bulk solids handling Volume 1 Number 3, September 1981

Dust Generation and Control in Materials Handling

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Staubentwicklung und -kontrolle in der Schüttgut-Fördertechnik
Production et suppression de la poussière pendant la manutention des matériaux
Generación y control de polvo en el manejo de materiales
材料管理におけるダスト発生と管理
物料处理尘埃的产生与控制
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Summary

The mechanisms are described by which dust is generated and dispersed in materials handling systems and the general approach to dust control is outlined. Specific methods of dust control mentioned include: modification of handling system, hoods, booths, containment, water sprays and air curtains; empirical design data is given where available. The problems discussed and the lack of comprehensive design procedures form the background to current work at Warren Spring Laboratory.

The present paper forms the basis of one of the lectures in a series of industrial awareness seminars that are organised by Warren Spring Laboratory.

1. Introduction

The economic control of dust in materials handling plant requires that it be considered as an integral part of the system at the design stage rather than adding ad hoc arrangements after the plant has started up. Solving the problem after it has brought the process to a standstill is not only expensive in terms of extra equipment and manpower but also in lost production.

The generation and control of dust depends upon the nature of the material being handled, the selection of the handling, processing and abatement equipment, plant layout, detailed engineering and the method of operation and control of the plant and processes. There are four important aspects to the overall control problem:

1. Minimization of the generation of dust at source.
2. Containment of the generated dust and prevention of its dispersion.
3. The selection and sizing of the dust abatement equipment.
4. The handling of the collected dust.

The discussion below concentrates on 1 and 2 above and it briefly summarises the state of the technology prior to the commencement of the current work at Warren Spring Laboratory. This work is directly financed by the Department of Industry (through the Chemicals and Minerals Requirements Board), 20 companies and the Health and Safety Executive.

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2. Generation of Dust at Source

It is convenient to introduce a special term to describe the mechanical process whereby bulk powder, or indeed part of a solid mass of material, is converted into a dust cloud. This term is *pulvation* [1] (Fig. 1). Pulvation is the process by which dust is produced and could be considered to be analogous, on the molecular scale, to evaporation. For a given material the amount of dust produced will depend upon the process of pulvation. As a result of pulvation a dust cloud is produced which may contain a very wide range of particle sizes. The coarser particles will, of course, settle out quickly but the finer particles will remain airborne and may be widely dispersed by the processes discussed later to cause a nuisance or a health hazard. The coarser particles, incidentally, have a role to play in the dispersion of the dust cloud as will be discussed later.

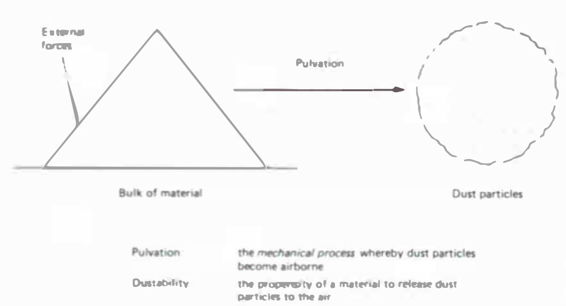

Fig. 1: Dustability and pulvation defined

The material property that determines the amount of dust generated can be termed *dustability* or *dustiness* which is a measure of the propensity of the material to produce dust and is analogous to vapour pressure on the molecular scale.

The nature of the pulvation process and the material dustability together determine the nature and the amount of dust generated and in order to determine the effectiveness in reducing dust of modifications to the material or the process, it is desirable that measurements can be made of these parameters.

The measurement of dustability is considered first. Many pulvation processes amount to air flowing through or past a bulk of powder and it is reasonable that any test for dustability should expose the powder to similar conditions.

Numerous tests for dustability have been devised but probably the most rigorous is the test based on fluidising the material, either on its own or in admixture with a coarser, dust free material [2]. The apparatus is shown diagrammatically in Fig. 2. The material is fluidised under known conditions and the rate of emission from the bed of different size fractions of dust is measured and recorded as shown in Fig. 3. It can be seen from Fig. 3 that the range of dustabilities is large over a range of common materials.

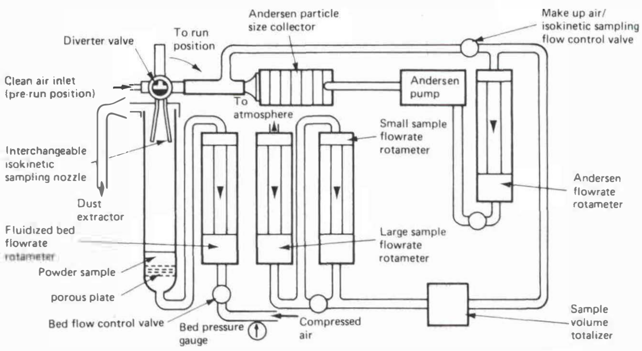

Fig. 2: Dust emission rig

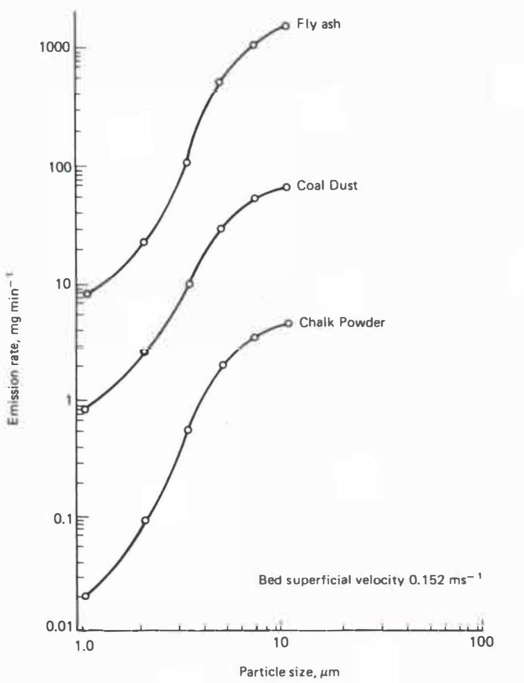

Fig. 3: Grade emission curves for a range of materials

If one considers the opposing forces acting on the particles which determine whether or not they will become detached from the bulk to cause dust, the following relationship describes the situation:

For a particle to become airborne:

$$\begin{bmatrix} \text{Aerodynamic} \\ \text{drag force on the} \\ \text{particle} \end{bmatrix} > \begin{bmatrix} \text{Particle} \\ \text{weight} \end{bmatrix} + \begin{bmatrix} \text{Force of cohesion} \\ \text{of the particle} \\ \text{to the bulk powder} \end{bmatrix} \quad (1)$$

that is,

$$\frac{1}{2} c \varrho a V^2 \geq mg + F$$

where:

c = the fluid drag coefficient (dependent on Reynolds number)

ϱ = the density of air

a = the area of the particle presenting resistance to air

V = the velocity of the air relative to the particle

m = the mass of the particle

F = the cohesive force holding the particle to its neighbours.

It is thus clear that for a given pulvation process the amount of dust is reduced if the particle weight (or size) is increased or the force of cohesion to the bulk powder is increased. These effects are illustrated in the dustability measurements shown in Fig. 4. If the powder is granulated then the larger the granules the lower the material dustability, as shown in Fig. 4. If the moisture content (or other liquid content) of the material is increased the cohesion force is increased and hence dustability reduces, as illustrated in Fig. 4. These two methods, granulation or addition of a liquid, are well tried methods of reducing dustability and the test described allows measurements to be made of their effectiveness. Further experimental work is in progress in this area.

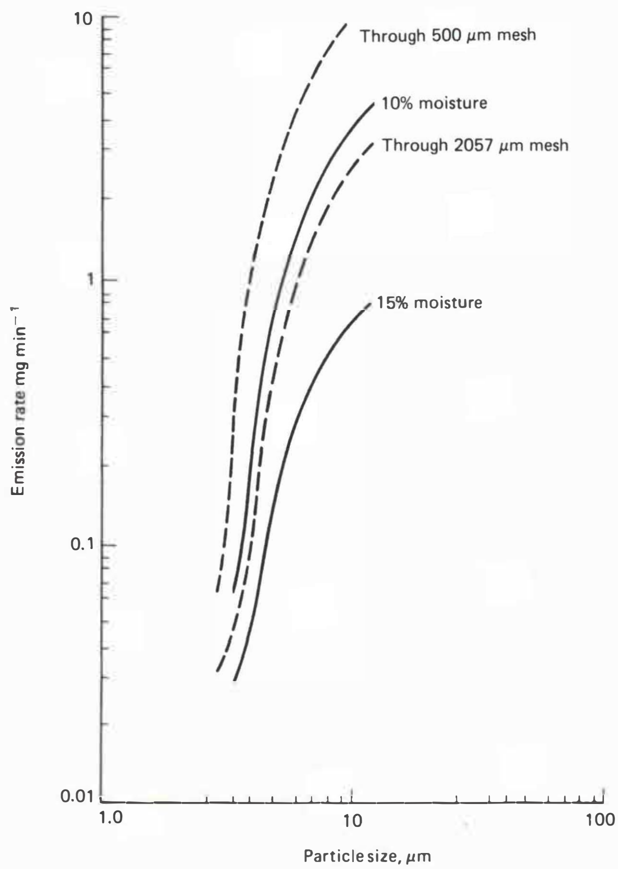

Fig. 4: Effect of moisture and granule size on dustability

The quantification of the pulvation process is more difficult because it is difficult to study the process in isolation from the dust dispersion air flows produced by the process but a start is being made by investigating pulvation processes in what amounts to a wind tunnel. In the equipment illustrated in Fig. 5 (the laminar flow test room) materials handling operations are carried out in a box with a uniform upward air flow so that any dust released from the process will be carried away by the air flow and subsequently measured. In this equipment it is possible to relate the geometry of the handling system and the material dustability to the amount and nature of the dust produced. This data can be used to predict likely levels of dust load to the abatement equipment and the effectiveness of remedial measures such as water sprays, containment and exhaust systems. A comprehensive body of quantitative information is not yet available but work is continuing in this area.

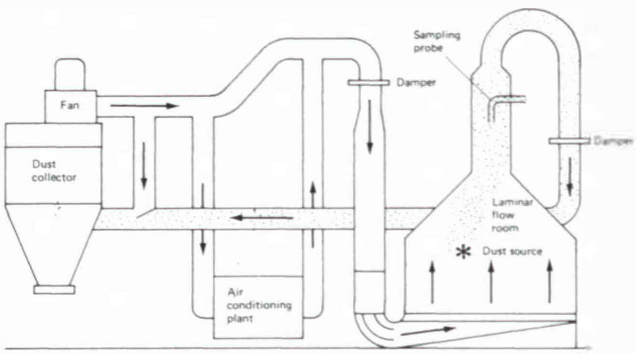

Fig. 5: Laminar flow test room

3. Dust Dispersion

Air flows induced by powder moving or settling and by other mechanical motion are the agents for the pulvation and for the spread of a dust cloud from its point of generation to the places where it can be a nuisance or a hazard.

Consider the simple case of a stream of material falling from one conveyor belt to another as illustrated in Fig. 6. The belts themselves with their powder burden cause air flows close to the belts on the moving powder. The falling stream of powder causes an overall flow of air downwards but with secondary flows into and out of the stream itself because of changing densities of the stream. When the stream hits the receiving belts or a heap of powder, the powder is compacted thus displacing air. It can thus be appreciated that the air flows around such a system are complex and are likely to cause pulvation and dispersion of the dust. Other situations where air flows occur with consequences relevant to dust generation and dispersion are summarised in Table 1 and illustrated in Fig. 7. Further investigations of air flows and pulvation process are continuing in the previously mentioned laminar flow test room in order to improve the design procedures for control systems to be discussed next.

Table 1: Operations resulting in the dispersion of dust clouds

Operation	Air Flow Mechanisms	Examples
Falling stream	Air drag of bulk stream, secondary flows, impaction of stream.	Hopper filling and discharge, container filling and emptying, stockpile building, belt to belt transfer, bag emptying.
Projected bulk flow	Air drag of bulk flow, drag associated with coarse settling particles.	Discharge from conveying equipment.
Displaced air	Air displaced by volume changes, changes of pressure caused by air drag of incoming stream to a container, settling or impaction of mass of material.	Hopper filling, IBC filling, bag filling, enclosed conveyors such as bucket elevators, load dumping e.g. lorries, front loaders, skip hoists weigher, discharge etc.
Materials handling equipment	Air flows caused by moving parts and bulk material flow, agitation of bulk material with changes in bulk density.	Belt conveyors, bucket elevators, vibratory conveyors, chutes, vehicle movements, bag emptying, skip hoists.
Mechanical equipment	Air flows caused by moving parts.	Cooling fans on motors, drive pulleys and belts, belt cleaners.
Processes	Changes in bulk density of material, intentional air flows through material, moving parts of machinery.	Crushing and grinding, mixing and blending, fluidisation, drying, sieving/classification.
Wind/draughts	Air drag of wind and draughts on stationary or moving material.	Outdoor stockpiles and conveying on open belts, open buildings, ventilation, thermal currents.

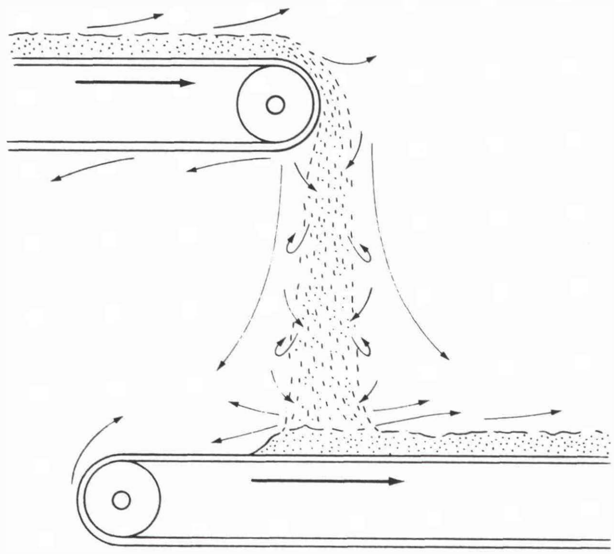

Fig. 6: Air flow around a belt to belt transfer

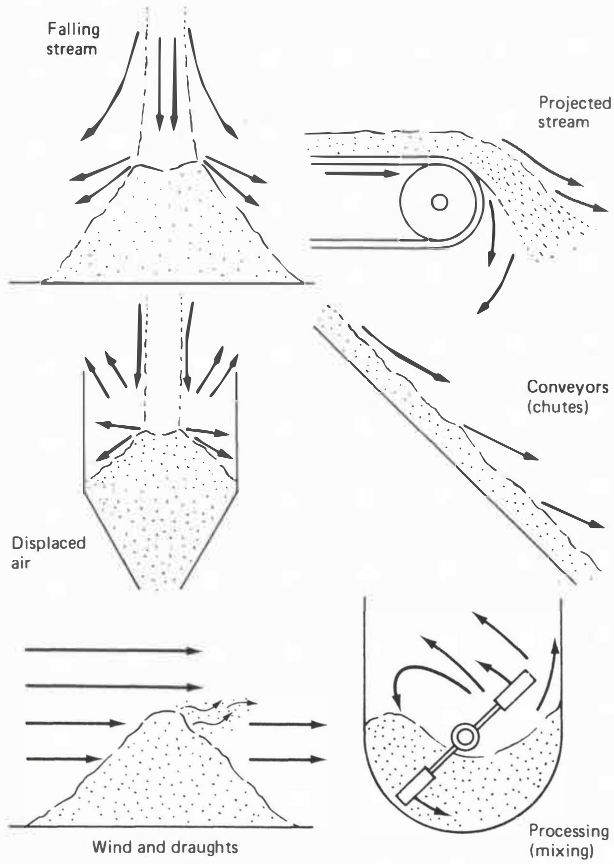

Fig. 7: Examples of dust dispersion processes

4. The Control of Dust Generation

The amount of dust generated in an operation is governed by equation (1) and this equation can be used as a basis for discussing what measures can be taken to reduce the formation of dust. The left hand side of the equation represents the forces tending to detach dust from the bulk and obviously if these forces are reduced dust generation will be reduced. Reducing the velocity of the bulk material or the air that comes into contact with the material is highly significant in this respect and some practical methods are suggested in Table 2. The first term on the right hand side of the equation relates to the size of the particles in the bulk material and clearly if the size of the particles exposed to air flow is increased dust release is reduced. Some practical methods are suggested in Table 2. The second term on the right hand side of the equation relates to the cohesion of the particles to the bulk and again methods for increasing cohesion are suggested in Table 2.

5. Control of Dust Dispersion

The control of dust dispersion essentially reduces to the control of air movements around the points of dust generation.

Simple containment of a materials handling process would shield dust sources from external air currents from

Table 2: Methods for reducing dust emission at source

Reducing External (Pulvation) Forces	Increasing Particle Size	Increasing Particle Cohesion
Reduce heights of fall.	Granulate or agglomerate.	Spray water/wetting agent onto stockpiles and flowing systems to increase cohesion at the surface of the bulk.
Shield material from external air.	Sieve out fines and recycle.	
Reduce conveying velocities.	Delay comminution to just before the process requiring it.	Mix water or compatible oil with bulk — may be combined with agglomeration.
Arrange continuous flow rather than dumping.		
Reduce surface area to volume ratio of flowing stream.		
Use gentle conveyors or processes to prevent undue crushing of particles or granules.		
Minimise handling.		

mechanical equipment, wind and draughts. Air flows within the containment can cause pressure rises so that even if complete containment could be achieved some sort of exhaust system would still be required to prevent dust escaping from the inlet and outlet of the system. In practice, of course, complete containment would not only be very expensive but very difficult where moving machinery is involved. Instead of complete containment, exhaust systems are usually provided close to specific dust sources so that the direction of movement of the dust cloud is controlled and the dust carried away to the abatement system.

The first difficulty in designing an exhaust system is in deciding what air velocities are required to ensure capture of the dust particles. This is still very much a matter of rule of thumb although Hemeon [1] has attempted to formulate general working principles. When pulvation occurs particles are ejected and, at some point from the source, the pulvation air flows will expend their energy and the fine particles then move around with the local air currents. The point at which this occurs is called the null point and it is illustrated in Fig. 8. The velocity of the exhaust air at the null point furthest from the exhaust system must be sufficient to ensure that the particles are diverted into the exhaust system. Hemeon recommends some velocities at the null point and his figures are given in Table 3.

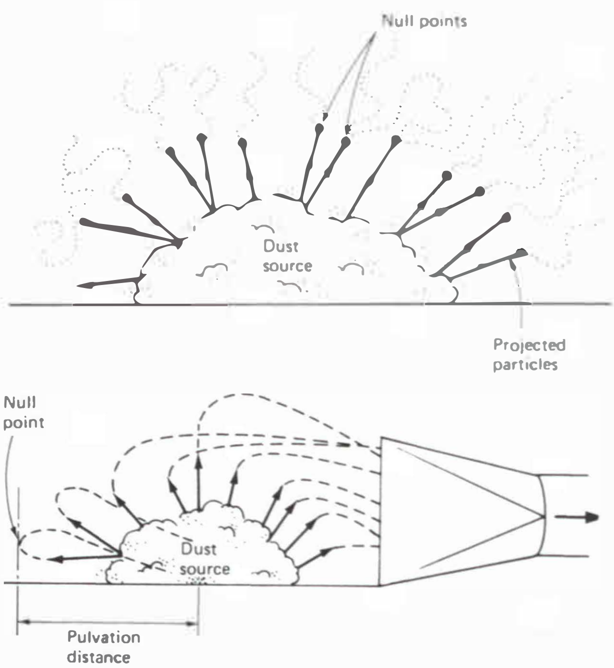

Fig. 8: Illustrating the use of the null point in hood design

Clearly under very draughty conditions some degree of enclosure would reduce the velocity requirements considerably.

The position of the null point is difficult to determine without experiment and very little guidance is available. In some circumstances null points can be estimated using a *dust lamp* to visualise the dust cloud.

Having established a suitable position for an exhaust hood and the position of the null point, it is then necessary to determine the face velocity at the hood to achieve the desired velocity at the null point. This procedure is fairly well established and iso-velocity curves for different types of hood are shown in Fig. 9 [3]. For non-standard shapes of hood, measurements would have to be made.

It can be appreciated by reference to Fig. 9 that the velocity into a hood drops off rapidly with distance from the face so that if the null point is a long way from the face high exhaust rates are required. Simple hoods are thus commonly used where they can be placed close to a relatively well defined dust source and some examples are given in Fig. 10 and even in these instances the drawbacks of hoods can be appreciated.

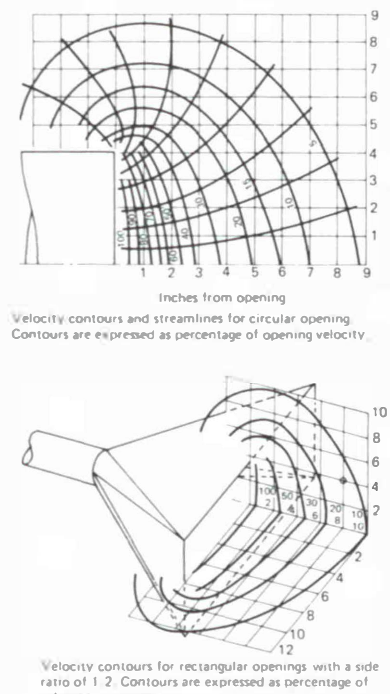

Fig. 9: Examples of iso-velocity curves for simple hoods (Dallavalle [3])

Table 3: Recommended air velocities for capture (Hemeon [1])

Draught Characteristics of Space	Lower Safety Factor (Non-toxic dusts or toxic at small emission rates)	Higher Safety Factor (Toxic dusts, large emission, rates of non-toxic dusts)
	Controlling velocities at farthest null point fpm (m s^{-1})	
Draughtless	40—50 fpm (0.20—0.25 m s^{-1})	50—60 fpm (0.25—0.30 m s^{-1})
Moderately draughty	50—60 fpm (0.25—0.30 m s^{-1})	60—70 fpm (0.30—0.36 m s^{-1})
Very draughty	70—80 fpm (0.36—0.41 m s^{-1})	75—100 fpm (0.38—0.51 m s^{-1})

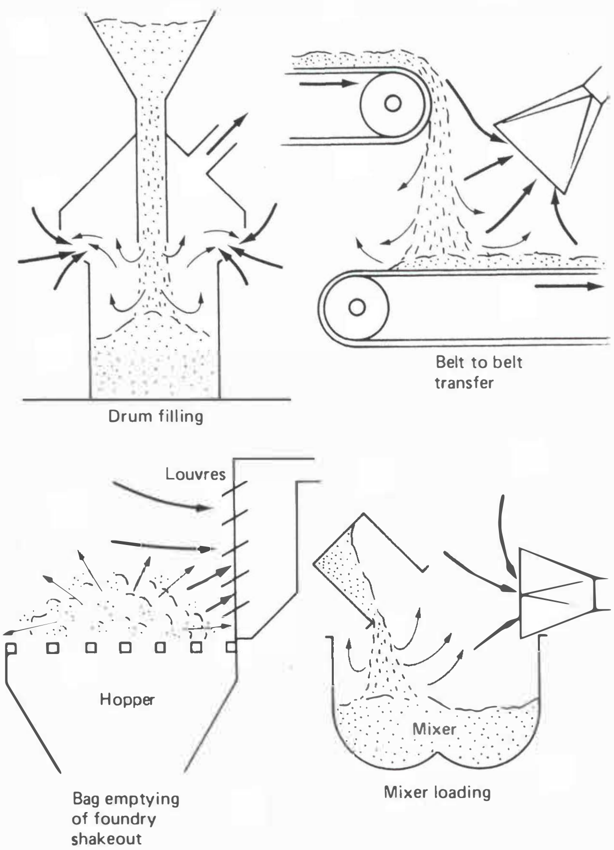

Fig. 10: Examples of hoods

The above approach is complicated by secondary air flows occurring at the dust source such as those that would be produced by a falling stream and Hemeon [1] has developed a method for determining the air flow induced in this situation. His method overestimates the air flow and after suitable modification due to Morrison [4], the induced air flow for fine dust is given by:

$$q = \left(\frac{RsgA^2}{15\varrho} \right)^{1/3} \quad (2)$$

where:

q = air flow rate, $m^3\ s^{-1}$
R = material flow rate, $kg\ s^{-1}$
s = drop height, m
A = area of cross-section of stream, m^2
ϱ = density of air, $kg\ m^{-3}$

This extra air flow is particularly important in determining the exhaust of hoppers or other containers during filling.

In many applications, particularly those concerned with manual handling where the dust sources are distributed, the use of hoods is impracticable and booths are sometimes used. Booths surround the operation except for one side for access. In the so-called laminar flow booth, a uniform flow of air at relatively low velocity (approx 0.5 m s^{-1}) is arranged to flow into the booth to prevent the emission of any dust generated within the booth. Heriot and Wilkinson [5] have recently described the use of laminar flow booths. Their construction and typical uses are illustrated in Fig. 11 and recommended control velocities are given in Table 4.

It must be emphasised that some dust will settle in a booth and not be carried away in the air stream. In such cases the inside of the booth needs to be vacuum cleaned periodically.

Where a dust source is fixed and access is required infrequently the source can be contained to a greater degree than can be achieved by using hoods or booths and, depending upon the degree of enclosure, much smaller air flows are required to prevent dust escape. Where the flow rate of material through an enclosure is high the exhaust rate is determined by the induced air flows which can be calculated by the previously mentioned method. When the flow rate is low or drop heights small it is usual practice to ensure an air flow into the enclosure of 0.4 m s^{-1} (70 ft min^{-1}) through all gaps in the enclosure. The above and other specific instances of recommended enclosure exhaust rates are summarised in Table 5.

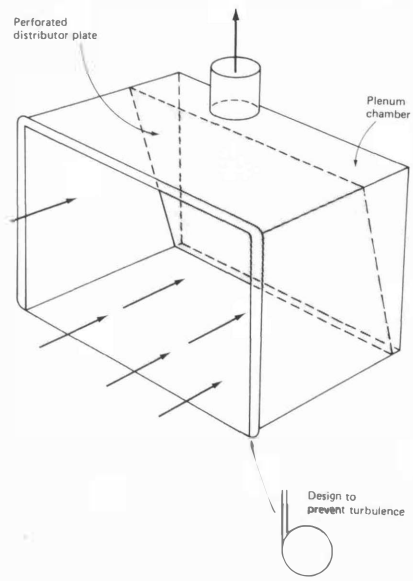

Fig. 11: Laminar flow booth (Heriot & Wilkonson [5])

It is desirable to minimise the amount of material drawn into the exhaust system in order to minimise the amount of dust that has to be handled subsequently and to ensure that the dust abatement system is not overburdened. The siting of the exhaust point on an enclosure is therefore highly important. The siting and geometry of the exhaust point should be such as to avoid direct projection of material into the duct and to avoid high velocity air flows close to agitated or moving powder. Some examples of enclosure design are shown in Fig. 12 where it can be seen, in some instances, that the exhaust duct widens out close to the flow so that the velocity is not too high near to the dust source.

Where physical containment is impracticable or undesirable, air curtains [7] and water sprays [8] are possibilities. Water spray systems form a barrier to the dust and also promote agglomeration of the fine particles so that they settle out. Their effectiveness has been demonstrated in quarry materials handling systems, but design procedures for wider application are not generally available. Air curtains are used in some specialised applications to control airborne particulates but their exploitation in general dust control has not been widely reported.

Table 4: Recommended minimum control velocities for large laminar flow booths (m s^{-1}) (Heriot and Wilkinson)

	Laminar Flow Booth Conditions		
Building conditions	No operator present Non-violent emission No internal secondary draughts	Operator present Non-violent emission No internal secondary draughts	Operator present Violent emission or internal secondary draughts
Non-draughty area	0.2	0.3	0.4
Draughty area	0.3	0.4	0.5

Table 5: Recommendations for exhaust rate of enclosures

Enclosed System	Recommended Exhaust Rate
Small flow rates and drop heights with no enclosed moving parts.	0.4 m s^{-1} (70 ft min^{-1}) through gaps in enclosures.
Falling streams of fine powder, i.e., through the enclosure or into enclosed container.	$(R.sgA^2/15\varrho)^{1/3}$ m^3 s^{-1} R = material flow rate, kg s^{-1} s = drop height, m A = area of cross-section of stream, m^2 but not less than 0.4 m s^{-1} (70 ft min^{-1}) through gaps in enclosures.
Belt to belt transfer, bucket elevator.	1 m s^{-1} (200 ft min^{-1}) through openings into enclosure.
Crushers.	1 m s^{-1} (200 ft min^{-1}) through crusher gap in direction of material flow.
High speed mills such as hammer mills discharging into an exhausted container [1].	$\frac{\pi D^2 W N}{4}$ m^3 s^{-1} D = diameter of hammer assembly, m W = width of hammer assembly, m N = revs per second (grossly overestimates flow)

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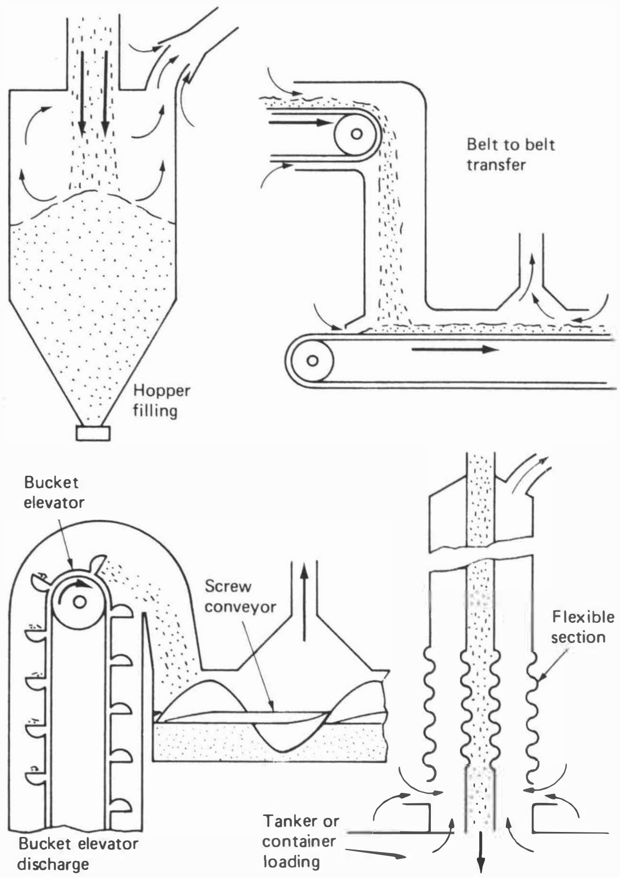

Fig. 12: Example of exhausted enclosures

6. Duct Design

When the positions of hoods, enclosures or booths have been fixed and the exhaust rates determined it is necessary to design the duct work to carry the dust laden air to the separator. Duct design is well established and only a few important principles will be given here. Comprehensive details are available from a number of sources [1], [6].

The length of ducting required should be a minimum avoiding long branches, equalising the length of branches, minimising bends and so on. The design of the duct work should therefore be anticipated when designing the powder handling plant as a whole. Consideration should also be given to the relative merits of a large centralised air cleaning system with the necessary complicated duct work or distributed smaller systems with simpler duct work.

After the layout has been determined it is necessary to determine the air velocity in the ducts and the pressure losses through the system.

6.1 Duct Velocity

The velocity of the air in the ducts must be sufficiently high to prevent the dust settling out anywhere in the duct work. Dust deposits can render the exhaust systems ineffective, the weight of dust can cause collapse of the ducts and cleaning of the ducts can be difficult and time consuming. Although a velocity will be selected to prevent depositon, the situation must be anticipated where the fan is shut off, or breaks down, so cleaning access and facilities for dust removal should be incorporated in the design.

Generally speaking, linear air velocities of 20 m s^{-1} are adequate for most dusts and some other recommended values are given in Table 6.

6.2 Pressure Losses

The total pressure loss through an exhaust system is the sum of inertia losses, straight duct friction losses, orifice losses, elbow and branch entry losses and contraction and expansion losses. The procedures for calculated pressure drops are available from a number of sources [1], [6].

Table 6: Duct Velocities

Contaminant	Duct Velocity, m s^{-1}
Smokes and fumes, light dusts	10
Medium density dry dust	15
Average industrial dust	20
Heavy dusts	25

Having determined the pressure drops throughout the system it is then necessary to ensure that the system is balanced and the required air flows are in fact achieved at the various hoods or enclosures. This can be achieved by a number of methods:

6.2.1 Balanced Flow Design

Using the pressure loss data and the minimum duct velocities the pipe diameters are adjusted so that pressure drops upstream from 'nodes' are equal in all the branches.

6.2.2 Blast Gate Adjustment

In this method no adjustment of pipe diameters are made at the design stage but blast gate valves are installed in each branch of the system and adjustments made during commissioning. The valve settings are then fixed. Blast gates can cause build-up of dust so this method has its limitations, although it is simpler.

It should be pointed out that unless the duct work system is designed to take account of additional ducting, ad hoc modifications and additions to duct work are likely to imbalance a system and render some exhaust systems ineffecitve. Great care must be exercised in the modification of exhaust systems and any likely modifications should be anticipated at the duct work design stage.

6.2.3 Plenum Ducts

Some of the problems with balancing conventional ducts can be overcome by the use of plenum ducts and the relative merits of conventional and plenum ducts can be discussed by reference to Fig. 13. In plenum ducts the conventional ducts from individual hoods or enclosures are connected to a large diameter duct or plenum which forms a low pressure drop path to the air cleaner. This means that the balancing of flow from the different sources is not crucial. In the plenum, however, the velocities are low and dust will settle out and some provision has to be made for removing the settled dust. Some examples are given in Fig. 14.

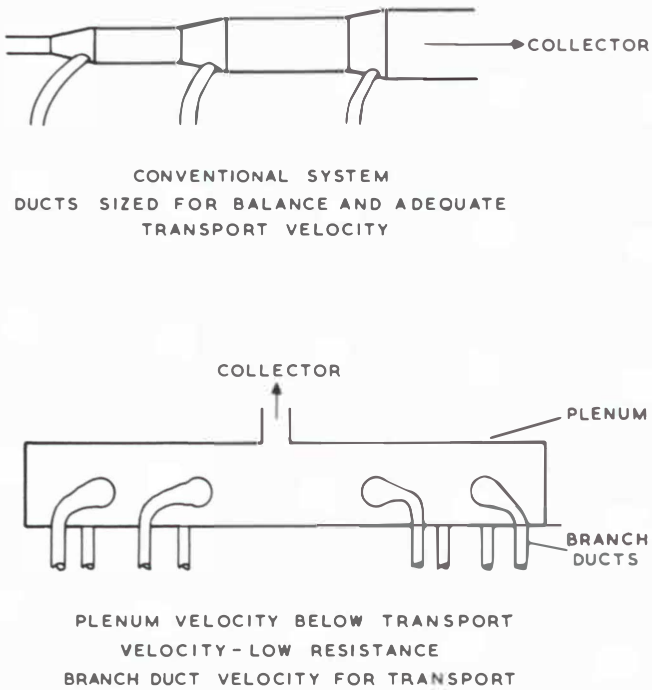

Fig. 13: Plenum vs. conventional ducts

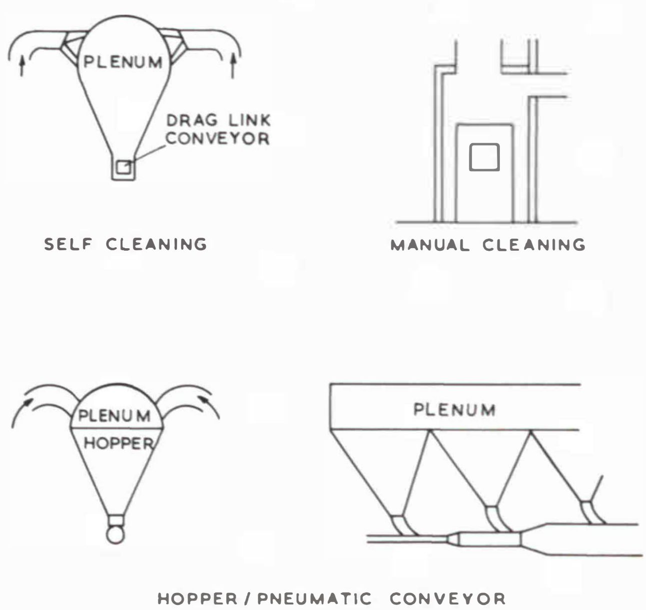

Fig. 14: Types of plenum

7. Dust Handling

Once the dust has been prevented from escaping from an enclosure or captured by a hood it is ducted to the abatement system and then the separated dust must be disposed of or recycled.

Handling the dust discharged from the separator can be particularly difficult because it is very fine. Fine powders are cohesive and do not flow well, particularly if they are allowed to consolidate in hoppers. The handling and storage of fine cohesive powders is beyond the scope of the present paper but attention is drawn to the possible problems. Where the dust has to be returned to the process the fine form is often unsuitable, and the dust can be agglomerated or granulated by tumbling in a rotating cylinder, or pan, with the addition of a binder, to produce a free-flowing, dust-free material.

An outstanding problem in this area is the prediction of the amount of dust likely to be collected from a given plant and this will be the subject of future investigations.

8. Final Comments

Materials handling and associated processes are potentially dusty and the mechanisms of dust generation and dispersion have been discussed. Factors affecting the generation and dispersion of dust have been outlined as a background to the consideration of remedial measures.

It is clear that the systematic design of a materials handling system as a whole is most important from the point of view of minimising dust and interfacing the control equipment with the materials handling equipment. Various methods are available for minimising the dust and controlling its dispersion but design is largely a matter of rule-of-thumb. It is against this background and with an increasing awareness of dust problems and their economic control that Warren Spring Laboratory initiated its Dust and Materials Handling Project to provide comprehensive design and operating procedures.

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