in places such as winzes or sumps.

Carbon dioxide has been called the "miners' friend" as far as gases go because it gives a warning of its presence, probably accompanied by other more dangerous gases, by causing rapid breathing and a headache and by its slightly acid taste.

4.3.8.4 Carbon monoxide

Carbon monoxide (CO) is a very much more dangerous gas because it is extremely poisonous and interferes with the blood's ability to transport oxygen. It is colourless, odourless, tasteless and very slightly lighter than air. CO is the product of the incomplete combustion of carbon. When any substance containing carbon is burnt when sufficient oxygen is present it forms CO_2. But if the supply of oxygen is limited it only burns partially to CO. To some extent this happens in nearly all fires, but more especially in mine fires where the supply of oxygen is more limited.

CO is also present in the exhaust gases of internal combustion engines and in blasting fumes.

4.3.8.5 Hydrogen

This is a very rare gas in nature, but it is sometimes mixed with methane which issues from rock fissures. It is a very light gas and is colourless, odourless and non-poisonous. It burns with a scarcely visible flame but does not support combustion. It is explosive (5 to 75%) and the explosive limits are not the same as for methane, the most violent explosion being with 30 percent hydrogen in air. Burning hydrogen develops more heat than burning methane. Hydrogen may be detected with a resistance type methanometer which indicates the summation of the methane and hydrogen percentages. Such a methanometer must be fitted with special flashback arrestors.

In some areas hydrogen and methane are known to occur together. Distinguishing between these two hazards is difficult and extreme vigilance and caution are needed in such cases.

4.3.8.6 Methane

Methane, (CH_4) is explosive and is believed to have caused more loss of life in mines than any other gas. It is, unfortunately, a colourless, odourless and tasteless gas, which, unless it is present in a big enough concentration to cause suffocation by reducing the oxygen concentration, does not affect breathing in any way. As a result it can lurk undetected by human senses and can strike unexpectedly.

In most coal mines methane is always either present or expected and consequently precautionary measures are applied. Anything up to $100m^3$ of methane can be released with each ton of coal mined.

Certain types of coal produce more methane than others and deep coal seams tend to be gassier than shallow seams. In metalliferous mines the gas may occur rarely and in unsuspected places potentially posing a bigger threat to the workforce than known sources of the gas. Of course, some gold mines are also very gassy in which case the usual precautions are enforced.

Methane gas burns but does not support combustion. When a jar containing methane is inverted and a burning taper inserted into it, the methane will immediately start burning at the bottom of the jar where it is in contact with the air. The taper, which is immersed in the gas, will be extinguished.

The ignition temperature of methane is about 650°C, which means that only flames or hot sparks are hot enough to ignite it. When methane, however dilute, is brought into contact with a flame, it will burn. When the gas concentration is low i.e. less than five percent, the molecules are far apart and one burning molecule does not generate a sufficiently high temperature to "ignite" the molecule nearest to it. When the concentration is high enough (between 5 and 15 percent) each molecule "ignites" the one nearest to it and the flame rapidly spreads throughout the mixture. This causes an explosion. If the mixture contains too much methane, the amount of oxygen is reduced and in turn the rate of combustion is reduced to the extent that insufficient heat is developed to propagate a flame and thus there is no explosion in these high concentrations.

Because methane is very much lighter than air it is more likely to accumulate in high places such as raises and roof cavities. When the air movement in a tunnel is poor any methane issuing from the rock may form a thin layer above the air. However, once mixed with the air the methane never separates out again.

Sometimes methane can be heard issuing from a fissure (it is then called a blower) or it can be seen bubbling through the water in a drill hole or on the footwall. In such cases immediate precautions must be taken to dilute it to a safe concentration. The most dangerous conditions often occur when a very small flow of methane issues unseen and unheard. It may then accumulate in a high spot due to insufficient ventilation or to a temporary fan stoppage, and an explosion may then take place by a spark from an electric motor or switch. In addition to the violence of the explosion, damage to life and property is caused by the terrific heat generated.

4.3.8.7 Hydrogen sulphide

H_2S is an extremely poisonous gas that sometimes emits from rock fissures together with water or other gases. It can also be formed by the action of acids on sulphurous minerals such as iron pyrites (FeS_2) or copper pyrites ($CuFeS_2$). Water can dissolve significant quantities of this gas under normal conditions and very much more under great pressure. This has implications for the safety of workers. For example, when a winze that has long been filled with stagnant water is drained by drilling into it from below, sufficient gas may be released to cause unsafe conditions if the working place is not ventilated.

Hydrogen sulphide is a colourless gas, slightly heavier than air. It has a very distinct smell — like rotten eggs. In mild cases of exposure there is irritation of the mucous membranes of the eyes, the pharynx and the upper respiratory tract. With more serious poisoning there is giddiness, vomiting, sudden loss of consciousness and paralysis of the respiratory centre.

When the gas is expected, testing apparatus such as electronic detectors should be used to warn of its presence as exposure to even small concentrations impairs the sense of smell which may be lost within a few minutes. This may lead to a false sense of safety.

4.3.8.8 Sulphur dioxide

Acolourless, pungent gas formed when sulphur burns in air, SO_2 is considered to be one of the most important air pollutants either alone or in combination with other gases and substances. Most of the sulphur dioxide in the general atmosphere comes from the combustion of the sulphur present in most fuels. All the sulphur in oil and from 80 to 90 percent of that in coal or coke is emitted in stacks or chimneys as sulphur dioxide, with a small proportion already converted to sulphur trioxide (SO_3).

This gas is dangerous to the eyes as it causes irritation and inflammation of the conjunctivae. It has a suffocating odour and is corrosive and poisonous. In moist air or fog it combines with water to form sulphurous acid, but is only very slowly oxidised to sulphuric acid. Concentrations of 6 to 12 ppm cause immediate irritation of the nose and throat, while 0,3 to 1 ppm can be detected by the average individual possibly by taste rather than by the sense of smell.

It chiefly affects the upper respiratory tract and bronchi. It may cause oedema of the lungs or glottis and can produce respiratory paralysis.

4.3.8.9 Nitrous fumes

Several oxides of nitrogen are usually found together in the same atmosphere and collectively they are known in mining terms as nitrous fumes.

Nitric oxide. (NO). A colourless gas with a faint smell and very poisonous. It is only slightly heavier than air and is relatively soluble in water. In concentrated form it combines readily with oxygen to form nitrogen dioxide. However this reaction is very slow when the concentration of NO is low, as is usually the case in mine air.

Nitrogen Dioxide. (NO_2). This is a reddish-brown gas, 1,6 times as heavy as air and with a distinct, pungent smell. It is five times more poisonous than NO and is very soluble in water.

Nitrogen Trioxide, (N_2O_3). This is also a reddish-brown, soluble gas that is of little importance, as such, because at the normal temperatures found in mines it rapidly decomposes to NO and NO_2.

Nitrous fumes are commonly a mixture of NO, NO_2, N_2O_4 with possible some N_2O_3. They occur in the gases formed by the detonation of nitro-explosives. The burning of such explosives produces even more of these gases. They are also present in the exhaust gases of diesel-powered engines and are also produced in small quantities by both oxy-acetylene welding and arc welding.

Nitrous fumes make up a gas mixture which causes irritation in the nose, throat and windpipe. After a short time in fresh air this irritation may disappear for several hours. However, during this period, damage to the lungs may be continuing (unnoticed). The inhaled gases combine with moisture (water) in the lungs and damage the lung tissue which results in bleeding and the accumulation of moisture in the lungs. One of the big dangers of exposure to these fumes is that the affected person, if not treated correctly, may eventually die from suffocation due to the filling of the lungs with moisture and froth. This is one of the reasons that it is mandatory to report all cases of gassing to ensure that appropriate measures are implemented to prevent any possible tragedy.

Note: Regulation 8.11 of the Mine Health and Safety Act and Regulations states that: the ganger or miner shall report without delay any case of gassing, however slight, to the manager, mine overseer or shift boss, who shall ensure the employee concerned receives prompt medical attention.

Even when the concentration of nitrous fumes is so low that it does not cause immediate irritation it may still cause lung damage, which, amongst other effects, could predispose to the development of silicosis.

Exposure to 0,1 percent nitrous fumes even for short periods is considered dangerous and 0,01 percent may be dangerous if breathed for more than 30 minutes.

Previously, all the nitrous fumes used to be grouped together and the set limit for exposure was 5 ppm. Under proposed legislation NO has been separated from NO_2 etc, and the proposed limits for exposure are 20 ppm and 3 ppm respectively.

4.3.8.10 Aldehydes

These are a series of organic compounds with the general formula: CnH_2nO. Several aldehydes, with formaldehyde predominating, are present in the exhaust gases of diesel-powered engines. They have a very distinct and pungent smell and are intensely irritating to the eyes, the mucous membranes and the skin. At high concentrations they may be so pungent as to be suffocating.

Aldehydes can be smelt at concentrations far too low even to cause irritation.

4.3.9 Hydrogen cyanide

HCN is also known as prussic acid. It is extremely toxic and affects respiration.

This is a colourless gas that has a distinct odour of bitter almonds. It is slightly lighter than air. The gas may occur in mines where acid water comes into contact with cyanide in sand that has been used for sandfilling. Where this is practised precautions must be taken to prevent exposure of persons to this highly dangerous gas. Cyanides are also used in the gold extraction process.

4.3.10 Lead

A number of minerals, especially metals, become airborne in the form of metallic fumes during the refining process. The inhalation of these metallic compounds can cause acute inflammation of the lung tissue. The acute effects are characteristic of gassing incidents in many ways and are often classified as such, even where the inhaled material has been a fume.

Lead poisoning (plumbism) is one of the longest known occupational diseases in the mining industry. In gold mining, lead is used mainly in the zinc-preparation of cyanide-extracted gold and also in the assay of gold-bearing ores. Metallic lead at normal temperatures does not pose a high health risk, unless in the form of fine dust.

4.3.11 Mercury

This is an extremely toxic substance. Mercury is used in some reduction works to recover gold - known as the amalgam process. Because mercury is a liquid with a significant vapour pressure even at room temperature it evaporates into the atmosphere. Well-ventilated areas are required where mercury is handled and the vapour should be captured via an extraction system. Captured vapour should never be discharged to atmosphere but absorbed in activated charcoal.

4.3.12 Refrigerants (Ammonia and Freons)

4.3.12.1 Ammonia, NH_3 - is a light, colourless gas with a very pungent smell. It is very soluble in water. Ammonia can sometimes be smelt after blasting with ammon-explosives has taken place. However, it can only appear in dangerous amounts when leaking from cooling plants where it is used as a refrigerant. In such cases it will cause intense irritation of the eyes, nose and throat and will produce coughing. In high concentrations it may arrest respiration.

4.3.12.2 Freon. This is a trade name given to various methane halides (chlorine, bromine, fluorine and iodine are called halogens) which are used in refrigeration plants because they are safer than ammonia and in the past were considered to have some other advantages.

Both Freon 11 (trichloromonofluoromethane - CCL_3F) and Freon 12 (dichlorodifluoromethane - CC_2F_2) are colourless and heavy gases. They are neither flammable nor poisonous but very high

concentrations can cause suffocation. However, in the presence of an open flame, Freon decomposes to form phosgene gas - $COCl_2$, which is very poisonous.

Freon gas leaks are tested by means of acetylene or alcohol gas flames, which change their colour if Freon is present.

Special Note. During the late 1980's there was a considerable discussion worldwide concerning the depletion of the world's ozone layer. Although the reasons are not fully understood, the use of chlorofluorocarbons - CFCs - was thought to be a major cause. Both Freon 11 and Freon 12 can be seen to be CFCs from their chemical formulae. A great deal of international support has been given to efforts directed at limiting CFC production and use, and there has been widespread public concern on this issue. International agreement on measures for the protection of the ozone layer (The Montreal Protocol) was achieved under the auspices of the United Nations Environmental Programme (UNEP) in September 1987.

Alternatives to CFCs were developed e.g. HFC22, Methylene Chloride and Di Methyl Ether.

4.3.13 Solvent vapours

Solvents are materials used to dissolve other materials where water is inadequate. They are used in processes such as extraction, degreasing, dry cleaning and ore flotation. Solvents are often an integral part of some products such as paints, varnishes, glues, pastes and many others. Organic solvents include naphtha, mineral spirits, turpentine, benzene, alcohol, perchloroethylene and trichloroethane.

There are certain dangers associated with using solvents.

- Flash point. This is the lowest temperature at which a liquid will give off a vapour in sufficient concentration to form an ignitable mixture with air when an ignition source is brought close to the surface of the liquid
- Explosion limits. Flammable liquids have a minimum vapour concentration in air below which the propagation of a flame will not occur. Furthermore, there is a maximum concentration of vapour or gas in air above which the propagation of a flame will not occur because the mixture is too rich in combustible vapour i.e. it is fuel rich and the flame will choke. (See 4.3.8.6). These two limits are known as the Lower explosive Limit (LEL) and the Upper Explosive Limit (UEL) respectively
- Auto-ignition temperature. This is the lowest temperature at which a flammable gas/air or a vapour/air mixture will ignite spontaneously or on contact with a heated surface. It is important to note that this will occur without a flame or spark being present. Gases and vapours will ignite spontaneously in the presence of oxygen and the presence of a catalyst can further lower the auto-ignition point

Halogenated hydrocarbons represent the most important and widely-used group of industrial solvents. Some are very poisonous and all are narcotic to some extent. Saturated members of this group, such as carbon tetrachloride and tetrachlorethane, cause liver and kidney damage. Some solvents give off phosgene, which is a highly poisonous gas, when heated to decomposition.

Chlorobenzene is the best known of the aromatic chlorinated hydrocarbons. It is a flammable liquid that has an acute reaction on the central nervous system and can rapidly lead to unconsciousness. Certain chlorinated naphthalenes also cause liver damage which can result in toxic jaundice.

It is interesting to note that diesel fuel is very often used as a degreasing agent or for cleaning oily machine parts. This fuel is really a mixture of hydrocarbons, but usually contains sulphur, nitrogen, and oxygen compounds. It also contains trace elements such as iron, lead, copper and aluminium. The more volatile components have a mild anaesthetic action and can produce a severe chemical pneumonitis. The fuel fractions that have a lower boiling point can cause dermatitis due to their defatting effect on the skin.

It is always advisable to consult the Material Safety Data Sheets (MSDS) for information on chemicals to be used, especially solvents, and to note precautions for safe use and the use of Personal Protective Equipment.

4.3.14 Welding fumes

Welding operations generally involve the melting of a metal in the presence of a flux or a shielding gas by means of a flame or an electric arc. The operation may produce gases or fumes from the metal, the flux, the metal surface coatings or surface contaminants. The flame or arc may also form certain toxic gases such as ozone or nitrogen dioxide. If there is an arc or spark discharge, the non-ionising radiation and the products of destruction of the electrodes should be investigated.

Welding fumes cannot be classified simply. When welding is done on a surface coated with cadmium, toxic fumes of cadmium can be involved. When zinc-coated surfaces are welded, toxic quantities of zinc oxide may be liberated. When painted surface are welded, lead or other pigment fumes may be liberated. When fluoride fluxes are used in welding very toxic fluoride fumes are involved. Also, when oily surfaces are welded, offensive and toxic fumes can be liberated and when the welding torch is improperly ignited i.e. the wrong gas mixtures are used, carbon monoxide may be evolved. In addition, oxides of nitrogen may be formed. It is therefore considered hazardous to inhale welding fumes.

4.4 Occupational Exposure Limits (OELs)

An Occupational Exposure Limit (OEL) is that concentration of an airborne substance to which nearly all workers may be repeatedly exposed day after day without adverse health effects.

The American Conference of Governmental Industrial Hygienists (ACGIH) has published threshold limit values (TLVs) for several hundred industrial materials. The information collected for one substance may run into hundreds of printed pages. The limits are not a dividing line between safe and unsafe conditions. Their main use is intended to be a link between medical doctors, the engineers who have to design control equipment and the occupational hygienist who has to monitor the occupational environment. These limits are based on the best available information from e.g. animal studies and workplace experience. The basis on which values are set may differ from substance to substance, depending on whether protection against health impairment, freedom from irritation or other forms of stress is being considered.

4.4.1 OEL _ TWA

It has been found in practice that concentrations of airborne pollutants may vary between wide limits within any one 8-hour shift. It was therefore considered that to assess worker exposure the time - weighted average concentration of the pollutant should be used. This approach has to take cognisance of any excessive peak concentrations, which in the case of some substances could cause significant health impairment and even death.

The airborne concentration to which nearly all workers may be repeatedly exposed for a normal 8-hour workshift (or a 40 hour work week) constitutes the Time-Weighted Average (TWA) limit and is a concentration expressed either in parts of vapour or gas per million parts of polluted air by volume at 25°C at 101,3 kPa pressure (ppm), or in milligrams of pollutant per cubic metre of air (mg/m^3).

4.4.2 OEL _ STEL

For many substances a peak concentration exposure may be tolerable, provided that the exposure is for only a limited time. These concentration values are designated short-term exposure limits (OEL _ STEL). These 15-minute exposure limits can be found in the Department of Minerals and Energy's Schedule as well as in other publications such as the ACGIH reference material. OEL _ STELs thus represent the maximum concentration to which a worker can be exposed continuously for a period of up to 15 minutes without adverse effects. Not more than four such excursions per day are permitted with at least 60 minutes between excursions and also the daily OEL _ TWA must not be exceeded.

OEL _ STEL values should not be used as engineering design criteria or for emergency exposure levels.

4.4.3 OEL-C

Certain hazardous substances such as chloroform, hydrogen chloride, nitrogen dioxide and vanadium fumes are predominantly fast acting. Even short-term exposure to high concentrations of substances

like these could have some adverse effect on the human body. In such cases OEL _ TWAs are obviously unsatisfactory. Substances of this nature are best controlled by a Ceiling (C) limit that should never be exceeded. In effect, these limits constitute maximum allowable concentrations and are not to be confused with OEL _ TWA limits

4.4.4 Lists of limits

Various organisations have compiled and published lists of substances for which OEL limits have been formulated. The ACGIH publishes a handbook on OELs (TLVs in this case) and Biological Exposure Indices, which is updated on an annual basis. The DME has selected substances from this list and set out a revised list in a schedule to mines. Only substances deemed to be relevant to the mining industry have been included. In a like manner, the Department of Labour has compiled a similar list comprising substances felt to be relevant to Industry.

4.5 Assessment of compliance with OELs

4.5.1 Analytical methods

The National Institute for Occupational Safety and Health (NIOSH) of the US Department of Health and Human Services produces a Manual of Analytical Methods. This manual is recognised world-wide as the most authoritative reference for both sampling and analytical methods/techniques. It contains over 250 sampling and analytical methods for over 400 substances. It is a compilation of methods for occupational exposures to toxic substances in air and biological samples. The methods have been developed specifically to have adequate sensitivity to detect the lowest concentrations and sufficient flexibility of range to detect concentrations exceeding safe levels of exposure, as regulated by the Occupational Safety and Health Administration (OSHA) and recommended by NIOSH.

For ease of reference the manual is available via the Internet, on computer diskettes and a compact disk. A companion Guide to Chemical Hazards has also been produced in these formats and these manuals offer definitive assistance with regard to airborne and chemical health hazards.

In South Africa the tendency is to follow the NIOSH analytical methods closely and to adhere to the NIOSH techniques. A common set of analytical methods lays the foundation for standardisation, comparisons of results and inter-laboratory checks. There is also no reason to "re-invent the wheel", as it were, since all the methods and techniques have been well-researched and authenticated.

4.5.2 Sampling strategies

Gravimetric dust sampling strategy

When the Government Mining Engineer introduced gravimetric dust sampling in mines in 1992, guidelines were issued on precisely how the sampling was to be performed. Mines were divided into areas which, in turn were divided into statistical populations. Statistical populations were supposed to consist of persons generally exposed to similarly dusty environments. These populations embrace 200 persons. Five percent of the population was sampled over each six month sampling cycle. The broad strategy is set out in Figure 4.1.

The individual sampling results were averaged, on a person-weighted basis, for each statistical population. The results for each statistical population were then averaged to produce an area average, which is in turn was used to produce a mine average. Samples for each statistical population had to be analysed for α quartz content in an laboratory using approved techniques. Once the quartz content was known for each statistical population the person-weighted risk was determined and ultimately the person-weighted risk for the mine was calculated. The risk was then used to determine the levy that a mine has to pay into the compensation fund. At the time the dust-sampling programme was introduced, sampling with konimeters was no longer required. In effect, this meant that dust sampling in individual workplaces and for engineering control purposes virtually ceased.

The dust-sampling programme outlined above was for levy purposes and did not assess whether the exposures of individual workers were in compliance with occupational exposure limits.

The air sampling required by the Occupational Hygiene Regulations is as follows:

- The mine is sub-divided into working places as per the working place code list found in the guideline
- The results of the identification process are compared to the relevant OEL and based on this, each workplace is categorised into one of three classification bands to determine the various homogeneous exposure groups (HEG) as shown below.

Table 4.6 Classification Bands

CATEGORY	PERSONAL EXPOSURE LEVEL
A	Exposures exceeding the OEL
B	Exposures between 50% of the OEL and the OEL
C	Exposures between 10% of the OEL and 50% of the OEL

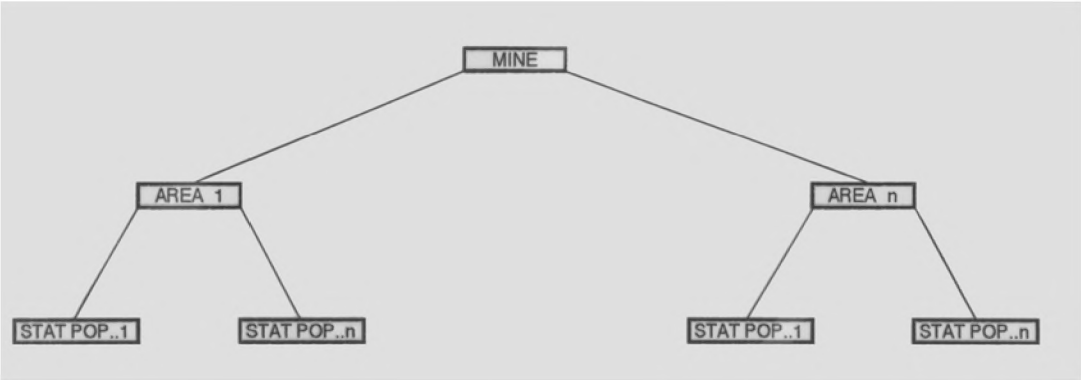


Figure 4.1 Breakdown of a mine into sampling units

- The number of samples to be collected in each group is formulated as per Table 4.7

Homogeneous Exposure Groups need to be reclassified when exposure levels change due to the implementation of controls or due to a deterioration of controls. The monitoring strategy within an HEG will have to be adapted to the new frequency of monitoring when either of the above occurs.

Similarly, HEGs must also be re-evaluated when, inter alia, the following occur:
- Employee complaints
- Process changes
- Occupational illnesses
- Other events warrant re-evaluation
- New toxicological data
- New regulatory initiatives

The exposures measured for any individual worker within a homogeneous exposure group would be allocated to the medical records of the specific worker and to all other workers within that HEG. For a given HEG, samples should be randomly assigned covering all shifts (to different employees on different days over the monitoring period). All job categories within a homogeneous exposure group must be randomly sampled.

Table 4.7 Airborne Pollutants: Sampling

CATEGORY	ACTION/FREQUENCY
A	Verify the results Issue appropriate Respiratory Protective Equipment (RPE) or Stop Work if no appropriate RPE is available to prevent overexposure Inform the Regional Principal Inspector of exposures exceeding the OEL Amend the action plan to institute control measures to eliminate overexposures. The following must also be complied with: Sample 5% of HEG on a monthly basis.
B	Sample 5% of HEG on a six monthly basis.
C	Sample 5% of HEG on an annual basis.

Although the above strategy appears to be straightforward, the previous sampling strategy ran into difficulties that were not addressed. Dust sampling can be affected by many factors and should not be over-simplified.

Sampling Methodology

Before sampling commences filters, either 25 mm or 37 mm diameter (depending on the anticipated dust loading but in general, most non-gold mines use 37 mm diameter filters) are numbered, dried, weighed and inserted in filter holders. Filters are weighed on an electronic microbalance with the capability of measuring to several decimals of a gram.

In addition, the pumps to be used for sampling have to have batteries charged according to the manufacturer's specifications. *The pumps then have to have the sampling flow rate set to 1,9 l/minute (as specified in the guidelines).* Flow rates are set by having the pump draw air through a calibrating apparatus that makes use of an electronically-timed soap bubble. The pump draws the soap bubble vertically upwards in a calibrating tube and the time taken for the bubble to traverse between calibrating marks is electronically timed. Using such apparatus , pump flow- rates can be set accurately to any desired flow rate.

The sampling pumps and all the accessories such as filter holders, cyclones, etc are attached to the workers to be monitored. A very efficient organisation is required to ensure that the pumps are allocated to the persons intended on time and started. Samples of dust present in the air are collected and deposited on the filter over the duration of the shift.

At the completion of the shift (or sampling period) the sampling pumps have to be retrieved, stopped and details of the sampling period recorded.

Records

Worker's details and also

(i) Sampling instrument number
(ii) Filter number
(iii) Pump flow rate (l/min)
(iv) Sample duration (minutes)
(v) Volume of air sampled (m^3) = {(iii) × (iv)/1000}

The pump flow rate has to be checked again and if there is a deviation of five percent or more from the pre-sampling flow rate the sample is to be rejected. Arrangements then have to be made for another sample to be collected.

After a suitable period of acclimatisation the mass of dust on the filter is determined as (mass of filter + dust) – (mass of filter) allowing for changes to the mass of the filter due to moisture changes. These changes are ascertained by checking changes to the masses of control filters during the period between initial weighing and weighing after sample collection.

Dust concentrations are then calculated from the volume of air sampled and the mass of dust collected on the filter and reported as mg/m^3.

Filters may then be analysed for quartz content. Either the x-ray diffraction or the infrared method may be used. With x-ray diffraction the filter is inserted into a special holder and placed into the machine after it has been warmed up and calibrated against standards. The sample is then scanned and the diffraction patterns in the various x-ray ranges automatically plotted. The peak concentrations in the quartz range are measured and the analytical mass of quartz calculated. This method does not damage the filter in any way i.e. it is a non-destructive method and the filter is available for further analyses or storage. The Infrared method may also be used but this requires the manufacture of a pellet using potassium bromide and this destroys the original filter. Either method may be used with equal accuracy of results, but the analysing laboratory has to be approved by the South African Bureau of Standards (SABS).

Once the quartz content has been determined the quartz concentration can be calculated. It is this contaminant concentration that is compared to an OEL and the hazard potential of the inhaled air assessed.

It is necessary to ensure that all equipment necessary throughout the monitoring is properly prepared i.e. batteries for sampling pumps are charged, flow rates are set, filters are weighed and sampling cassettes are loaded and the necessary paper work completed. This is not only a necessary aspect of any investigation but vital for the compilation of exposure profiles in the mine.

It must also be noted that monitoring can take three forms:

- Personal monitoring - establishing the concentration of contamination to which the worker is exposed. The major dust sampling effort of mines has this exclusive aim
- Environmental Monitoring - establishing the environmental concentration to which it is believed that everyone working in the area is exposed. This technique can be useful for zoning hazardous areas. However, the sampling strategy outlined earlier makes no provision for this type of sampling. Because of the averaging process inherent in gravimetric sampling this type of sampling is not entirely suitable to localise dust generating processes and operations and an alternative sampling method or technique is indicated
- Special Monitoring - establishing the concentration of the contaminant for special purposes, e.g. research on the effectiveness of control measures

4.5.3 Airborne dust

4.5.3.1 Airborne dust criteria

For chemical substances present in inhaled air as suspensions of solid particles for droplets, the potential hazard depends on particle size as well as mass concentration because of:

1) effects of particle size on the deposition site within the respiratory tract
2) the tendency of many occupational diseases to be associated with material deposited in particular regions of the respiratory tract

The Chemical Substances TLV Committee of the American Conference of Governmental Industrial Hygienists (ACGIH) has recommended size-selective TLVs for crystalline silica for many years in recognition of the apparent association between silicosis and respirable mass concentrations. The Committee is now re-examining other chemical substances encountered in particulate form in occupational environments with the objective of defining:

1) the size fraction most closely associated with the health effect of concern, and
2) the mass concentration within that size fraction

Analyses of specific air contaminants and the potential diseases associated with different regions of the respiratory tract indicate that size-selective sampling is necessary for a meaningful evaluation of the inhalable hazard to the worker. Different particle size distributions of the same contaminant will cause major changes in deposition in the various regions of the respiratory tract. This changes not only the relative amount of material deposited within the region but also the probability and nature of associated disease processes. Thus, the development of Particle Size-Selective Sampling - TLVs (PSS-TLVs) is an important and necessary step toward the improvement of air contamination standards established for the protection of workers.

PSS-TLVs are expressed in three forms:

1) *Inhalable Particulate Mass TLVs (IPM-TLVs)* for those materials that are hazardous when deposited anywhere in the respiratory tract.
2) *Thoracic Particulate Mass TLVs (TPM-TLVs)* for those materials that are hazardous when deposited anywhere within the lung airways and gas exchange region.
3) *Respirable Particulate Mass TLVs (RPM-TLVs)* for those materials that are hazardous when deposited in the gas exchange region.

Collection efficiencies representative of several sizes of particles in each of the respective mass fractions are shown in Figure 4.2.

The particles are collected according to defined efficiencies for their respective masses. The most significant difference from previous definitions is the increase in the median cut point for the respirable particulate matter sampler from 3,5 µm to 4,0 µm. This is in accord with the International Organization for Standardisation/European Standardisation Committee (ISO/CEN) Protocol (ACGIH, 1997)

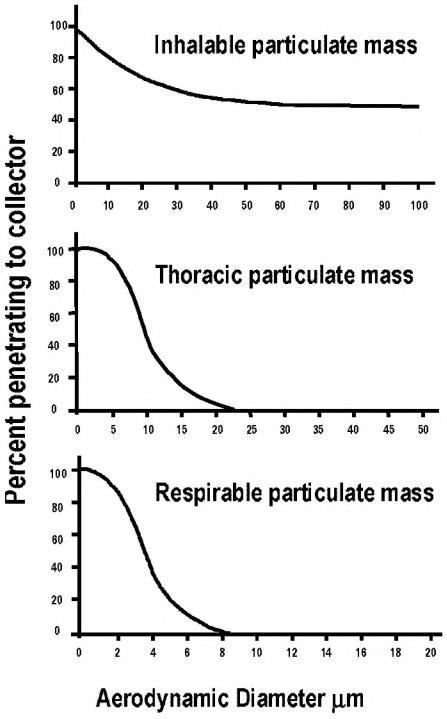


Figure 4.2 Inhalable, respirable and thoracic size fractions (after Phalen)

The application of information on how the aerodynamic size of aerosols determines the inhalability, i.e. the fraction of airborne mass that actually enters the nose or mouth during inhalation, and the regional deposition of particles within the respiratory tract can lead to acquiring size-selective samples that more closely relate to aerosol inhalation hazards. Size-selective aerosol samples may be defined as reliably collected aerosol fractions which are expected to be available for deposition in the various subregions of the respiratory tract (ACGIH, 1997).

4.5.3.2 Dust sampling

Because fine dust particles which are the main cause of pneumoconiosis cannot be seen by the naked eye and because the dust which can be seen is coarse and comparatively harmless, the human eye is not a reliable guide to any dangerous dust in the air. It is therefore necessary to make use of dust sampling instruments which are capable of providing indications of the fine dust in the air to determine whether the dust constitutes a danger to health, what it is caused by, what can be done to reduce the concentrations of airborne dust and whether such action is having the desired effect. Any respirable dust-sampling instrument should be so designed that it will capture only dust particles of a size considered to be dangerous to health - usually smaller than about 5 to 7 micrometres.

This is achieved in some instruments through the way air is drawn in at a fixed rate via the inlet, which is designed so that the air travels very slowly at first thereby allowing the coarse particles to settle out before reaching the region where the dust is actually retained as a sample.

Gravimetric dust sampling

The requirements for a sampling pump are:

(i) the battery powering the pump should last longer than an eight-hour shift
(ii) the sampling flow rate should remain constant, as far as possible, irrespective of the charge remaining in the battery
(iii) the sampling flow rate should remain constant, irrespective of the dust burden on the filter. In other words the flow rate should be maintained as dust builds up on the filter
(iv) the sampling flow rate should remain constant, irrespective of the barometric pressure. Sampling pumps should be capable of use at any elevation in the workings and deliver a consistent performance. This is very important in deep mines where a large range of operating pressures can be experienced.
(v) the pump and battery should be light enough not to cause the wearer of the sampling apparatus any discomfort.
(vi) The sampling pump should be intrinsically safe.

Several manufacturers produce suitable sampling pumps with miniature batteries that meet all the criteria outlined above. The pumps feature some sort of timing device that indicates lapsed sampling duration and an adjustable rotameter that provides a rough estimate of the sampling flow rate. There is an external battery charging facility and an indicator of battery condition. Most models have security features that cover the on/off switch and the rotameter adjuster to prevent inadvertent or even deliberate changes to the settings. Some models can be programmed to start and stop at predetermined times. An example of a dust-sampling pump is shown in Figure 4.3.

Figure 4.3 Personal air sampling pump (courtesy of Rotheroe and Mitchell)

The dust-sampling pump is only one element of a sampling train, as it is called. There is also a sampling cassette, which for respirable dust sampling consists of a separating cyclone, sampling head and filter medium. The sampling head is connected to the sampling pump by a thick-walled (to prevent kinking), non-static, flexible tube.

Figure 4.4 Sampling head for respirable dust (courtesy of Casella)

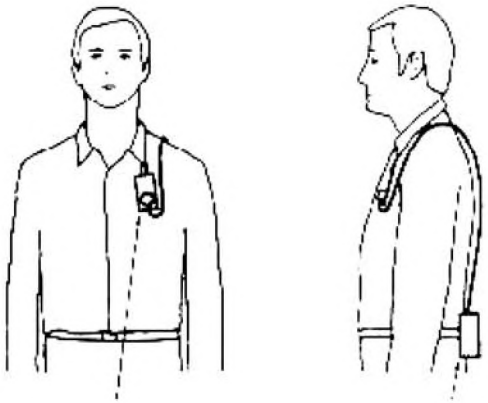


Figure 4.5 Personal dust sampling equipment attached to a wearer

Figure 4.6 Sampling head for inhalable dust (after Hinds)

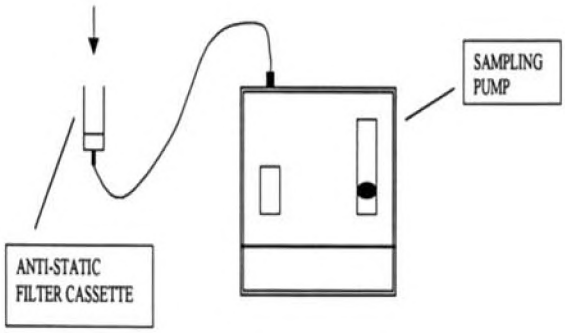


Figure 4.7 Sampling head for airborne asbestos. Open face with anti-static cowl

When the pump is activated, air (with dust) is drawn into the separating cyclone, which, through centrifugal force, separates the large from the small particles. The former settle in the catchpot while the latter i.e. the respirable fraction of interest is retained on the filter.

An actual sampling cassette assembly is shown in Figure 4.4 where the various components are seen.

Once all the sampling equipment has been correctly assembled it has to be attached to an employee for a full shift sample to be collected. The cassette is positioned in the breathing zone of the person being sampled. This is defined as the zone within a 30 cm radius of the nose. Since the sampling cassette will be in this zone throughout the shift it is reasonable to expect that a representative sample will be collected for the person being sampled. Figure 4.5 shows one method of attaching the equipment to the wearer.

It must be noted that the actual sampling requirements and techniques for various airborne particulates can differ. For example, lead samples are collected as "total dust" samples and asbestos fibres are collected via an anti-static tube onto the open face of a filter. In addition, to prevent overloading of filters with fibres and background dust such samples are collected for ten-minute periods during each hour's sampling. Evaluation and sampling are in accordance with the Asbestos International Association (AIA) Recommended Technical Methods or variations thereof.

Asecond way is to make use of a harness, which attaches the sampling train, without the long tube, to the chest of the wearer.

4.5.3.3 Real time monitoring

A disadvantage of the sampling methods described above is the inevitable delay before the results of dust sampling can be judged. A number of sampling instruments have been developed for making a rapid assessment of the concentration of respirable dust, using physical phenomena such as beta radiation attenuation, electrostatic precipitation coupled to a piezoelectric balance and the scattering of a light beam.

One such instrument is the digital tyndallometer, seen in Figure 4.8

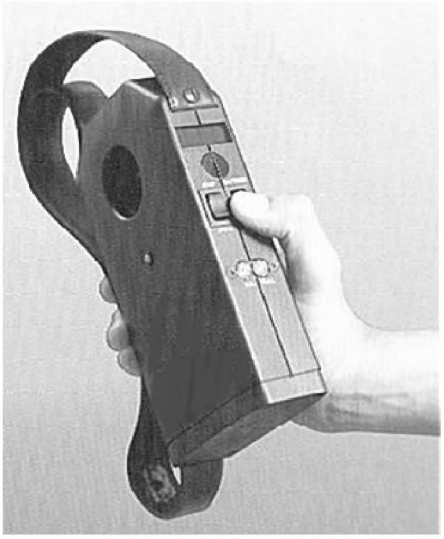
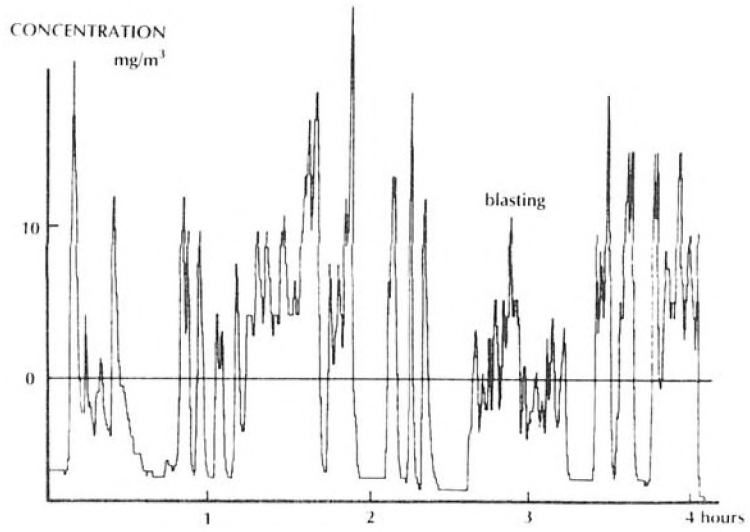


Figure 4.8 A typical digital tyndallometer (courtesy of Hund)

This is a portable instrument that makes use of the light scattering properties of dust. A beam of monochromatic light with a wavelength of 0,94 µm passes across a sensing chamber that is open to the atmosphere being investigated. The presence of dust in the path of the beam causes the beam to scatter. The intensity of the scattered light within a 70± scattering angle is measured with photocells and displayed as a digital readout. This type of instrument has an integrated data memory and an internal real-time clock. It has the capability of providing averaging over random intervals of between five seconds and up to eight hours (in battery mode). Current values are measured every second. Results can be downloaded using suitable software and deposition patterns charted.

Deposition patterns similar to the one shown in Figure 4.9 can be obtained. The instrument is designed to give a volume-proportional signal related to the concentration of fine dust in the beam, according to its deposition probability in the human lung.

Unfortunately, it is not only dust that is sensed but also all *aerosols*. This means that oil mists, water vapour and diesel soot are also "seen" as dust in the path of the beam but no distinction from dust particles is possible. The instrument has potential in trouble-shooting exercises and is useful for testing the effectiveness of control measures. However, in the hands of an inexperienced operator very unreliable results are possible (and inevitable).



Dust deposition pattern.

Figure 4.9 A typical dust deposition pattern

Even though the tyndallometer may not measure dust alone, with intelligent interpretation of results very useful information can be derived. High airborne pollutant concentrations can be linked to specific events, as can be seen in Figure 4.9.

4.5.4 Gases and vapours

Different gases found in a mine require a range of sampling and detection techniques. The available techniques can be divided into two main groups:

- measurement by means of direct reading instruments
- sample collection followed by subsequent laboratory analysis

As in the case of dust measurements, an air sample should be collected over the entire working period if a time-weighted average concentration is required. Most of the direct reading apparatus operates on the principle of spot measurements or grab sampling. This means that the sample is collected over a short period of time. Some instruments have built-in recorders, or can be fitted with recorders, in order to measure maximum (peak) and minimum concentrations over a working shift. These real-time traces can be used to calculate average concentrations if required. Some direct reading equipment can be linked directly to a computer to record concentrations and the variations thereof and yet others can give real-time readings on site as well as log the data which can later be downloaded for analysis.

4.5.4.1 Sample collection

As far as mines are concerned samples are collected in three ways, usually for different reasons:

- Air is drawn into a container, most usually a tedlar bag, for whatever time period is deemed to be necessary and transported to a laboratory for analysis. This technique is used when gases in a workplace are required to be identified and concentrations quantified
- In a similar way air samples are collected from boreholes in containers, normally specified by the analysing laboratory, and transported to the laboratory within the time period and manner specified for analysis.

Figure 4.10 Direct reading gas monitors showing their relative size (courtesy of Crowcon)

Points to be noted are:

(i) A large enough volume of air has to be sampled to ensure the provision of sufficient gas for analysis
(ii) The collected gas must remain in the same state as when it was collected at site and must be stable during transport to the laboratory
(iii) A minimum of manipulation in the field is required

4.5.4.2 Direct reading instruments

These are generally instruments that draw air through a collector and the reaction with the collector is indicated directly on a meter, either analogue or digital. Examples of direct reading gas monitors are shown in Figure 4.10 below. It can be seen how small the instruments are and how easy it is to read the gas concentration.

Most instruments use some form of electrochemical cells that are supposed to be specific to a given gas but when dealing with non-explosive gases cross-sensitivities to other gases are known to exist and can cause problems. There is available a carbon monoxide monitor that is attached to a miner's cap lamp and which flashes when CO levels exceed a pre-set limit. This device is used mainly in collieries for the early detection of "heatings" but can be used in any mine where there may be a danger from fires.

Shown in Figure 4.11 is a further example of a direct reading gas monitor. The monitor is an H_2S monitor in this case.

Instead of using several separate monitors to test for different gases there are available multi-gas testing monitors. Shown in Figure 4.12 is a direct reading gas monitor equipped with various electrochemical cells and which is capable of monitoring several gases simultaneously and continuously. This is a very versatile instrument but is generally not used on a routine basis. Such an instrument could be used when the need to monitor important gases in a specific locality exists. For instance, it may be necessary to monitor different gas concentrations along a route travelled by diesel-powered vehicles. This type of monitor makes it possible to monitor levels of CO, NO and NO_2 simultaneously.

The advantages of using a direct reading instrument are:

(i) that the results are rapidly and readily available and any remedial action can be implemented with a minimum of delay by a suitably qualified person

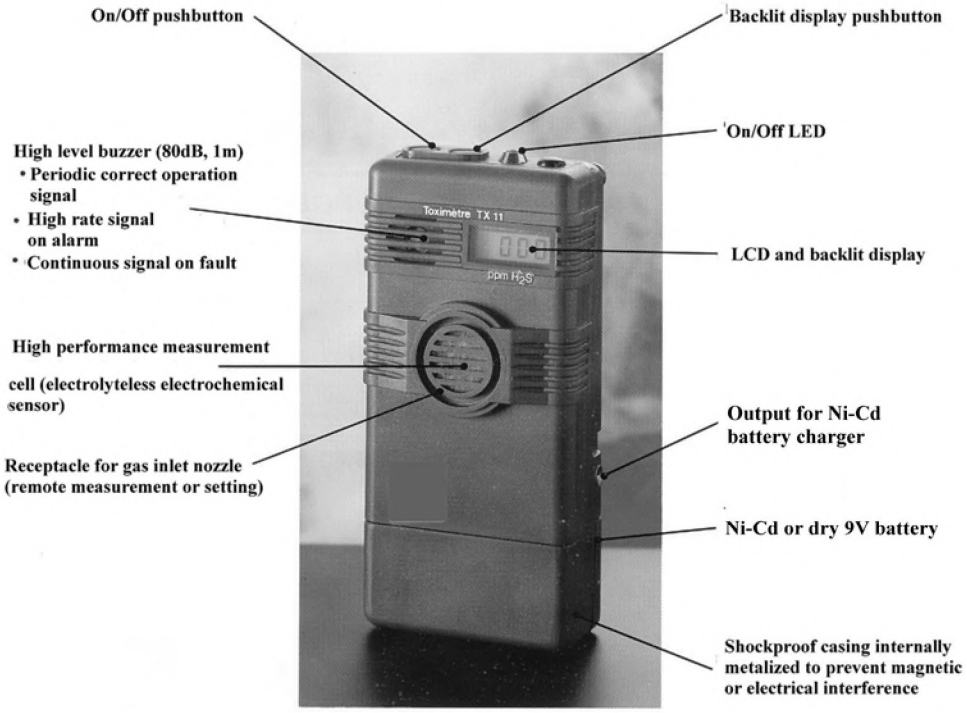


Figure 4.11 Direct reading gas monitor (H_2S) with an electrochemical cell (courtesy of Oldham)

Figure 4.12 Multi-gas direct reading monitor (courtesy of Crowcon)

(ii) the instrument is usually capable of producing a continuous record of gas concentrations, including peaks
(iii) the instruments can readily be used to trace a source of pollution or a specific contaminant

However, certain problems concerning the use of these instruments should be noted:

(i) Calibration is not always easy and obtaining reliable calibration gases has been shown to be problematical. Inter-laboratory checks have shown significant differences in the calibrating gas concentration. This means that a close watch has to be kept on this aspect
(ii) As mentioned already, cross sensitivity to interfering gases or impurities can result in incorrect indications of gas concentrations. To a certain extent this can be dealt with if the interfering gas is either known or anticipated
(iii) This type of equipment is not always available; it cannot always be used for personal monitoring and is considered to be very expensive
(iv) Electrochemical cells have a limited shelf life, whether in use or not

4.5.4.3 Colorimetric testing methods

Chemicals or reagents are sealed in glass tubes and after the seals are broken a specified amount of air is drawn through the tube. The amount of air is determined by the manufacturers and relayed to the user by specifying the number of strokes to be used with the aspirating pump. Typically, one single stroke or aspiration will draw 100 ml of air through the sampling tube. Shown in Figure 4.13 is a sampling bellows in use with a chemical detector tube.

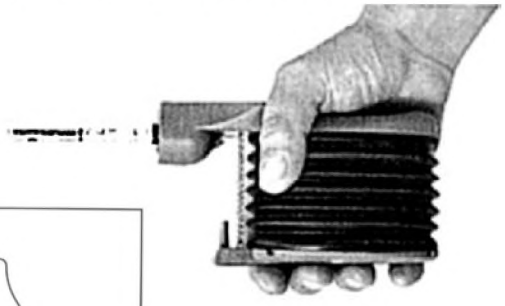


Figure 4.13 Sampling bellows for chemical detector tubes (courtesy of Drager)

The contaminant in the air being sampled reacts with the reagent to produce a change in colour. The gas concentration can be deduced from the colour gradient or the intensity, or from the amount of discolouration of the reagent i.e. the length of discoloured material in the detector tube.

Detector tubes are available for a large number of different gases. Some gases, e.g. carbon monoxide, (CO), have tubes supplied in two ranges viz. low range and high range. *Note: where there is any uncertainty of the range, for the sake of safety all gas concentrations should be regarded as "high" until proved otherwise.*

A CO detector tube is shown in Figure 4.14. The tubes can be used to measure concentrations of gases at the ppm level and the colour reagents are supposed to be specific for a given gas.

However, once again the problem of cross-sensitivity to interfering gases is known to exist and appropriate precautions need to be instituted to avoid complications.

Advantages of this method are that it gives a rapid response, the equipment is highly portable and it is relatively inexpensive. It does provide a quick indication of the presence of an atmospheric contaminant.

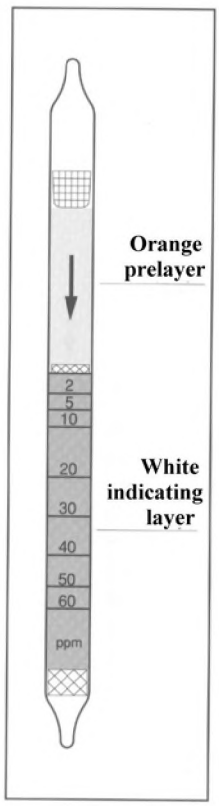


Figure 4.14 Chemical detector tube for carbon monoxide

Disadvantages of this method are:

(i) Poor accuracy. The relative standard deviation can often be as much as 40%
(ii) Sampling tubes have a limited shelf life
(iii) Built-in differences as a result of the manufacturing process can occur
(iv) Although there are long-duration sampling tubes this type of monitor is not very suitable for personal monitoring
(v) The colour reaction can be influenced by environmental contaminants in the air that is being sampled. This is especially important if diesel exhaust emissions are to be measured. If the manufacturer's cooling fins are not used then inaccurate measurements are a foregone conclusion. Furthermore, if corrections for ambient pressures are not made additional inaccuracies will result. The manufacturer's handbook should be referred to for the calculations to correct for temperature and pressure.

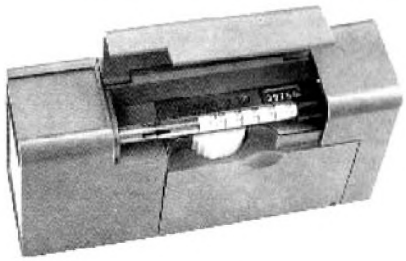


Figure 4.15 Long duration chemical detector tube sampler (courtesy of Drager)

On occasion it is desirable to collect gas samples over a number of hours instead of the short time needed for the standard chemical detector tubes. There is a monitor known as a polymeter that uses special chemical tubes for long duration sampling. The air is drawn through the tube by means of a battery driven, mechanical sampling pump and the sampler can be set to sample over the required number of hours. It is therefore possible to determine 8-hour TWA exposure levels using this equipment. The apparatus is shown in Figure 4.15.

4.5.4.4 Chemical badges

Chemical badges are available to determine shift-long exposure levels for selected gases. These badges are attached to the wearer at the commencement of the shift and removed at the completion of the shift. A simple colour comparison will give the exposure in terms of ppm.hours which, if the sample duration is known, can be converted to an 8-hour time-weighted average (TWA) value. A second similar type of badge has to be sealed after removal from the wearer and then analysed in a computerised analytical procedure.

4.5.4.5 Sorbent tubes

Many of the substances of importance in occupational hygiene appear in the working environment in the form of gases and vapours and therefore cannot be collected like particles on a filter medium. Many industrial biological processes produce and release gases. Many of them can be toxic and others can cause asphyxiation in confined places.

There is a large variety of gases and vapours present in industry and they require a wide range of sampling and detection techniques. Broadly, the available techniques fall into two main groups, namely:

- Direct measurement by means of direct-reading instruments and,
- Indirect analysis in which an air sample is collected in the workplace and then analysed in a laboratory.

One way of sampling chemicals (impurities) in the atmosphere is by drawing the air through an absorbent or adsorbent such as activated charcoal. This will concentrate specific gases or vapours for analysis at a later stage. This concentration makes the analysis more reliable.

The most commonly used adsorbers are:

- activated charcoal tubes
- silica gel tubes as well as tubes equipped with specialised adsorption materials e.g. Tenax. Whatever method is deployed certain general considerations must be observed; and
-

- passive monitors that work on the principle of diffusing the contaminant in question through a membrane of sorts. The gas or vapour is then adsorbed onto an activated charcoal disk for later analysis

When charcoal or silica gel tubes are utilised air pumps are used to draw air through the tubes at a fixed, known rate for a specific period of time.

Adsorption is usually a dry method of sample collection

4.5.4.6 Bubblers

Another commonly used method is glass impinger tubes and glass containers which have porous glass bubblers. Contaminated air is drawn through a specific liquid i.e. the collection medium, usually at a rate of between 2-3l/min during which time a chemical reaction takes place between the contaminant and the absorber. One or more impinger tubes are placed in series to ensure total absorption of the contaminant.

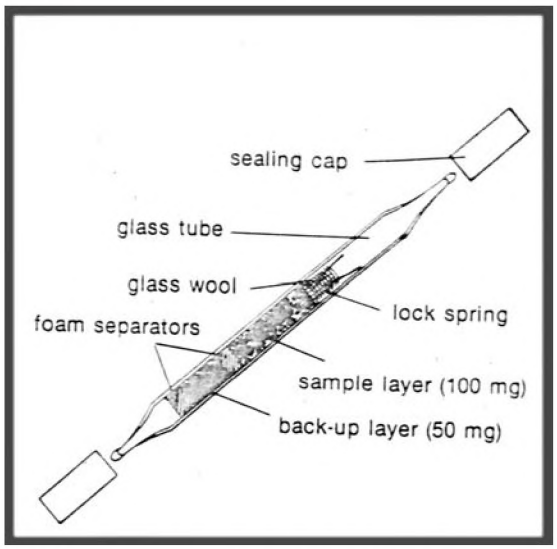


Figure 4.16 Typical sorbent tube (courtesy of Plog)

Absorption is a wet method of sample collection.

- The integrity of the sample must be maintained to prevent degradations or reactions in the collection medium
- The sampling procedure should be optimal for the analytical procedure to be used
- It must be ensured that the gas or vapour sampled is stable and capable of being stored without wall losses in the container used for sampling
- Precautions are necessary to prevent leaks and sample contamination

As far as possible the time interval between sample collection and sample analysis should be kept to a minimum and samples should be protected from exposure to direct sunlight and temperature extremes.

4.5.5 Diesel exhaust emissions

As noted in Table 4.2 diesel exhaust emissions consist of gaseous and particulate components and their respective OELs must be observed.

In any mine workings both tracked and trackless vehicles may be encountered and the exhaust products may be emitted into confined spaces. Where the ventilation is not adequate, pollutant concentrations may become elevated and immediate action may be necessary.

Section 4.3.8 shows the characteristics and dangers of general airbody gases and diesel exhaust emissions were covered under this item. Because diesel-powered vehicles are mobile they are capable of spreading exhaust pollutants through large working areas. It therefore becomes important to know the working areas affected by the operation of such vehicles and to formulate a sampling strategy that will be representative of the operating atmosphere.

In addition to mobile equipment other equipment, such as drill rigs, may also be diesel-powered.

Personal gas monitors, either multiple sensor units or individual units, should be used along diesel routes and samples collected over the full shift. Operators of such vehicles should also be monitored to determine exposure levels. In a similar way, samples where stationary diesel-powered equipment is deployed are also necessary.

In addition to gas monitoring where diesel-powered equipment is operated, particulate emissions also need to be monitored. This is done by using standard gravimetric dust sampling equipment and samples are collected over the full shift. The collection of these samples is most important because of the potentially carcinogenic nature of the diesel soot. Once the samples (filters) have been returned to the laboratory and stabilised they are weighed to determine the mass of mineral dust and diesel soot. Thereafter the filters are combusted under controlled conditions to burn off the diesel soot and the filter. The importance of using ashless filters can thus be seen. From initial filter preparation data the mass of the unused filter is used together with other weighing data in calculations to determine the mass of mineral dust and the mass of diesel soot. The relevant concentrations are then calculated.

Note: In South Africa diesel fuel in use fortunately does not have a sulphur component and this can be ignored as a pollutant hazard.

It should be noted that grab samples or samples with chemical detector tubes have not been recommended for reasons given in Section 4.3.8. Such short-term samples can not be representative of full shift sampling and do not allow for comparison with OELs, which are generally 8-hour TWA based.

4.5.6 Welding fumes

Dust conditions in workshops vary widely and two primary contributors are oxy-acetylene torches and electric arc welding plants. These operations cause local contamination and also give the general atmosphere a mixed airborne contamination content, usually with a high concentration of metal fumes.

Generally, it is recommended that welding fumes be removed from the work zone by local extraction rather than general ventilation. This may be achieved by using booths, ventilated benches or adjustable hoods. Where the type of work prevents the use of local extraction e.g. cutting a steel beam, then general ventilation must ensure that all areas where welding may take place receive sufficient ventilation to dilute the fumes. A third method is to make use of a suitable respirator.

In the past most welders may not have been too concerned with the need for a respirator. However, with increasing awareness of potentially hazardous contaminants in the workplace, it is critical to understand the importance of respiratory protection. There are different respirators for different contaminants and with different filtration characteristics. One contaminant may have an OEL of 5mg/m^3 and another an OEL of 0,1 mg/m^3. Obviously, the required respirators for these two contaminants would differ considerably.

A fourth protective measure exists: a helmet connected to a compressed air supply that positively ventilates the helmet and prevents the ingress of contaminants to the breathing zone of the operator.

As pointed out in Section 4.3.14 welding operations can give rise to many different airborne contaminants. Hence, when exposure levels have to be determined at welding operations it is important to ask the following questions before sampling:

- What are the raw materials?
- What is produced?
- What products are formed in the process?
- What by-products may be released?
- Where is the main activity to be conducted e.g. in a workshop or outdoors?

Monitoring exposure levels at welding operations is not straightforward. Welding may take place in booths, on a shop floor, outside the workshop or in a plant or even, in some cases, in underground workplaces. Monitoring requirements can thus be seen to vary considerably.

Personal monitoring is the measurement of a particular employee's exposure to airborne contaminants. It is usually done during a specific time period viz. full shift or over 15-minutes to ensure compliance with OELs or STELs. It is necessary to draw attention to this aspect because

welding/cutting operations are not static and do not take place throughout the day at a steady pace nor necessarily at a single place. Work may be sporadic and the operator exposed to high peak concentrations of contaminants for relatively short periods of time. Although the 8-hour OEL-TWA limit may not be exceeded, STEL values, on the other hand, could well be exceeded. Also, different materials may be cut or welded and therefore different contaminants will be liberated. It is because of this variability that it is important to observe persons being monitored. A critical aspect in personal monitoring is the position of the sampling filter head. If it is not placed inside the welder's hood the results will not be representative of the level of contaminants being inhaled by the operator.

Area sampling is another method used to evaluate exposure. Here, exposure is measured not in terms of a particular employee, but rather in terms of the ambient air concentration of a particular substance in a given area at a given period of time. Monitors are normally placed, adjacent to workers' normal workplaces. If area sampling is thorough, knowledge of a worker's activity at a given place may give reasonable estimates of a person's exposure, but the procedure is inferior to personal monitoring if true exposures are to be assessed.

Although the DME quotes the 8-hour OEL _ TWA as 5 mg/m^3 for welding fumes, it should be recognised that this is a "generic" value and does not take cognisance of specific contaminants. If these are known, then monitoring for them specifically should be undertaken. In addition to personal monitoring, area monitoring should also be conducted and operators should actually be observed and where applicable peak values ascertained.

4.5.7 Evaluation of results

The first step towards implementing pollutant control measures is a thorough examination of results from the identification and/or monitoring processes.

The interpretation of results is more difficult than at first appears. Interpretation is done by comparing the results obtained with the acceptable level of concentration i.e. the OEL value or health standard. However, there are many factors that can influence the acceptance of results such as their repeatability or highly changeable pollutant levels within a workplace. The following aspects should be taken into account during any analysis or interpretation of results:

- Certain environmental factors can have a detrimental effect on the body after only a short period of exposure e.g. heat while for others deleterious side effects manifest after a long exposure, for example silica dust. These deleterious effects are related to the exposure in ways not yet fully quantified or understood
- People react in different ways to the same exposure. Some people are hypersensitive while others display a higher tolerance to the same exposure concentrations
- Non-occupational exposure is a complicated and variable factor. It occurs when a worker is exposed to an environmental factor when not at work
- People's attitudes and reactions also differ greatly. It is not unknown, for instance, for a worker to try to influence the results of dust sampling by deliberately 'salting' the sample in the hope of securing some sort of compensation for working in an unfavourable atmosphere. Although the number of such occurrences is not accurately known they do exist and any suspicious results always need further investigation
- If a health standard exists, it must be used. However, due caution in interpretation of results must be exercised because there are many factors that can influence them
- The period of exposure as well as the time a worker spends in such an area, bearing in mind that OELs generally apply to an eight-hour work shift and a forty-hour working week
- The number of samples collected must be in proportion to the number of workers in any defined exposure group. There are formalised procedures prescribed in the Guidelines of a Mandatory Code of Practice for an Occupational Hygiene Programme (Department of Minerals and Energy)

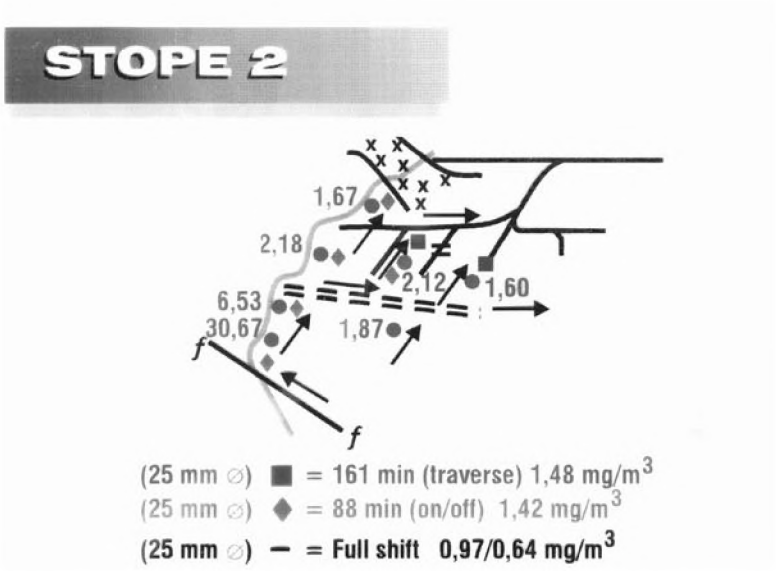


Figure 4.17 Results of a dust survey conducted in a stope using the short duration sampling method (all units are mg/m³)

4.6 Testing for flammable gases

Air sampling and gas detection are conducted to test for the presence of noxious or flammable gases and to determine whether the composition of the atmosphere complies with the standards set for safety and health.

Air sampling means the collection of samples of air for subsequent analysis in a laboratory whereas gas detection means the use of suitable instruments on site in the atmosphere to be tested in order to obtain a result immediately.

Noxious or flammable gases may issue from faults or fissures in the rock. They may be products of oxidation or may result from mining activities such as blasting, the operation of diesel-powered engines, the charging of batteries or from accidental occurrences such as fires and gas explosions.

Wherever possible, air is tested on site and this is obvious in the case of methane. Underground workings may contain dangerous accumulations of explosive gases. The testing for these gases can be done accurately and safely provided persons are fully aware of the dangers involved and are conversant with the characteristics and limitations of the instruments being used.

The safety slogan "knowing's not enough — do it the safe way!" should be kept well in mind when testing for gas.

Methanometers can detect low concentrations of gas — less than the legal limit of 1,4 parts per hundred (%) ± 0,2% (instruments may, however, be calibrated at a calibration concentration of 2,4 %). At the maximum allowable concentration no work may be carried out, the matter must be reported and arrangements made for the safe clearance of the gas accumulation. Gas concentrations are indicated on a graduated scale or by means of a digital display. The air sample enters the instrument through diffusion and this can make testing for gas in layers very difficult.

When combustible gases such as hydrogen or carbon monoxide are present in significant concentrations along with any methane, or on their own, methanometer readings become abnormal and difficult to interpret. In general, a combustion type methanometer will add the concentrations of the various gases together and indicate the total. In these circumstances a methanometer can only be relied on to indicate the presence of the gases and not the true concentrations. In the vast majority of cases methane is the only combustible gas present and the above complications do not arise.

Methanometers must be checked and calibrated according to specifications set out by the manufacturer. Calibration is carried out by testing the instrument with a standard methane-air mixture of known concentration, as mentioned above.

Methanometers are issued to persons working in known or suspected gassy places. They are meant to be operated continuously to warn timeously of the presence of methane. The warning may be audio or visual or both.

Methanometers are also issued to persons whose job it is to check on environmental conditions.

4.7 Control of airborne pollutants

General control measures, which may be deployed, include:

- Selection of workers (pre-employment examinations)
- Good housekeeping policy and education — adequate facilities, counselling, etc as part of the induction programme
- Removal of persons from the contaminant e.g. out of the mine during blasting operations
- Control of the primary causes of the problem i.e. capture at source and reject polluted air or else filter out the pollutant. For example, one potential source of dust is at tips. There are three ways of reducing the amount of dust that is liberated into the ventilating air by tipping operations:

  (i) making the tip openings as small as possible
  (ii) reducing the vertical drop distance of the rock to a minimum, and, lastly,
  (iii) the most expensive approach — drawing off and filtering air from underneath the tip in order to counter the updraught

As discussed earlier diesel exhaust emissions may also be a cause for concern. Here emission problems can be addressed in a number of ways:

(i) Low emission fuel can be used
(ii) Engines can be maintained in top condition
(iii) Diesel particulate filters can be used to control the emission of soot
(iv) The ventilating air should be sufficient both to *dilute and remove* pollutants from the working places
(v) Series ventilation systems should be kept to a minimum
(vi) Vehicles should not be allowed to idle unnecessarily
(vii) Pollutant levels in working places where diesel-powered vehicles operate should be checked frequently and remedial measures instituted as required
(viii) Personal exposure levels of vehicle operators should be frequently checked and remedial measures instituted as required.

Control of emissions at source, especially in plants is through the use of ventilation hoods, ducting and filters, either wet scrubbers or bag filters.

Water is used in rockdrills to prevent the liberation of dust during drilling and water is also used to wet rock in the working places before the rock is moved. This is a very important point to note because once dust has become airborne it is very difficult to remove from the airstream, other than by filtration, which would be too expensive and impractical to apply on a large scale. Figure 4.18 illustrates the difficulty in attempting to control or capture airborne dust with normal size water droplets. It is seen how the dust particle simply bypasses the water droplet in the slipstream of the droplet as it passes through the air. This clearly refutes the notion that dust-laden air can be sprayed with water to clean it. Water droplets more closely approximating the dust particle size are needed to collide with the dust particles, coalesce with other droplets and ultimately settle out. However, the production of a fine water mist or fog is expensive, is energy intensive and in addition the ventilating air stream can carry off the fog before it can control the dust.

Most of the above is covered by legislation, but this is under revision.

- Dilute the contaminant to acceptable concentrations
- Control the spread of the problem — containment, limiting the periods of exposure, etc
- Improve the working environment — control other factors
- Respiratory protective equipment (RPE)

Protection of individual workers by means of RPE should be a last resort, but such measures may be implemented as a first step provided they are seen as temporary. However, all too often unless care is taken, temporary measures appear to work and then become the ultimate solution. It must be realised that under hot, humid conditions RPE is likely to be both unpopular and impractical since it becomes uncomfortable and also hinders breathing and speech. Control at source, although more costly initially, should be preferred over personal protection because it can be shown to be more cost-effective in the long run.

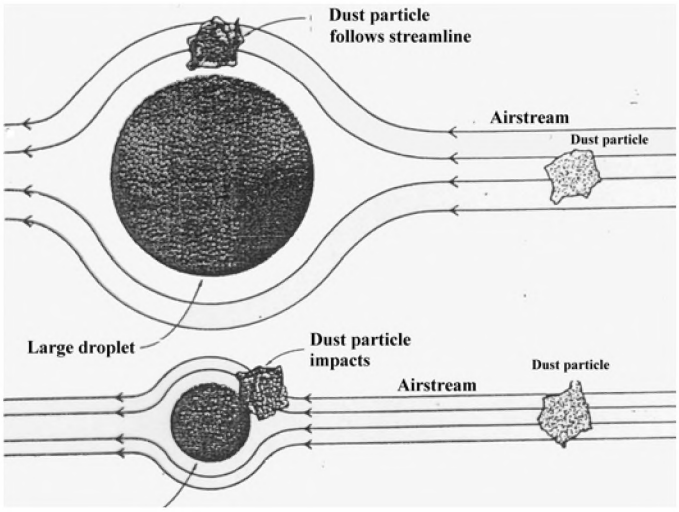


Figure 4.18 The effects of water droplet size on dust control

The importance of educational programmes should never be overlooked. No worker can be expected to assist in making a control programme effective if he does not know the reasons for it in the first instance.

Control of the pneumoconioses can be linked to the control of dust liberation into the working environment. Pollutant levels in the workplace are therefore an indicator of risk and the possibility of the development of disease.

Control measures must be diligently applied and the success of deployment must be evaluated regularly. This means that a continual evaluation programme should be implemented.

- The results of any pollutant surveys should be made available to all employees
- The results of such surveys should be discussed at the relevant health and safety meetings and action courses, when necessary, discussed
- The reasons for the surveys should be made clear to all employees and the seriousness of non-compliance with action courses explained
- Employees should be encouraged to participate actively and in a positive manner in all pollutant control activities

4.8 Guide to information resources

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