SOURCES OF DUST IN OPENCAST MINE

By

Dr Patitapaban Sahu

Associate Professor

Department of Mining Engineering

Indian Institute of Technology (Indian School of Mines), Dhanbad

Definition of Dust

- Generally finely divided solid particles of mineral, rock and other matters of less than 1 mm size are considered as dust
- All dust, however, do not become airborne.
- Only particles with an upper size limit of 100 μm are considered as airborne dust

Main Sources of Dust Production in Mines

- Coal cutting machinery
- Drilling
- Blasting
- Loading operation
- Transportation and crushing
- Dust raised in travelling and material transport roadways

Coal cutting machinery

- Coal-cutting machines such as continuous miner, shearer, surface miners and drills are prolific producers of dust.
- Dust production depends not only on the action of cutting picks (tensile and compressive), but also on pick penetration and pick spacing on a cutting head.
- The greater the penetration, the less the proportion of fine dust per tonne cut.
- Cutting with blunt picks results in increased crushing and enhanced dust production.
- Dust production also depends on the pick peripheral speed with lower dust production for lower speed.
- As coal gets loaded onto the armoured face conveyor, secondary crushing of some coal takes place producing dust.
- A machine cutting into a shale or sandstone roof or floor of a coal seam produces a higher dust concentration

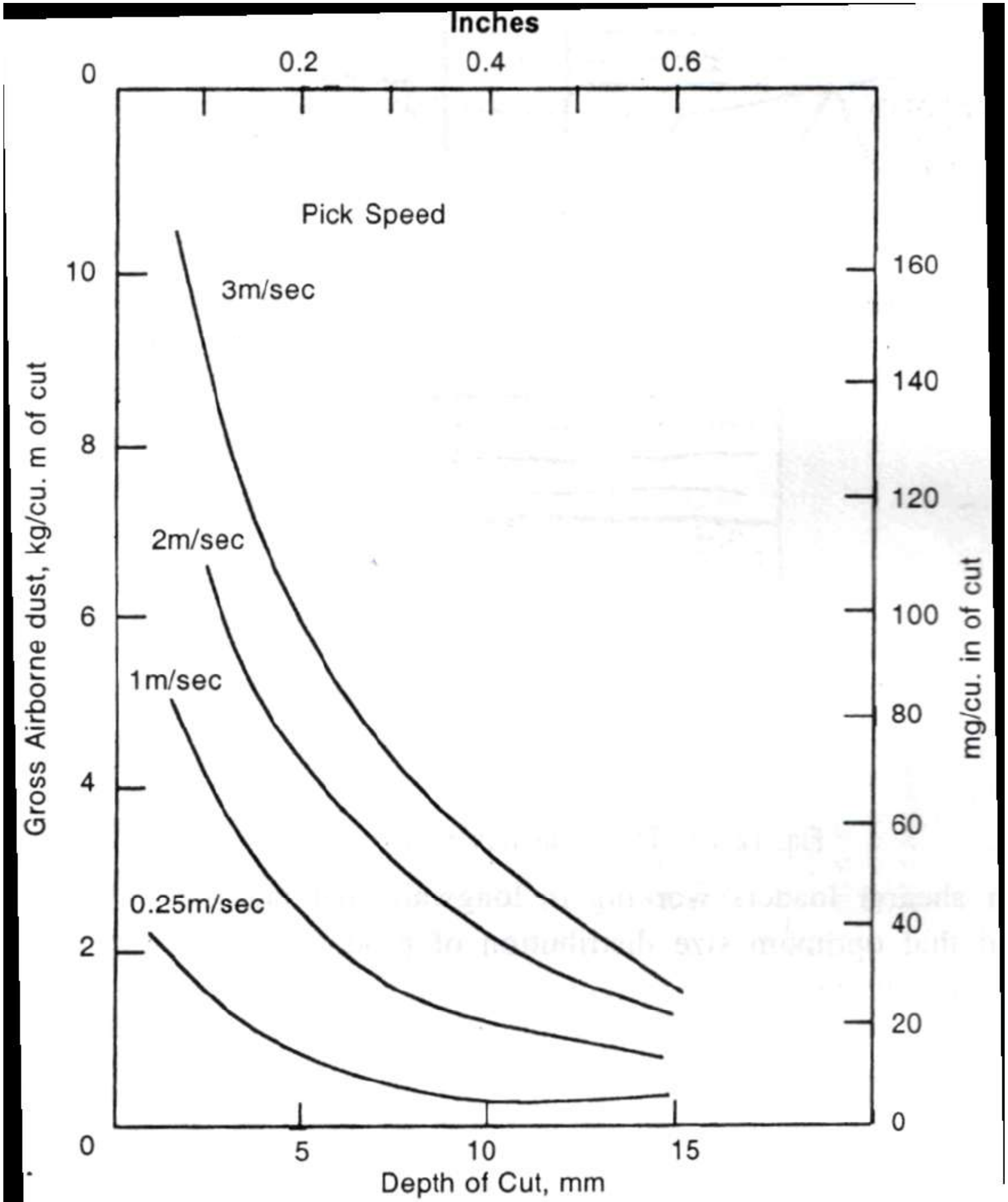


Fig. 12.17 The effect of pick speed and depth of cut on dust production

Drilling

- Rotary drills produce dust that is coarser and contains less fine material than do percussive machine.
- Skochinsky and Komarov (1969) estimated that 85% of the dust produced in mine was from drilling, 10% from blasting and other activities such as loading and transportation of minerals accounted for only 5% of the total dust production.
- In surface mines, the large diameter rotary blast hole drills produce a lot of dust.

Blasting

- Blasting produces a large quantity of dust.
- The amount of dust produced depends upon a number of factors including
- the type of rock,
- choice of explosive,
- the drilling pattern,
- the charge density and
- type of stemming used

Loading operation

- Lots of dust is released during loading operation in opencast coal mines.

Transportation and crushing

- Dust is produced at various points in the mineral transportation system, including conveyors, transfer points and bunkers (discharge points).
- Dust on conveyors may become airborne owing to the vibration of the belt as it passes over the rollers.

- Dust produced at transfer points depends on the drop of the mineral and degree of wetting of the mineral.
- As ore is unloaded at ore bins or bunkers, the amount of dust produced depends upon the free fall and the impact of material.
- Crushers in mine are prolific sources of dust.

Dust raised in travelling and material transport roadways

- Pedestrian traffic often raises the dust level in the air stream.
- Similarly, dust is raised in mineral transportation, irrespective of whether carried out by tracked or trackless vehicles

Various dust sources in a typical retreat longwall face

In a typical retreat longwall face with antitropal ventilation system, the intake air starts picking up dust in the gate road itself long before reaching the face.

The various dust sources may be:

1. Outbye bunker at pit bottom or main intake.
2. Belt transfer point between gate belt and main belt (there may be no. of such transfer points in an extensive mine with long panels).
3. Conveyor belt tension end and loop take up.
4. Pick-up from conveyor belt by ventilation air.
5. Dust adhering to bottom belt.
6. Dust raised by men while walking in gate roads.
7. Dust raised while material transportation in the bottom gate.

8. Dust from conveyor rollers and structures.
9. Transfer point from stage loader to belt conveyor.
10. Transfer point from AFC to stage loader and feeder breaker.
11. From drilling and blasting or other operation at the stable end.
12. Coal wining machine, say a shearer.
13. Dust pick-up over the AFC at the face.
14. Chock movement and grinding of roof over chocks.
15. Waste flushing.
16. Auxiliary ventilation or a venturi at tailgate end of the face.
17. Material transport in the return gate.
18. Drilling for roof bolting and other support operations in the return gate.
19. Drilling for methane drainage and water infusion if practiced.

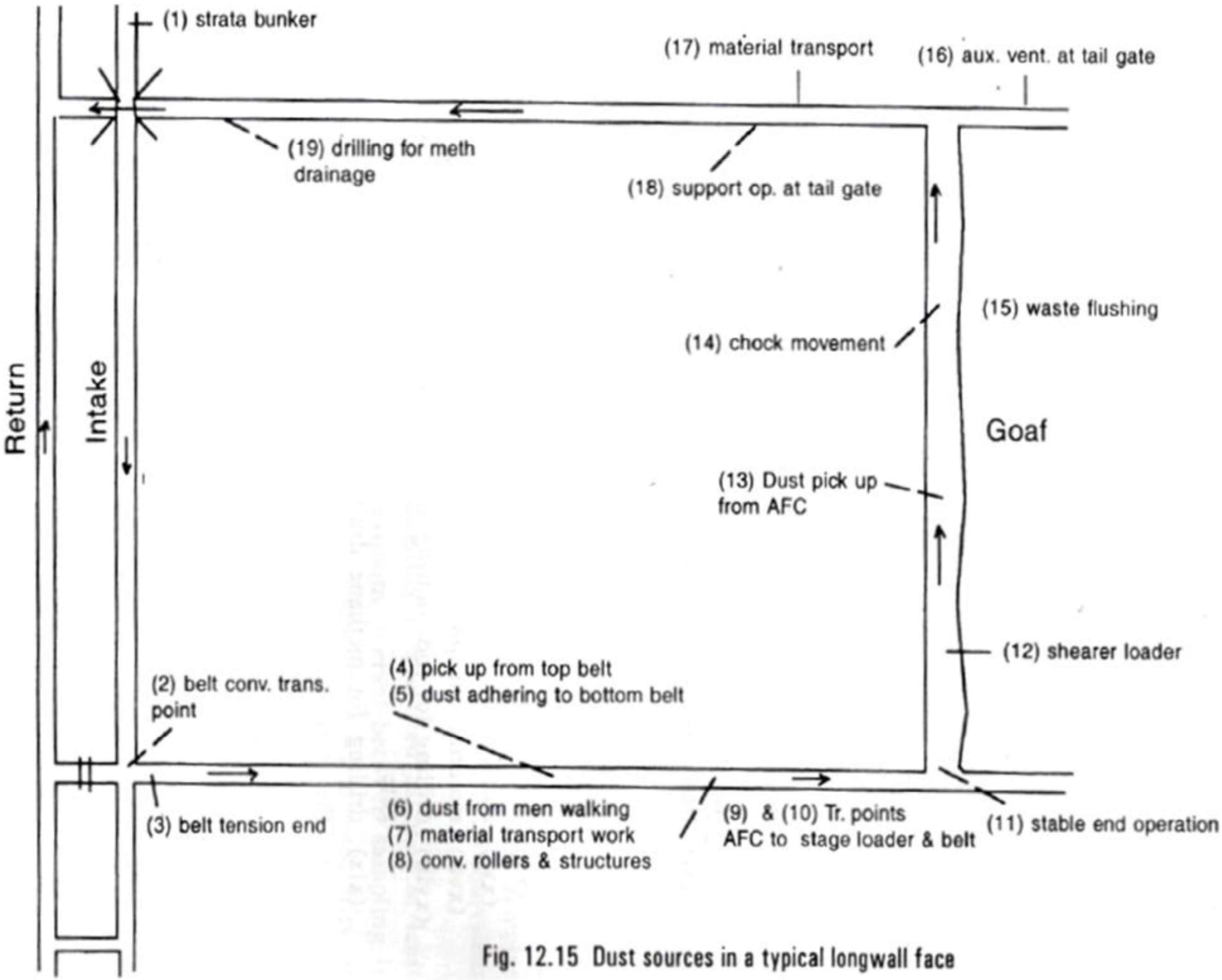
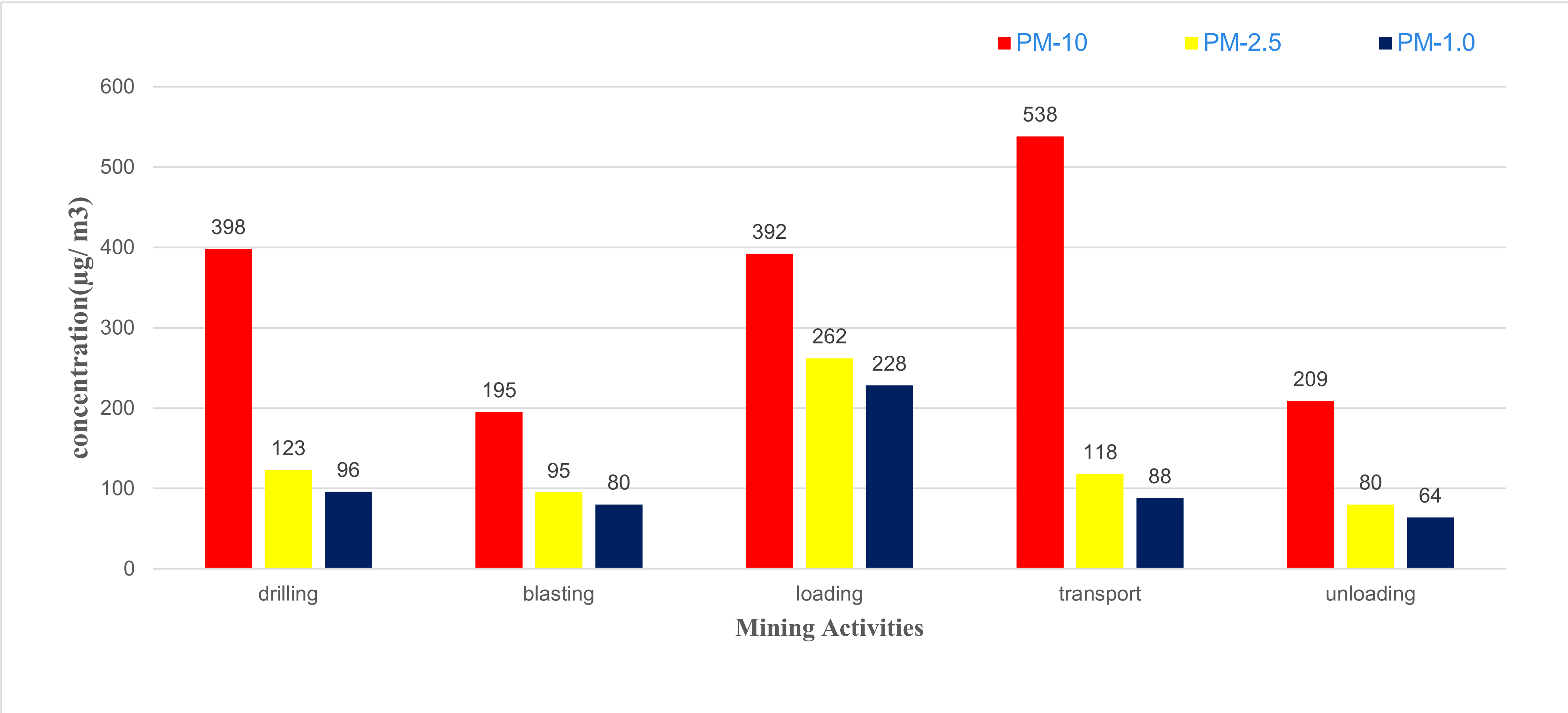
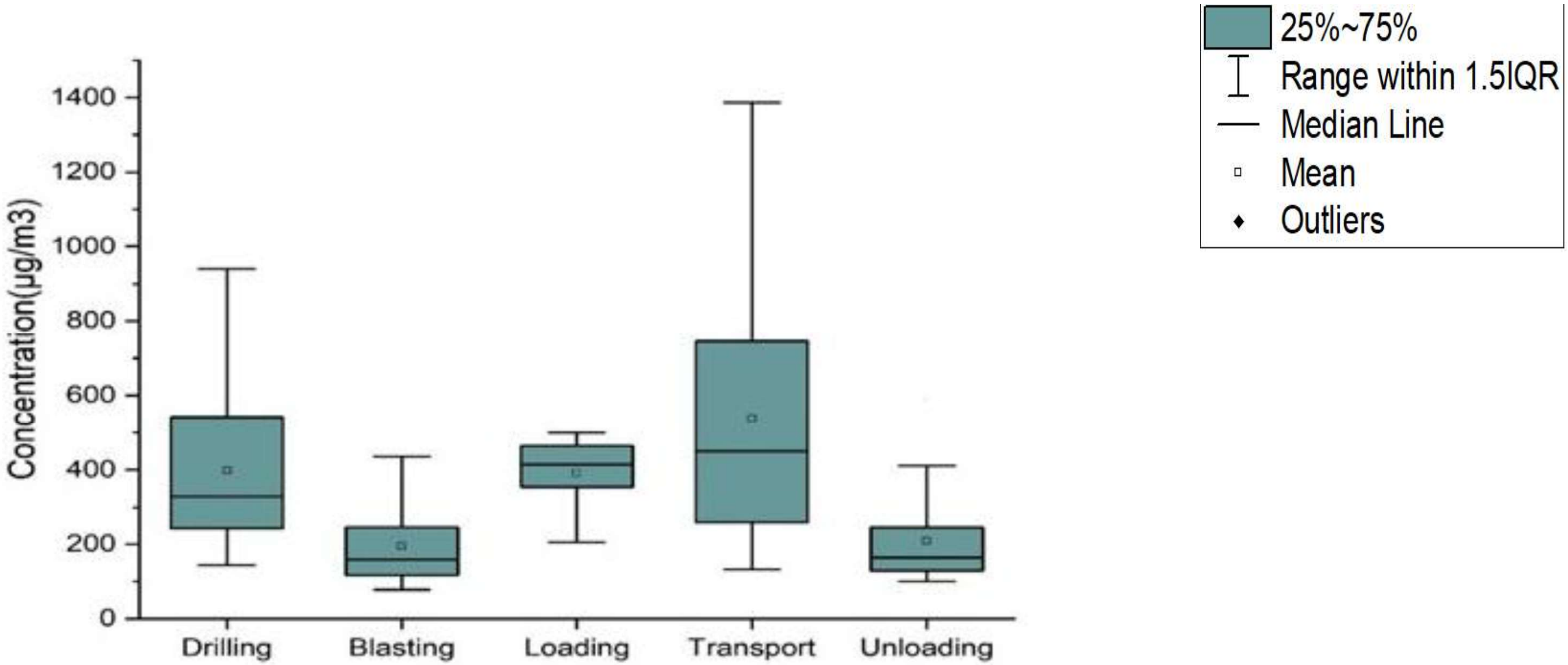


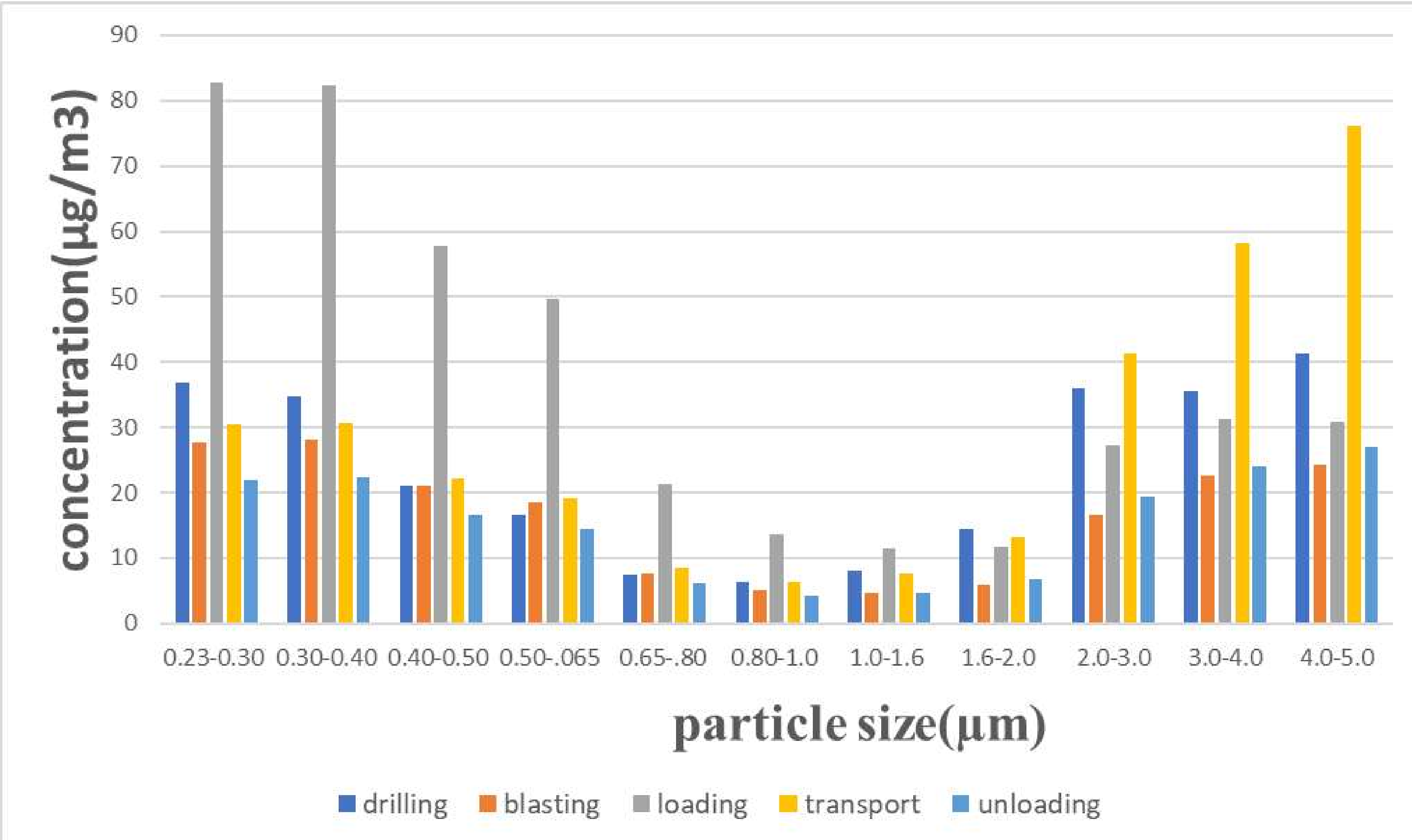
Fig. 12.15 Dust sources in a typical longwall face

Dust concentration in different mining activities



BOX PLOT of Respirable dust concentration in different mining activities




90
80
70
60
50
40
30
20
10
0
concentration(µg/m3)
0.23-0.30
0.30-0.40
0.40-0.50
0.50-.065
0.65-.80
0.80-1.0
1.0-1.6
1.6-2.0
2.0-3.0
3.0-4.0
4.0-5.0
particle size(µm)
drilling
blasting
loading
transport
unloading

Harmful Effects of Mine Dust

Mechanization by cutter loader technique resulted in increased dust production. About 10-100 gms of dust below 5 micron (1 micron = 1/1000 mm) size is produced per ton of coal and about 1% of this dust is dispersed in air.

Coal dust increases explosion and fire hazards Coal, stone and rock dust increase health hazards. Moreover, dust causes nuisance.

Sources of Mine Dust

Main sources of dust in underground are

- machine cutting and loading (55 - 65%)
- drilling and blasting (15-20%)
- loading, transfer points and transporting of material (15-25%).

Dust Concentration

The tentative dust concentrations at different places of coal mining activities are as follows :

- Shearer cutting and loading with in-built dust suppression arrangements - 9.5 to 51 mg/m^3. During dry machine cutting 5 to 10 gm/m^3 are also noticed many times.
- Heading drivages with roadheader/dinters - 17 to 60 mg/m^3 (with dust suppression arrangement)
- Belt discharge point - 8 mg/m^3 (av) (with spraying arrangement)
- Drilling in depillaring - 10 mg/m^3 (av)
- Shot firing activity - 16 mg/m^3 (av)
- Loading operation - 3 mg/m^3 (av)
- Resting place underground - 0.6 mg/m^3 (av)

(After Mukherjee & others, CMRS)

Air borne dust in active mine workings (near chutes) fluctuates between several milligrams and several grams per cubic metre

To have some relative idea of dustiness, the following figures may be helpful.

1.5 mg/m^3	-	air not dusty,(dwelling place etc)
5 mg/m^3	-	moderately dusty.
10 mg/m^3	-	dusty, coal face, drilling operation etc.
20 mg/m^3	-	very dusty, crushing mill with dust extraction arrangement.
100 mg/m^3 and above	-	extremely dusty mining operation conducted with no or very poor dust control features.

1 mg/m^3 of dust means 200 particles per cm^3 (or 2×10^8 number of dust particles/m^3 upto 2 micron size)

- In cities, 5×10^4 to 2×10^5 number of dust particles per cm^3 (or 5×10^{10} to 2×10^{11} particles per m^3) are observed.

This is calculated on the following basis:

- Number of working days a worker is generally exposed to dust per year - 250 days.
- Worker working for 30 years.
- Total dust deposit in lungs should not exceed 250 gm during his service period of 30 years (say)

► Dust dose is defined as the weight of dust inhaled in mg due to exposure in a dust-laden atmosphere.

$$\text{Dose} = C \times T \times 60 \times V \times R \times 10^{-3} \text{ mg.}$$

where C = dust concentration in air mg/m^3
T = time spent in dust laden atmosphere, hours.
V = tidal volume in litres; it is generally taken as 500 cc during rest and 750-1200 cc during active work.
R = number of respirations per minute. (10-15 times per minute during rest and 20-30 during work.)

► Thus, breathing in and out some 5-7 litres/min during rest and 20 litres/min-during work-(30-40 litres/min during heavy work) ($R \times V$ = vol. per min).

Exposure Time

Average exposure of workers in dusty atmosphere (study in Indian mines as per CMRS) is given below.

- Drillers at coal face for drilling work - 2.5 hours.
- Shot firer spends - 1.5 hours active hrs.
- Loader spends - 4.0 hours active loading.
- Shearer operator- 2-3 hours active work.
- Road header operator - 2-3 hours active work
- Belt attendant at discharge point - 5 hours.

Classification of dust based on their sizes

- The size of dust particles considerably influences their behavior. Dust particles are usually divided into three classes:

i. Particles greater than 10 μm, which settle according to the laws of gravity, i.e., with increasing velocity in still air.

ii. Particles between 0.1 to 10 μm, in still air settle at a constant velocity, which can be calculated by Stoke's Law (the uniform settling velocity depends on particle size and density, viscosity of the medium, and acceleration due to gravity.).

iii. Particles between 0.01 and 0.1 μm which do not settle but diffuse in the air and remain in colloidal state.

12.5 Respirable fraction of dust

The primary method of dust deposition in the respiratory system is by gravitational settlement. The terminal settling velocity of dust particles in a streamline flow condition, as obtained from Stokes law is—

$$V_t = \frac{D^2(\rho - a)g}{18\mu} \quad \ldots \quad (12.1)$$

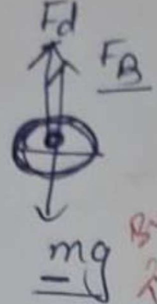
V_t = terminal settling velocity of dust

Where D = diameter of the particle

ρ, a = density of the particle and air respectively

μ = air viscosity

Equation 12.1 shows that the terminal velocity increases with square of particle diameter and density and explains why a vast majority of the particles above 5 μm are deposited in the respiratory tract before entering the alveolar space. In view of the irregular shape and varying density of the dust particles, the concept of either the Stokes' equivalent diameter or aerodynamic equivalent diameter is used in applying equation 12.1. The Stokes' equivalent diameter of a dust particle is that diameter of a sphere that has the same density and terminal settling velocity as the particle in question. The aerodynamic equivalent diameter on the other hand is the diameter of a unit density (1 g/c.c.) sphere that has the same settling velocity as the particle in question. Stokes law for terminal settling velocity is not applicable when the particle size is so large and velocity of fall becomes so high that a turbulent wake is produced. For example, for quartz particles falling in air, Stokes law is applicable only for particles less than 42μm in size. At very small size (e.g. for less than 1.7 μm size in case of



drag force

$\frac{4}{3}\pi r^3$

$F_d = 6\pi\eta r v$ → stokes law

Buoyancy force

$F_B = \rho_m g V$

$F_g = mg$

$F_g = F_d + F_B$

gravitational force.

$\rho_p \times \frac{4}{3}\pi r^3 g = 6\pi\eta r v_T + \rho_m g \times \frac{4}{3}\pi r^3$

$\frac{4}{3}\pi r^3 g\left[\rho_p - \rho_m\right] = 6\pi\eta r v_T$

$$v_T = \frac{\frac{\cancel{4}^{2}}{3}\cancel{\pi} r^{\cancel{3}} g\left[\rho_p - \rho_m\right]}{\cancel{6}_{3}\cancel{\pi}\eta\cancel{r}}$$

$D = 2r$

$$\boxed{v_T = \frac{2}{9}\frac{r^2 g\left[\rho_p - \rho_m\right]}{\eta}}$$

T.S cos θ ...

for spherical particles, the following equations
ive the terminal settling velocity in "V_t" for
ifferent particle diameters.
, The settling velocities are somewhat lower
or particles of other shape ~~through~~ though
t is hard to predict them theoretically.

Stoke's Law equation

(i) $V_t = 4.95\, \rho^{1/2} D^{1/2}$, m/s
for $D > \frac{0.021}{\rho^{1/3}}$, m (turbulent motion)

$V_t = \frac{D^2(\rho - a)g}{18\mu g}$ where a = density of air.

(ii) $V_t = 3.03 \times 10^4\, \rho D^2$, m/s (Streamline motion)
for $D < \frac{1.141 \times 10^{-3}}{\rho^{1/3}}$, m

where ρ = density of particle in kg/m^3
and D = particle diameter in m.

→ The above equations assume a standard air density of 1.2 kg/m^3, g = 9.81 m/s^2 and dynamic viscosity of air = 1.8×10^{-5} Pa s.

→ They are also valid for still air or air-flow in the laminar regime.

→ For settling from turbulent flow streams, the terminal velocities have to be multiplied by a suitable eddy factor.

dynamic viscosity: → a quantity measuring the force needed to overcome internal friction in a fluid.

$\frac{kg}{m^2} \times \frac{m^3}{kg\, s} \cdot \frac{kg}{m\, s} \times \frac{m^3}{kg}$

1 Pa s = 1 kg/m/s

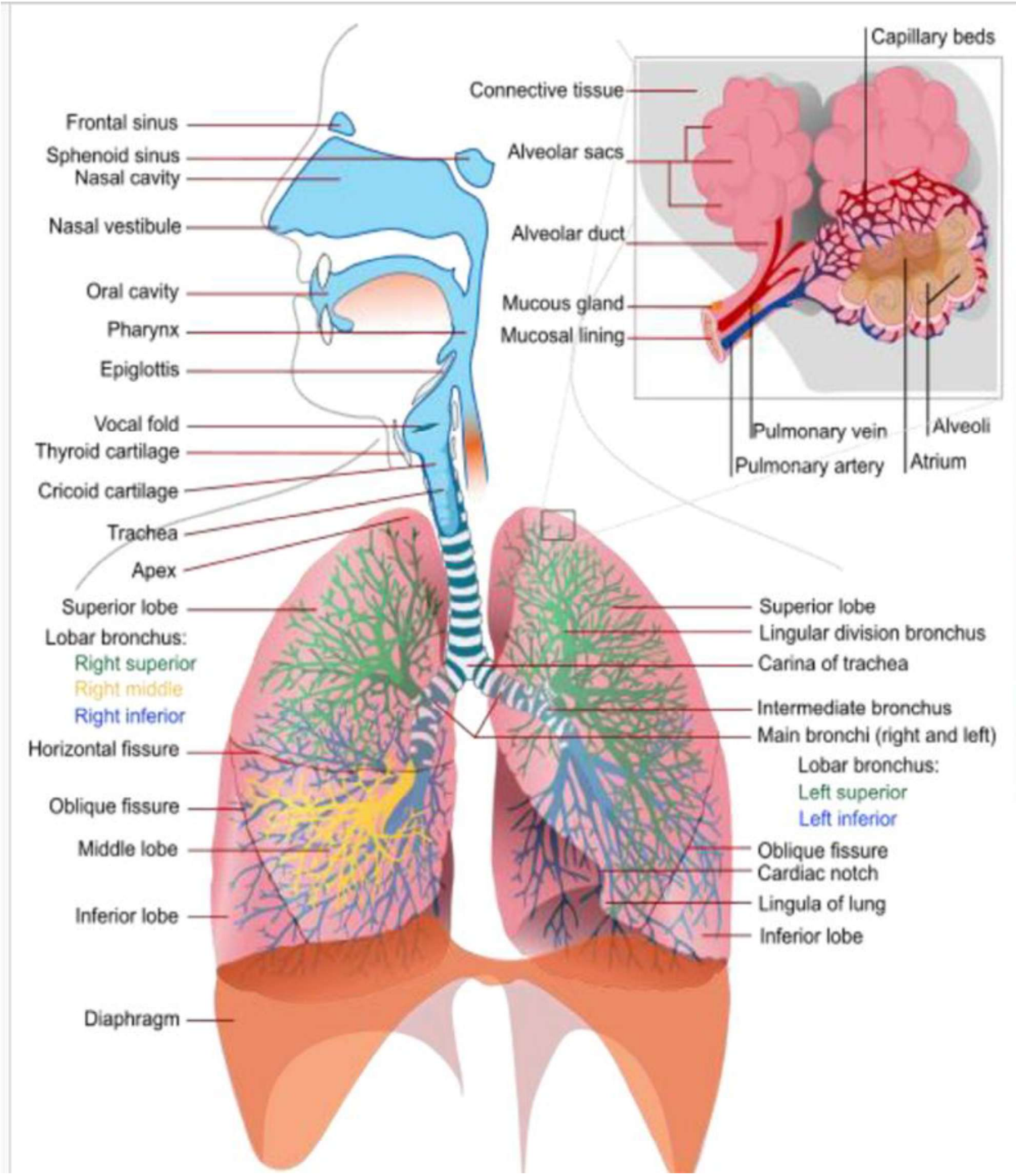
Kinematic viscosity: quantity measuring viscosity of dynamic fluid per unit density

- Respirable dust: A small fraction of the dust cloud, the very small particles (<5 µm or < 10 µm), can be retained in lungs.
- Inhalable dust (visible dust below 100 µm): is dust that enters the body but is trapped in the nose, throat and upper respiratory tract.
- Combustible dust: is dust which takes part in explosion.

Airborne respirable dusts

- All dust, however, do not become airborne Only particles with an upper size limit of 100 μm are considered as airborne dust.
- Again all airborne dust particles cannot enter the human respiratory system, since nasal hairs in the nostrils act as a filter.
- The nasal cavity being of much larger cross section than the nostril, cause reduction in inhaled air velocity that causes deposition of large size dust, say 10 μm size.

- The upper respiratory passages, i e the naso pharynx, trachea, bronchi and bronchioles are all lined with hair like structures (and mucous secreting cells
- Cilia move back and forth, pushing the dust either towards the nostrils, where it is blown out or towards pharynx, where it travels through the digestive system and out with the rest of the body’s waste.



Capillary beds
Connective tissue
Frontal sinus
Sphenoid sinus
Nasal cavity
Alveolar sacs
Nasal vestibule
Alveolar duct
Oral cavity
Mucous gland
Pharynx
Mucosal lining
Epiglottis
Vocal fold
Pulmonary vein
Alveoli
Thyroid cartilage
Pulmonary artery
Atrium
Cricoid cartilage
Trachea
Apex
Superior lobe
Lobar bronchus:
Right superior
Right middle
Right inferior
Horizontal fissure
Oblique fissure
Middle lobe
Inferior lobe
Diaphragm
Superior lobe
Lingular division bronchus
Carina of trachea
Intermediate bronchus
Main bronchi (right and left)
Lobar bronchus:
Left superior
Left inferior
Oblique fissure
Cardiac notch
Lingula of lung
Inferior lobe

- Maximum particulates in the size range of 5-10 µm get trapped in the upper respiratory tract by deposition, impact, diffusion or interception on the mucous and thus eventually gets out of the respiratory system as cough through whip like motions of cilia.
- Hence, only a few dust particles greater than 5 µm (depending also upon the density and shape of the particles) reach the alveoli.
- **Only 5 µm fraction is generally considered as respirable dust (some statutes define it as 10 µm)**
- According to Hamilton(1970),less than 5% of the respirable dust is produced at a mine face.

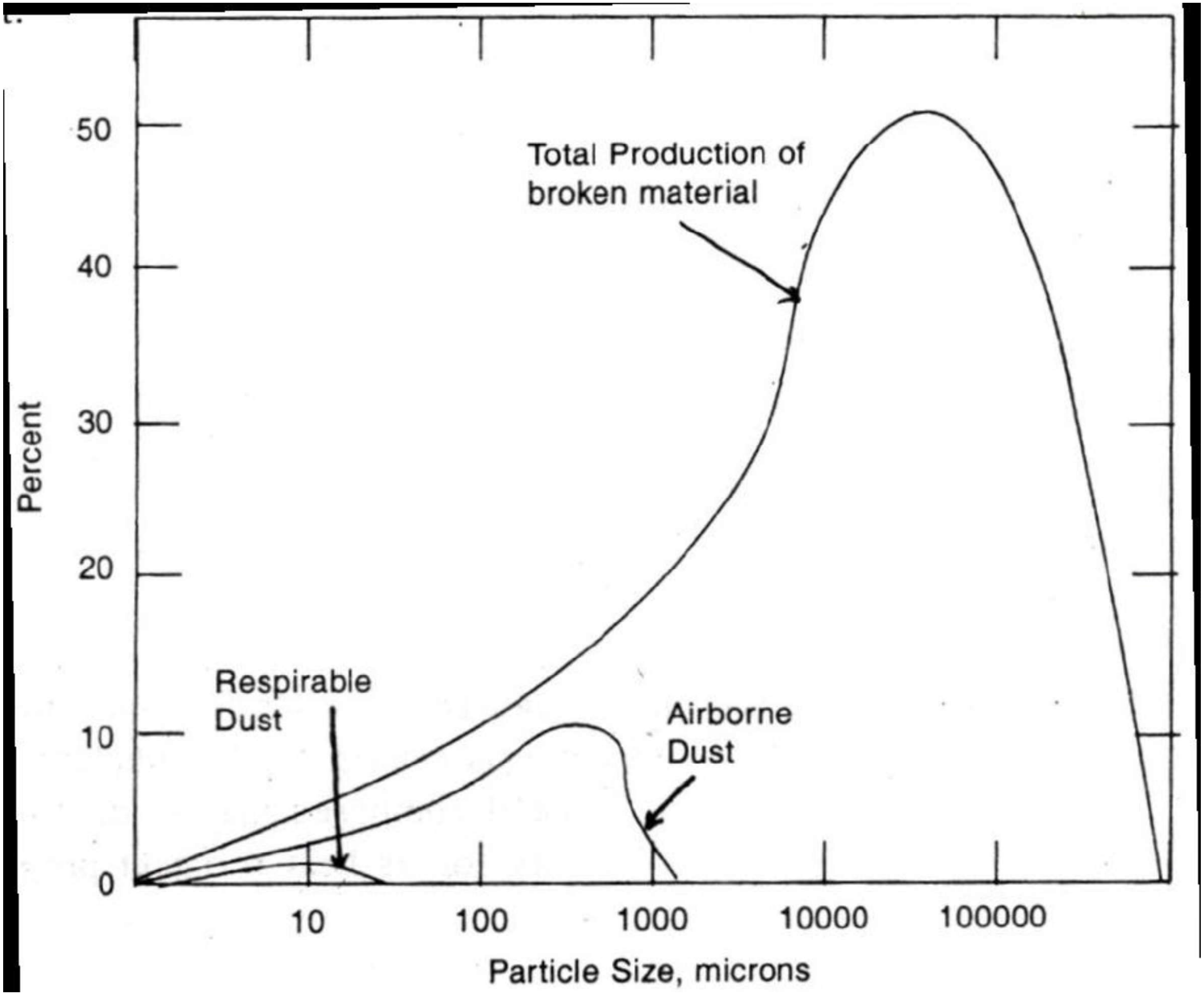
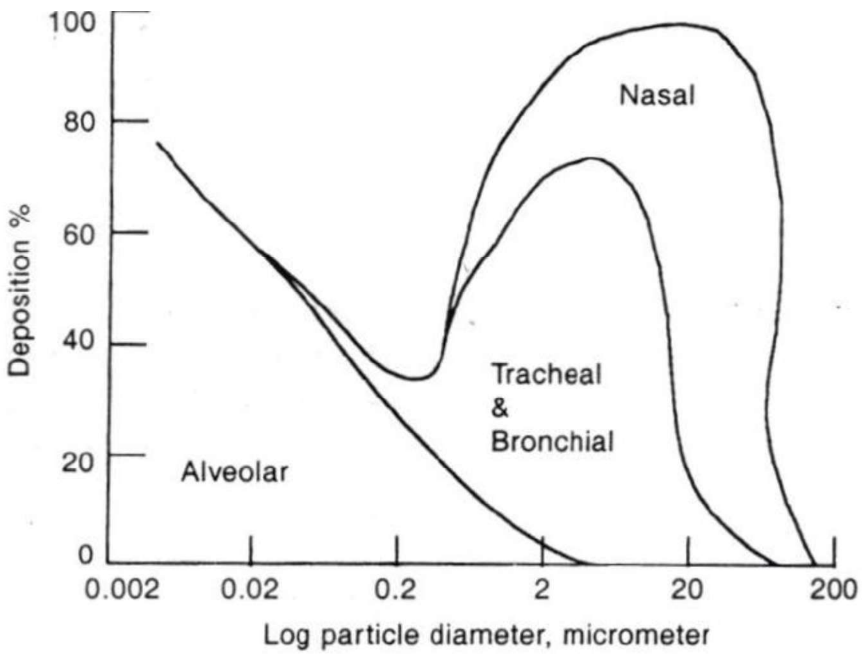


Fig. Typical size distribution of dust produced by mining machine

- Most of the dust reaching the alveoli does not settle in the lungs, but goes out with the exhaled air and only a part is retained.
- Very small particles of say less than 0.3 μm size are imparted a random motion (Brownian motion) by continuous bombardment by air molecules and hence these particles get deposited in the lungs mainly by diffusion.



(a) Dust deposition

Figure (by Walli) shows the deposition of dust of various sizes in different parts of the respiratory system

(a) Dust deposition

Dust size (µm)	Max. deposition
20 to 200 µm	In nasal passage
2 to 20 µm	In the tracheal and bronchial parts
< 0.2 µm	Mostly in the alveolar region

- Maximum retention in alveoli is for dust of size between 1 to 2 μm at around 60%, reduces exponentially to about 6% as the size goes up to 5 μm and the retention percentage also falls down to about 20% as the dust goes down to 0.2 to 0.3 μm size.

- There is a gradual decrease in retention percentage in the upper respiratory tract for dust sizes smaller than 5 μm and hardly any dust size less than 1.2 μm is retained in the upper respiratory tract

- In 1952 the British Medical Research Council (BMRC)adopted a definition of respirable dust' based on the dust fraction reaching the alveolar region.

- It is based on the use of an ideal horizontal elutriator having such cut-off characteristic that the dust passing the elutriator matches the lung deposition size characteristic

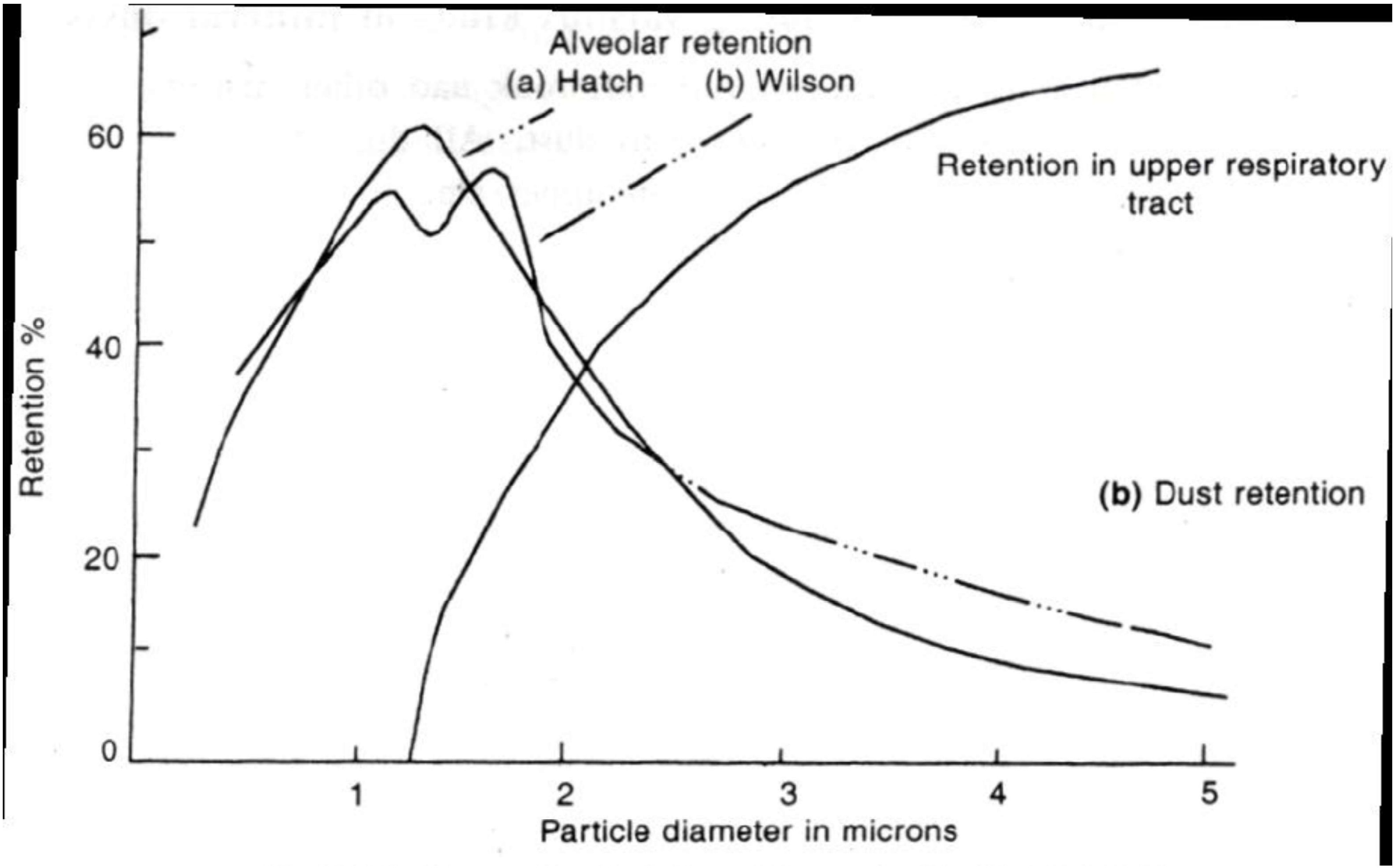


Fig. Curves for alveolar and upper respiratory tract retention of dust for various particle sizes

TABLE 12.2 CUT-OFF PERCENTAGE FOR DIFFERENT DUST SIZES AS PER BMRC CURVE (AFTER LIPPMANN[10])

Dust size (Aerodynamic diameter or unit density sphere, µm)	% Respirable	% Cut off
2.2	90	10
3.2	80	20
3.9	70	30
4.5	60	40
5.0	50	50
5.5	40	60
5.9	30	70
6.3	20	80
6.9	10	90
7.1	0	100

A second sampling criteria has been adopted by ACGIH in 1968 as below :

Dust size (Unit density sphere, µm)	<2.0,	2.5	3.5	5.0	10
% respirable	90	75	50	25	0

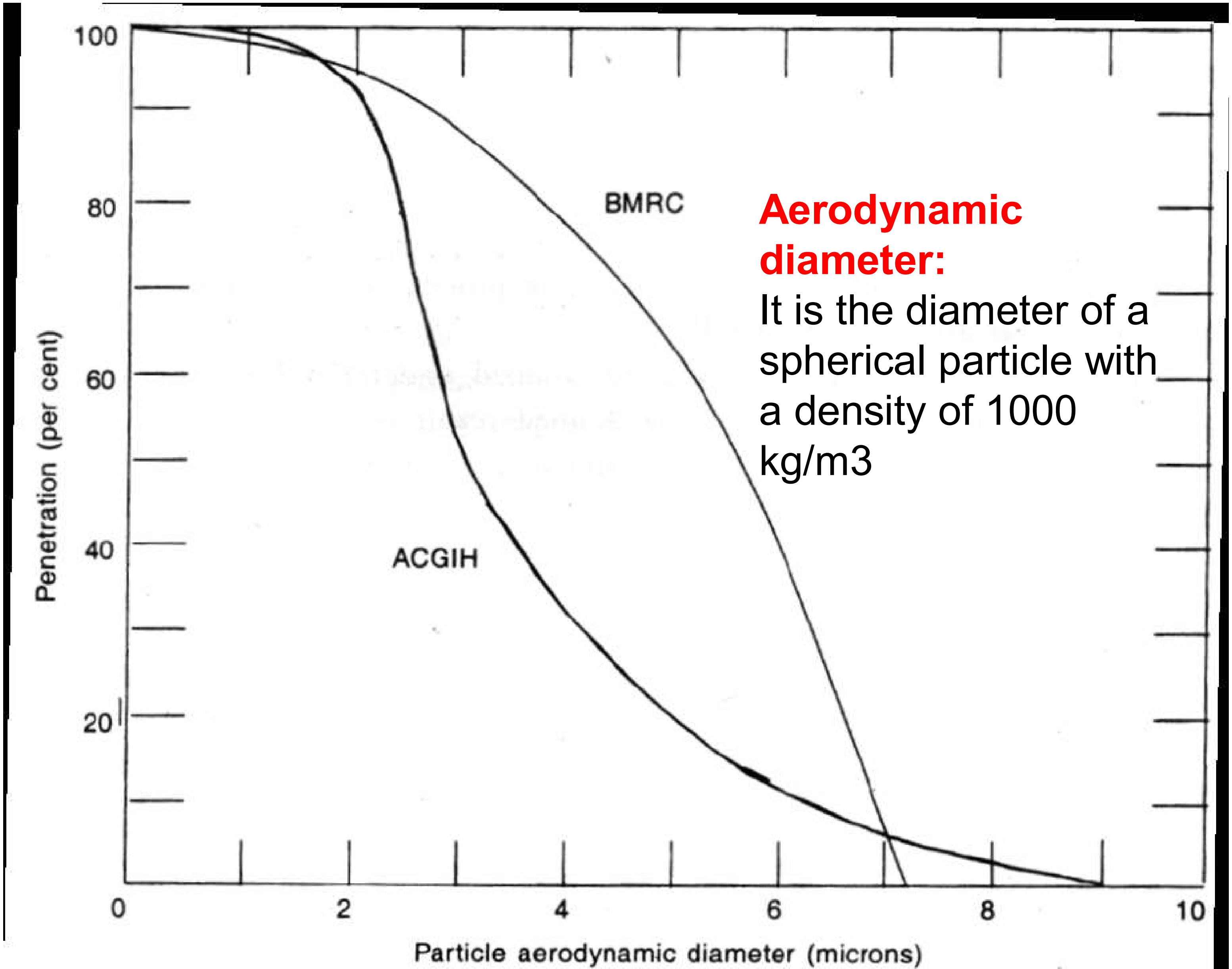


Fig. 12.4 Cut-off characteristics of dust samplers (a) BMRC (b) ACGIH curves

Aerodynamic diameter:
It is the diameter of a spherical particle with a density of 1000 kg/m3

ACGIH: American Conference of Governmental Industrial Hygienists

BMRC: British Medical Research Council

Sampling of Airborne Dust

- It is essential to have suitable device to estimate or sample airborne dust to effect suitable preventive and suppressive measures for allaying dust in a mine.

The following facts must be considered in sampling of airborne dust:

- Whether the parameter of dust assessed is a true measure of the danger to health.

- The sample should be able to give knowledge of the necessary dust concentration in the dangerous size range. Mass concentration of the respirable fraction of dust is widely accepted today as the relevant concentration.

- Sample should be able to assess the dangerous component of dust as regards composition, which necessitates adequate volume of sample to be collected for chemical and mineralogical analysis.

- The duration of sampling should be such as to give a true picture of dustiness of any mining operation or place of work without necessitating a large number of samples to be taken.

- The present trend is to obtain a continuous sample over at least a working shift.

- The sample should be representative of the dust cloud in the breathing zone of the worker.

- The sampling instrument should be
  - portable and robust for rugged underground conditions
  - should require minimum maintenance,
  - should be operated with minimum skill,
  - should have self-contained power supply and
  - should render the dust measurement in as little time as possible.

Duration and interval

- The cycle and duration of sampling should be carefully chosen to give a fairly accurate estimation of the dustiness of any particular operation over a long period.

- A true estimate however be obtained by a continuous sampling device working over the whole shift or even over several shifts, from which a true shift mean can be obtained.

Position of sampling

- The following points must be borne in mind while considering the positioning of sampling points:
  - uniformity of distribution of dust in an air-stream is dependent on the uniformity of flow in the airway.
  - In order to get a representative sample, it is necessary to collect the sample in a straight portion of the airway at least 10 diameters away from any bend or major obstruction.
  - The sampling velocity should be as far as practicable, equal and equidirectional to the velocity of air from which the sample is being collected. This is essential for minimizing the loss of particles by inertial separation before entry into the sampler.

- The best sample having direct relevance to health hazard is one collected at the breathing point of the worker.

- This has led to the development of personal dust samplers (PDS) which collect a sample of the respirable dust fraction over a sufficiently long period, usually a shift.

- For fixed point 'area sampling' (also called static sampling), the location is so chosen as to obtain representative concentration of respirable dust associated with the dust generating sources.

- **The National Dust Prevention Commitee (NDPC) for coal mines in India by its recommendation of 1993 gave sampling locations for area sampling in (a) board and pillar, (b) longwall, (c) drivage and (d) opencast workings and surface plants.**

Location of sampling in bord and pillar workings:

- **Intake airway of a working district** within 20 to 30m of immediate outbye ventilation connection from the 1st working face (a).
- **Return airway of a working district** within 20 to 30m of immediate outbye ventilation connection from the last working face (d). Where there is more than one return airway, all the return airways are to be sampled.
- **Working place or face** where dust concentration is likely to be maximum (b).
- **Resting place** of workers.
- 3 to 5m on the **return side of other places** where substantial dust is generated, e.g. loading/transfer point (c).
- **Main return airway of the mine**.

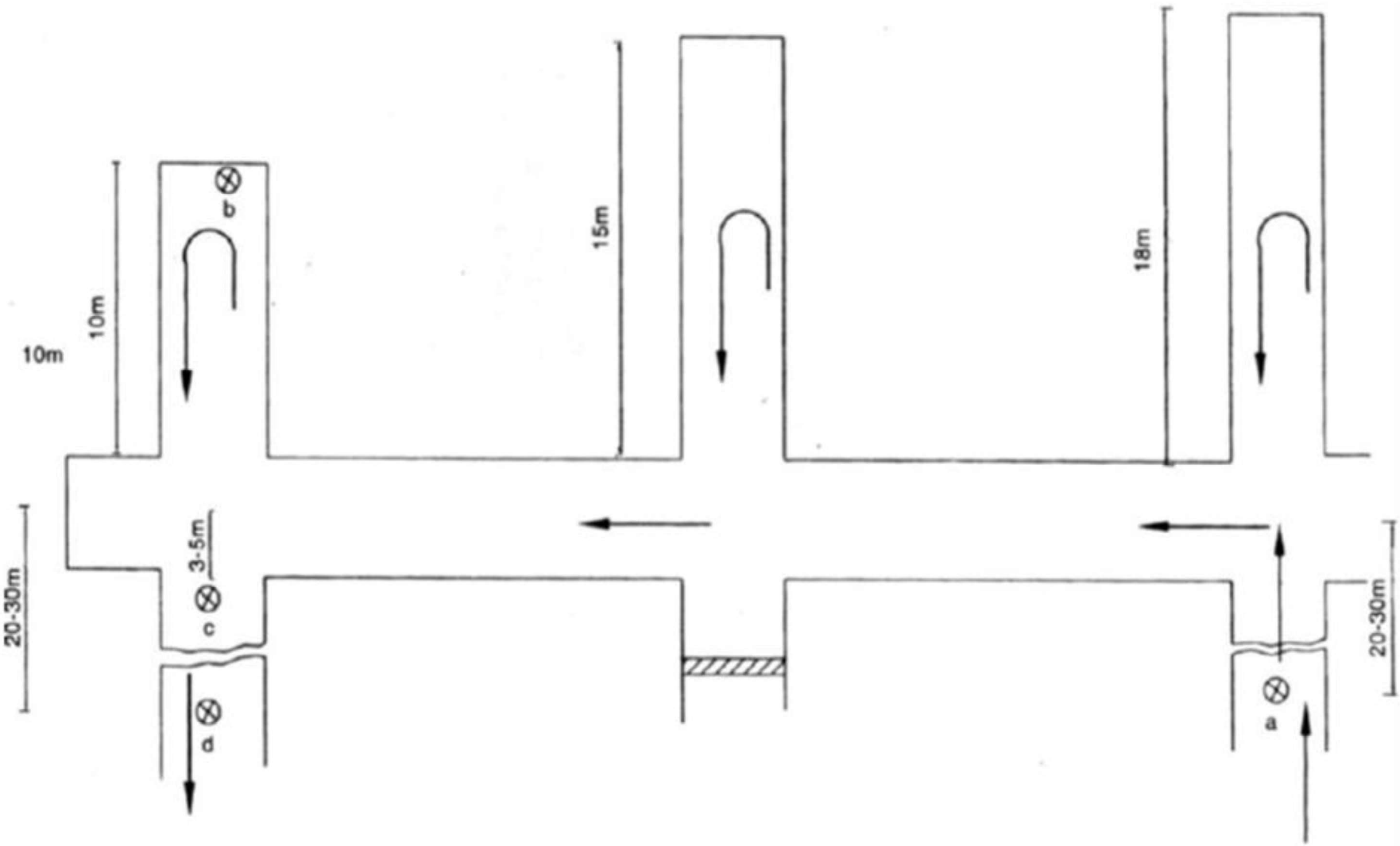


Fig. 12.13 Dust sampling locations in a bord and pillar district

Location of sampling in longwall workings:

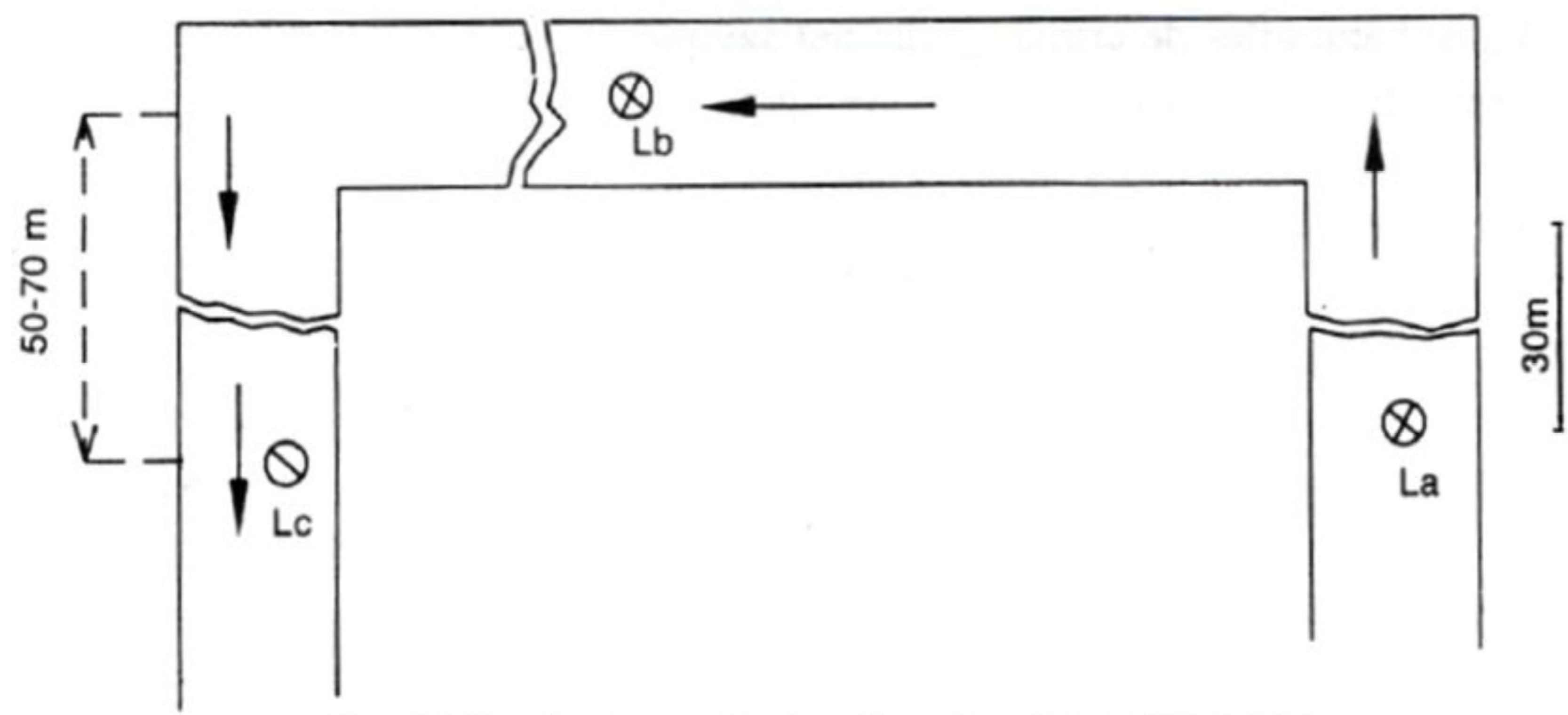


Fig. 12.14 Dust sampling locations in a longwall working

- 30m outbye of the face in the intake airway (La).
- At the centre of the face (Lb), and
- 50 to 70m outbye of the face in return airway (Lc).

Location of sampling in drivages and long headings:

- Sampling shall be done in the drivage when they are driven more than 30m or when the system of working is fully established to enable collection of a representative sample.

Location of dust sampling in opencast workings/surface plants

- Samples should be taken at the working places near workers.
- In surface plants like coal handling plant (CHP), crusher house, siding and other places in processing plants where dust is generated.
- In opencast workings, sampling by personal dust samplers is considered more reliable than sampling by fixed-point samplers.
- Sampling time for a static sampler during a working shift is defined as the starting of the sampling instrument as soon as the first man arrives at the workplace and switching off the instrument when the last man leaves the work place.

- During shot firing, a sampling instrument sited near the face may get damaged and hence has to be removed along with the workers leaving the face, but the instrument should remain switched on and be relocated at the same place when work resumes at the face.
- As the instrument is generally removed to the intake to a site with very low dust concentration, the time weighted average (TWA) dust concentration of a place should be calculated on the basis of the face working time only.
- In most countries, these days the personal dust sampler (PDS) is used as the statutory dust monitoring instrument.
- As the instrument is worn on the body of a worker, there is no sampling location specified. A PDS can be used also as a fixed-point sampler.

- Some trials conducted in USA showed that the respirable dust concentration at a place obtained with a cyclone-type PDS is lower than that obtained by an MRE 113A type apparatus. In USA, the PDS values are multiplied by a factor of 1.38 to get the statutory MRE 113A value.

- In India, also the National Dust Prevention Committee recommended that the results obtained with MSA-PDS (a personal sampler based on 10 mm cyclone) be multiplied by a factor of 1.4 to get the equivalent MRE 113A value.

MRE: Mine Research Establishment

Frequency of dust sampling in opencast workings/surface plants

- The frequency of respirable dust sampling was specified as once at least every month in coal mines as per CMR 2017.
- In the mining statutes of USA, also similar varying sampling frequencies of 180, 120 and 90 days are specified.

- In New South Wales, Australia, sampling of respirable dust has to be done at intervals not exceeding six months where the longwall mining is carried out and at intervals not exceeding 12 months in continuous miner districts or in opencast mines, crusher stations and washeries.

Example

The following gives the working history of a miner at a mine:

Nature of work	Number of months worked	Average dust production in the respirable size range (mg/m^3)	Percentage of free silica in the respirable dust
Drilling	39	1.8	5.6
Mucking	48	2.4	8.2
Drill shop	85	0.9	4.8
Surface	72	0.4	0.5

Calculate cumulative dust dosage as well as his average dust exposure of the miner. Assume 150 working hours in a month. Estimate the exposure to dust hazard of the miner. Also find the factor of safety in dust exposure of miner according to the norm.

A miner works at a grizzly for 5.5 hours on an average per shift wearing a dust mask which is 90% efficient for -5μm dust. He spends 0.5 hours per shift in travelling inside the mine. Calculate his cumulative dust dosage in a 5 year working span considering 280 working shifts in a year. Also calculate the average dust concentration that he is exposed and estimate his exposure to dust hazard if the respirable dust contains $\leq$5% free silica. The respirable dust concentrations at the grizzly and in the general body of mine air are 15 mg/m^3 and 0.2 mg/m^3 respectively.

Following table gives the data about respirable dust samples collected by a gravimetric dust sampler. Calculate the average dust concentration.

Duration of sampling, hr	Sampling rate, m^3/s	Mass of respirable dust collected, mg
5.67	0.0021	68
7.87	0.0022	85
3.50	0.0020	35

- A long heading 3 m wide and 2.5 m high is ventilated by a forcing tube circulating 2.8 m3/s of air at the face. Calculate the distance from the face at which all the +10 μm dust particles would have settled down from the air stream. The dust particles have a density of 2650 kg/m3.

- Drilling in a stone drift 3 m × 4 m in cross-section in a coal mine produces 1.5 gm of dust of < 5 μm size every minute. Calculate the airflow rate required to dilute the dust to the TLV if the intake air has a respirable dust load of 0.8 mg/m3 and the respirable dust has a free silica content of 8%.

THANK YOU