

MIDHS

*Methods for the Determination of
Hazardous Substances*
Health and Safety Laboratory



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The dust lamp

A simple tool for observing the presence of
airborne particles

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INTRODUCTION

1 The minute scintillations in a cinema projection beam or in a shaft of sunlight entering a darkened room, are familiar examples of light scattering by airborne particles. The phenomenon is often termed the 'Tyndall effect', after the British scientist (John Tyndall, 1820-93) who first investigated it.¹

2 Little practical use of these observations was made until the early 1950s when a number of engineers and scientists began to use photographic spot lamps to investigate what happens to dust clouds from industrial processes and to aid the design of exhaust ventilation systems.² Early users were surprised by their observations. Thus in the case of pedestal grinders:

... photography of the dust cloud resulting from grinding showed that the conventional exhaust system is by no means as efficient as was supposed.

And similarly for portable grinding wheels the dust lamp

... indicated that the dust of small size range did not follow the line of sparks but flowed over the wheel top and appeared as a vortex between the wheel and the operator's face. The work indicated the dust control system which had been arranged to collect large particles such as sparks, failed to collect dust of dangerous size range.

Further examples of these types of observation and photographs can be found in publications by government committees and the British Occupational Hygiene Society.^{3, 4, 5, 6}

3 In the absence of effective control measures, airborne particles are released into the workplace atmosphere by many industrial processes. Such particle clouds can be invisible under normal lighting conditions,

but may be made visible by the use of a high intensity beam of light. This technique is commonly referred to as the dust lamp. Use of the lamp enables the existence of particle release at a process to be simply demonstrated, or the performance of an extractor system to be assessed. Photography or video recording can be used to make permanent records of the observations.

SCOPE AND CONTEXT

4 This guide is written for occupational hygienists, ventilation engineers, health and safety practitioners and others interested in how exposures to airborne particles occur. It briefly explains the principles of the dust lamp, its use in observing the presence of airborne particles, and identifies its advantages and limitations. Appendices covering lighting terminology, lighting equipment, test results on some lamps, still photography, video recording and lamp suppliers are also included.

5 The presence of many different types of particles, both solids (eg dusts, fumes and fibres) and liquids (organic or inorganic mists), can be revealed by the dust lamp. However, it does not give a quantitative measure of either particle concentration or size.

6 The main use of the dust lamp is to make fine airborne particles visible (ie particles below $\sim 10\mu\text{m}$ aerodynamic diameter, usually termed respirable⁷). Some of the important general properties of fine particles can be summarised as follows:

- they move with the air in which they are suspended;
- they settle out of the air slowly and can remain airborne for long periods of time.

They can be revealed by the beam of the dust lamp as particles swirling and flowing with the air in which they are suspended. The dust lamp in this context usually shows that particle clouds occupy a far greater volume of air than is suspected.

7 Although the main use of the dust lamp is to make fine airborne particles visible, it can also enhance the visibility of dust clouds containing coarser particles, such as those generated from woodworking operations. Through experience and careful use of the dust lamp it is possible to observe the extent, pattern and direction of a particle cloud's movement.

8 The dust lamp is a useful tool in the investigation of processes, controls and exposure but it must be seen in context. It is an occupational hygiene tool that can be applied to exposure and control problems. As with any other occupational hygiene investigation, the user should have a good understanding of the process and work method, and be able to relate dust lamp observations to other occupational hygiene data and findings.

PRINCIPLE

9 For fine particles, the intensity of the scattered light is greatest at a small angle to the incident light beam, as shown in Figure 1 (the actual values of intensity differ for different dusts and incident light beams and the units are therefore not specified). As the angle is increased, the intensity of the scattered light falls rapidly, consistent with diffraction theory, but at angles greater than about 120° the intensity increases somewhat as the diffracted light is augmented by reflection. For particles smaller than 0.1 µm, scattering by mechanisms other than diffraction occurs and the variation in intensity with angle is reduced; the intensity of the light scattered by such mechanisms is relatively low, however, and is not important in dust lamp use.

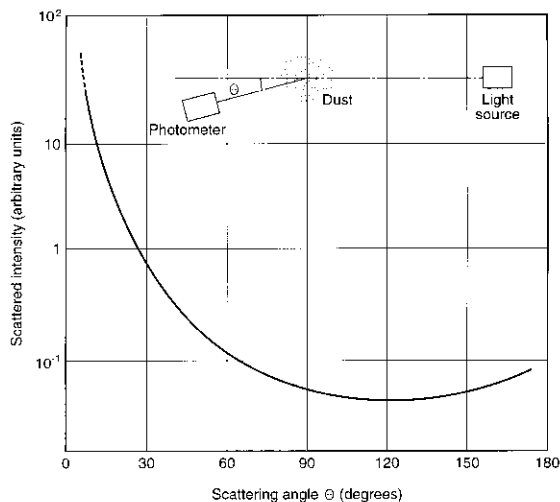


Figure 1 Intensity of scattered light as a function of angle

10 The curve in Figure 1 was obtained from photometer readings; to the human eye, however, the visibility of the particle cloud depends not only on the intensity of the scattered light (I_s) but also on that of the background (I_b), ie on the contrast, defined as $(I_s - I_b)/I_b$. Thus if viewing at a small angle results in appreciable background illumination, or exposes the observer to glare from the direct light beam, it may be preferable to view the cloud at a larger angle. In practice, an observer

must make a judgement as to the viewing angle that provides maximum contrast between the scattered light and the background.

11 At small viewing angles, the wavelength of the scattered light will be that of the incident light beam, ie a white light will show the dust as white, regardless of the true colour of the dust. At larger viewing angles, however, reflected light may show the true colour of the dust.

12 The greater the intensity of the incident light beam, the greater will be the intensity of the scattered light and the more visible will be the particle cloud; thus the principal requirement for a dust lamp is that it should give a defined beam of high intensity. A parallel or near parallel beam is desirable, so that the intensity does not fall off rapidly with distance, thus giving a greater range. Such a beam is produced by a parabolic reflector having a small, compact filament at its focus and a plane lens, solely for protection. However, if the narrow beam of a spot lamp does not illuminate a sufficient area it may be necessary to use a divergent beam lamp. The latter usually requires mains power to obtain the necessary illuminance, and may require a dark background to give sufficient contrast.

13 It is difficult to specify a minimum intensity requirement for a dust lamp since this depends on the nature and concentration of the particles, the distance of the lamp from the cloud, the background illumination and the skill of the operator. From experience, however, a value of 32 000 lux (see Appendix 1 for terminology), measured by a photometer at a distance of 2 m from the lamp, should be satisfactory in most situations, although a higher value is likely to make the task easier. A lower value may be satisfactory if the background is relatively dark.

EQUIPMENT

Lighting units

Battery powered lamps

14 Battery powered lamps are convenient and easy to handle, making them particularly convenient for routine hygiene surveys or when visiting a number of different installations. Most battery powered lamps produce a narrow beam of high intensity light based on the use of a halogen bulb and a parabolic reflector. The limited area illuminated is not usually a problem as the lamp can be readily panned around the area under investigation.

15 By housing the battery in a portable case or attaching it to a waist belt, the operator has improved freedom of movement. Either lead-acid or nickel-cadmium batteries are suitable for powering typical 50 to 100w bulbs. A nickel-cadmium battery will generally give appreciably longer endurance.

Mains operated lamps

16 These are mostly diverged beam devices providing even illumination over a wide area. The use of this type of lamp enables the whole volume of the particle cloud to be illuminated at the same time. The use of 'barn doors'

(hinged metal flaps attached to the lamp housing) allow some control over the beam geometry.

17 Mains operated lamps are generally high powered (1000 to 2000w) and use tungsten-halogen bulbs operating at high temperature. Care must be taken to avoid burns. Two classes of lamps are suitable: those designed for amateur video recording and lightweight professional lamps for location filming.

18 Further details on both battery powered and mains operated lamps are given in Appendices 2 and 3.

STILL PHOTOGRAPHY AND VIDEO RECORDING OF PARTICLE CLOUDS

19 By the use of a still or a video camera, permanent records of the observations can be made. The technique of taking good images can only be developed by experience and experimentation. However, this should not deter those with a limited knowledge of photography from using the dust lamp. Adequate photographs can be taken by beginners using either a compact or single-lens reflex (SLR) camera. Black and white film gives better contrast than colour film but either may be used. To get a reasonable image of the particle cloud and the process and/or work being observed a relatively high speed film is best, for instance film rated at ISO 400. Further details are given in Appendix 4.

PRACTICAL APPLICATIONS

20 The dust lamp can be used in a variety of ways which include:

- as a tool to investigate work operations and processes to gain an understanding of the potential for exposure before any air sampling is done;
- after air sampling has demonstrated significant over-exposure, as an aid to understanding how and why exposure is occurring; and
- as a useful tool in investigating the effectiveness of controls during their development in confirming effectiveness after installation and as part of routine monitoring of controls.

21 The method of operation is demonstrated in Figures 2 and 3. A bright beam of light is shone through the area where it is thought a particle cloud may be present. The observer's eyes are shielded from the main beam by means of a piece of card, or by using the worker's body or a convenient piece of machinery as a shield. The particle cloud should be observed looking up the beam towards the source of illumination, preferably at a small angle off the centreline of the beam (see paragraph 9), and, if possible, against a darker background, for instance a portable curtain. Dense clouds can be made visible with the dust lamp under normal lighting conditions, but to see a small leak, for instance, or to trace the extended movement of a cloud as far as possible, the ambient lighting may need to be suppressed.

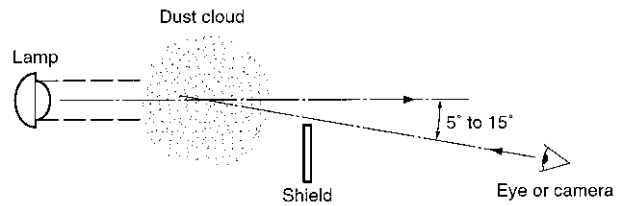


Figure 2 The use of the dust lamp to observe the presence of airborne particles

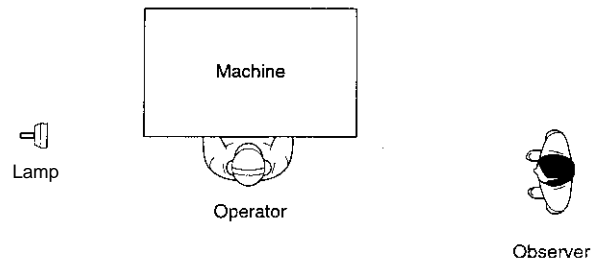


Figure 3 Diagram of an example of the dust lamp in use

Note: The lamp can be panned around the operator; once the area of interest has been located, the lamp is secured on a stand. The operator is used as a shield to obscure the main beam.

22 Although the dust lamp is a powerful tool in the right hands, success depends very much on the skill of the user. There are a number of common mistakes:

- the user shines the beam and looks into the cloud in the same direction. With this arrangement the dust lamp is not set up to observe the forward scattered light and only the far weaker reflected light is observed;
- there is insufficient contrast between the scattered light and the background against which the particle cloud is being observed. The cloud, although present, is not visible;
- the user tries to observe or to take photographs or video footage of a particle cloud while the dust lamp and the main beam are fully visible and illuminating the observer/camera. Contrast is dramatically reduced under these conditions and observations of the density and extent of the particle cloud will be limited.

23 The four examples of the use of the dust lamp which follow illustrate the diversity of application in terms of particle composition, concentration, particle size and industrial process.

24 The set of photographs in Plate 1 show a finishing job in a woodworking shop, using a vertical belt sander. The operator is holding the piece of wood, in this case hard wood, against a fast moving sanding belt, and dust particles up to 2 mm in diameter are generated. A local exhaust ventilation (LEV) system at the end of the table collects most of the dust. (The LEV was shut off during photography in order to show the technique to good effect.) Plate 1a shows the positions of the camera, the machine and the dust lamp. The camera was shielded from the main beam by parts of the machinery. Using a

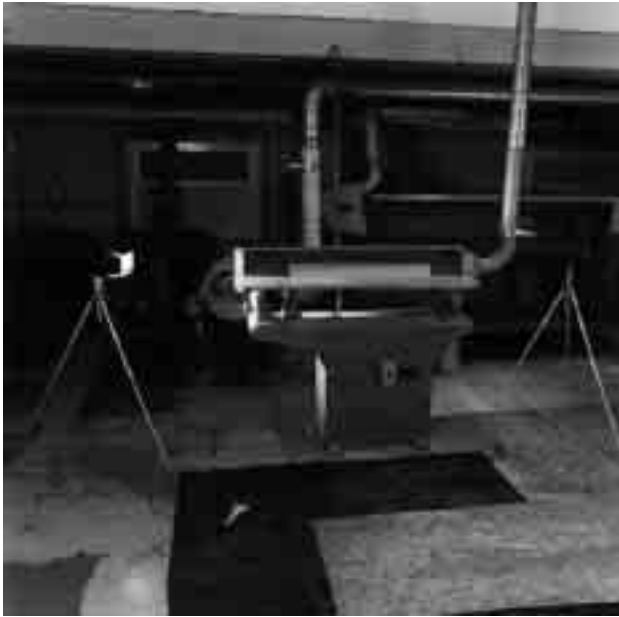


Plate 1a The arrangement of the lamp, sanding machine and camera for dust lamp photography, set up on a vertical belt wood sanding machine



Plate 1b Photograph showing dust cloud from the sanding operation



Plate 1c Wood dust cloud from sanding (using black and white film)

mains operated diverging beam lamp (Hedler Turbo Lux 1250w), a wide area was illuminated, and a dark background was utilised to enhance the contrast (Plates 1b and 1c). Kodak VPH ISO 400 colour and Ilford XP2 black and white films, f8 aperture and 1/30 s exposure time were employed. Flash was not used. The technique shows the large volume into which the dust dispersed and the swirling motion of the cloud. Some large individual particles can be identified.

25 The second example is a typical bagging operation in a mineral processing plant. The operator fills a bag with the finely ground mineral by holding it over the filling spout. The feed stops automatically when a pre-set weight has been bagged and the operator then withdraws the bag and tucks in the flap to seal the bag. Clouds of dust are produced

during feeding, as the bag is withdrawn from the spout and when tucking in the flap. The particle size (~90% less than 25µm) of the material made the airborne dust almost invisible under ambient lighting. Plate 2a is a photograph of the operation taken with flash which shows no sign of the dust cloud. Plate 2b is a similar shot but this time a narrow beam lamp (TB/100 lamp) has been shone from the far side of the operator. A dust cloud within the operator's breathing zone is now clearly visible. When shot from the same side as the lamp (Plate 2c) there is little evidence of the dust cloud apart from reflected light showing up some pink particulate. For best results, however, the set-up in Plate 2b was repeated but without flash. As shown in Plate 2d the swirling dust cloud is clearly seen enveloping the operator. Kodak VPH ISO 400 colour film, f8 aperture and 1/30 s exposure time was used in this set of photographs.

26 The third example (Plate 3) shows the products (tennis balls) of a moulding press where rubber fume is released for a short time when hot. In this process the rubber contained only a small amount of oil so the volume of fume released was low. Using a black and white film (Ilford XP2 ISO 400, f8 and 1/30 s exposure time) and a dark background, the fume appeared as a hazy white cloud hanging above the products. A narrow beam dust lamp (TB/100 lamp) was used in this instance. Under ambient light it would be impossible to see such a low level emission. Useful colour photographs were also obtained using a compact camera (Kodak Gold ISO 400 film) with the automatic flash blacked out or disabled.

27 The extent of solder fume exposure in a modern electronic laboratory was visualised using the dust lamp, as shown in the set of photographs in Plate 4. In this example, the operator was enveloped in a plume of fume as he was soldering components on an electronic circuit board. The fume was only just visible in ambient light or using flash (see Plate 4a). When the process was repeated in reduced light without flash but with a narrow beam dust lamp (Lectro Science Nite Tracker 25w), and



Plate 2a Bagging operation in a mineral processing plant: under ambient light and with flash, dust cloud is not visible



Plate 2b View from small angle towards lamp and with flash: small volume of dust cloud is visible



Plate 2c View from the same side of the lamp and with flash: dust cloud is not visible



Plate 2d View from small angle towards the beam of light and without flash: a dust cloud is clearly seen enveloping the operator



Plate 3 Rubber fume is revealed using the dust lamp

the camera aperture fully open looking into the main beam at a small angle and using the operator's body to obscure the main beam to get the maximum contrast, the plume of fume appeared like a flame and the photograph is also very grainy, partly due to the long exposure time of 1/8 s (Plate 4b). For best results, Plate 4c was taken in identical conditions but with a separate flash unit pointing slightly downward behind the operator's shoulder, acting as an additional wide area dust lamp. The flash was used to freeze the motion of the fume. The photograph revealed the whole volume and detail movement of fume. An SLR camera and Kodak VPH ISO 400 colour film were used in this example. Good pictures were also obtained using a compact camera (Kodak Gold ISO 200 film) with automatic flash.



Plate 4a Solder fume viewed under ambient light and with flash



Plate 4b View using dust lamp, under reduced light, without flash



Plate 4c View from small angle of the dust lamp, under reduced light

SUMMARY

28 The dust lamp is a simple qualitative tool for making fine particle clouds visible or enhancing the visibility of partially visible clouds. With a certain amount of experimentation observations can be recorded on still or video film. The dust lamp is a remarkably powerful tool in the right hands and can be used in a variety of ways to gain understanding of how work processes cause exposure or controls fail to prevent emissions. The very fact that the technique makes the invisible visible explains the impact it can have on employers and employees. One of the aims of this publication is to facilitate and encourage greater use of the dust lamp.

HEALTH AND SAFETY

29 The Electricity at Work Regulations 1989 apply at

all times, in particular Regulation 4 (2) which requires that all electrical appliances are adequately maintained. The assistance of a resident electrician or other competent person with suitable training should be sought at the workplace as and when required.

30 A high sensitivity residual current circuit breaker should be fitted to protect the operator from any possible electric shock during the use of mains operated dust lamps. The circuit breaker should be tested regularly and any fuses should be of the correct rating for the circuits they are intended to protect.

31 Many users prefer to use battery powered lamps. If a battery is to be charged, the manufacturers' instructions should be observed and the battery charged in a well ventilated area. It is important that the charger is switched off or disconnected from its power supply before the charge leads are firmly connected to the battery or disconnected.

32 The lamps should not be used in potentially flammable atmospheres (suitably certified safe lamps should be used - seek advice from specialists; see below). Lamps should be protected from water or other liquid splashes during operation, so as to avoid shattering because of the high temperatures they can attain. The lamps must be allowed to cool down before being packed and any dust on or within them must be removed so as to prevent any damage to the envelope of the halogen bulb while the lamp is in use.

33 Halogen lamps have a high operating temperature and therefore should only be used in accordance with manufacturers' instructions. The user must be aware of the risk of burns. Because of the brightness of the lamp during use, the observer should avoid looking directly at it and use a shield to protect the eyes from direct glare where appropriate.

ADVICE

34 Advice on this method may be obtained from the Aerosols Section, Health and Safety Laboratory, Health and Safety Executive, Broad Lane, Sheffield S3 7HQ (tel: 0114 2892000, fax: 0114 2892500 or e-mail aerosols@dust.demon.co.uk). Suggestions for improvement should also be sent to this address.

ACKNOWLEDGEMENT

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APPENDIX 1 LIGHTING TERMINOLOGY

The term *luminous* (or light) flux describes the quantity of emission from a source, measured in *lumens*. By definition, 1W of radiation at 555nm wavelength is equal to 682 lumens.

The intensity of illumination falling on a surface is termed *illuminance*, measured in *lux*; 1 lux is defined as an illuminance of 1 *lumen/m²*.

In the USA, 1 *lumen/ft²* is termed the *foot candle*, equal to 10.76 lux.

The luminous intensity of a source, in any direction, is measured in *candelas* (formerly *candlepower*); a uniform point source emitting 4π lumens of luminous flux, emits 1 candela in every direction.

The luminous efficiency of a lamp is measured in *lumens/W*.

APPENDIX 2 LIGHTING UNITS

Battery powered lamps

1 Battery powered lamps are convenient and easy to handle, making them particularly attractive for routine hygiene surveys or when visiting a number of installations where an appropriate mains voltage and outlet socket may not be available. Halogen bulbs give high light outputs from small, compact filaments and are often used. Touching the envelope of a halogen bulb can cause staining, reduced light output and may cause premature bulb failure. If finger contact occurs, the envelope should be cleaned with methylated spirits and dried before use.

2 By housing the battery in a portable case or attaching it to a waist belt, the operator has much improved freedom of movement. A 12V lead-acid battery of 7Ah nominal capacity should give an endurance of about 35 minutes with a 100w bulb or 60 minutes with a 55w bulb. A nickel-cadmium battery of similar voltage and nominal capacity may give appreciably greater endurance. Where much greater endurance is required, a large car battery can be used, or alternatively, a transformer (if mains power is available). The latter not only gives indefinite endurance but also enables a higher voltage to be used to offset the voltage drop in the lead to the lamp.

3 Battery powered lamps are available in a range of sizes and prices. A selection of these lamps has been tested, and test data for a number of lamps are given in Appendix 3, Table 1. The table may be used as an aid to lamp selection.

4 Most battery powered lamps produce a narrow beam of high intensity light. The limited area illuminated is not usually a problem as the lamp can be readily panned around the area under investigation. Once the area of interest has been identified the lamp can be secured on a stand.

Mains operated lamps

5 These are mostly divergent beam devices, providing even illumination over a wide area. Use of this type of lamp enables the entire extent of the particle cloud to be observed and photographed or recorded on video tape. However, even a 2Kw flood lamp is unlikely to give the level of illuminance of a good 100w spot lamp

Table 1 Test results on lamps

<i>Lamp</i>	<i>Reflector diameter (mm)</i>	<i>Bulb power (w)</i>	<i>Supply voltage (V)</i>	<i>Current (A)</i>	<i>Power (w)</i>	<i>Illuminance at 2m (lux)</i>	<i>Endurance (min)</i>
Tyndall Beam Dust Detection Lamp TB/100	176	100	12(10.5)	8.2	98	32 000	85
			10			18 000	
Clulite Clubman de Luxe	102	50	12	4.4	53	13 000	75
			10			7500	
Coleman 800 000 candle power NightSight	172	100	12(10.2)	6.4	77	47 000	no integral battery
		H1	10			29 000	
Cibié SuperOscar Long Range Driving Lamp	169	100	12(11.0)	6.5	78	58 000	no integral battery
		H1	10			34 000	
		55	12	4.2	50	38 000	
		H1	10			23 500	
Lectro-Science Nite Tracker	135	55 H3	6	8.2	49	18 000	18
			5			11 000	
		25 H3	6	4.15	25	12 500	54
			5			7500	
Centaur Cenlite	123	55 H3	6	7.5	45	18 000	18
			5			11 500	
Hedler Turbo-Lux (mains operated)	63	1250	240			3200	not applicable

Notes

1 The illuminances quoted were measured on the lamp centreline at a distance of 2 m. For the battery lamps the illuminance decreased rapidly with distance from the centreline, falling to low value at about 150 mm. Although the mains operated lamp (Hedler) gave a much lower central (peak) illuminance, at a distance of 1m from the centreline, the illuminance was still 1700 lux.

2 H1 and H3 (column 3) are manufacturers' terminology for the type of bulb. Bulb voltages, for 12V at the connecting lead plug, are shown in brackets in column 4. The data indicate the fall in illuminance with voltage and the importance of a low resistance connecting lead.

3 The data were obtained in tests on particular lamps; nominally identical lamps may give somewhat different values due to difference in bulbs, focusing, etc.

4 The two Nite Tracker lamps were similar, except for the power of the bulbs; complete with integral 6V 4Ah battery each lamp weighed 1.23 kg. The bulbs were standard H3 halogen bulbs but with a negative lead spot welded to the bulb by the lamp manufacturer. Changing the battery or the bulb may not be easy.

5 The Centaur lamp was similar in concept to the Nite Tracker but weighed 1.45 kg; a door in the lamp facilitated changing the battery more readily to extend 'on-site' use time of the lamp without recharging the battery.

6 A list of suppliers is given in Appendix 5.

7 It was not possible to test all commercially available lamps; lamps other than those shown in Table 1 may also be suitable as dust lamps.

and may necessitate careful screening and a darkened background to provide adequate contrast.

6 The lamps that have been used as dust lamps fall into two classes:

- (a) those designed for amateur video recording, and available from the larger photographic or video stores; and
- (b) lightweight professional lamps for location filming. These are available from professional equipment suppliers or hire companies.

Amateur video lamps

7 These are small lightweight units designed to be hand held, but can also be mounted on stands supplied by the manufacturer. The use of a lighting stand is recommended. These lamps use tungsten-halogen bulbs, commonly of 1000w rating, some types having the capability of using two bulbs, with switching so that one or both may be used as required. Some types of lamp are fitted with fan cooling. Under normal conditions of use, the air movement due to the cooling fan does not affect the shape of the particle cloud being studied. An example of these is the 1250w Hedler Turbo-lux lamp (see Appendix 5 for list of suppliers).

Professional lighting units

8 These may be slightly larger, and of more robust construction than the amateur lamps, but are still easily portable. Examples of this type of lamp are the 800w 'Redhead' and the 2Kw 'Blonde' unit. Alternative bulbs for use on 110 volt power supplies are available if required.

9 To provide some control of beam geometry 'barn doors' (hinged metal flaps attached to the front of the lamp) can be used to restrict the light to the required area only. The flaps get very hot after only a short time in use. The user must be aware of the risk of burns.

APPENDIX 3 TEST RESULTS ON LAMPS

1 The illuminance of a selection of battery powered lamps was measured over a range of constant supply voltages. The current was measured and, where possible, the bulb voltage.

2 For lamps supplied complete with batteries, the endurance was measured, ie the time for the battery voltage to fall from fully charged (12 or 6V battery) to 10 or 5V, respectively. Discharge to lower voltage is not recommended.

3 A summary of the results is given in Table 1, together with data for a mains operated lamp.

APPENDIX 4 STILL PHOTOGRAPHY AND VIDEO RECORDING OF PARTICLE CLOUDS

Still photography of particle clouds

Choice of film

Black and white films

1 Black and white film is used by many workers in this field because it produces better contrast than colour film, and excellent results can be obtained. It is particularly suitable when the pictures are to be used in a publication, where only black and white illustrations are usually required. In the absence of in-house processing and printing facilities, black and white pictures are more expensive than colour pictures. This is because the high volume processing of amateur snapshots is an industry totally geared to the processing of colour negative film. This means that for quality processing of black and white film one has to use a commercial processing laboratory that caters for the professional market. However, if one considers the total cost of a typical occupational hygiene survey, the additional cost of black and white prints will be small.

2 There is one black and white film which can be processed in colour negative film chemicals, and that is Ilford XP2. This gives a black and white negative which can be printed on black and white paper. The high street minilab will process XP2 to the negative stage, but will not usually attempt to print them.

Colour films

3 All commonly available colour negative films are designed to produce their best results when the subject is illuminated by daylight; subjects lit by fluorescent lighting will be reproduced with a slight overall green colour, and subdued red response. This is not usually a serious problem. Subjects lit by tungsten photographic lamps reproduce yellow, when photographed on daylight colour film. This means that a particle cloud, illuminated by any of the lamps described, will appear yellow in the picture, while background features are likely to show some excess green if lit by fluorescent tubes. The results are in fact quite acceptable in most cases.

4 If there is some special reason that makes the accurate reproduction of the colour essential, a colour temperature correction filter, dichroic blue, must be fitted to the lamp. The large amount of light lost by the use of the filter causes problems of loss of contrast, so the more powerful lamps are required.

5 In the case of both black and white, and colour negative films, materials rated at ISO 400 will be found to give good results under a wide variety of conditions. The high sensitivity of these materials permits the use of short exposures required for hand held shots, and the large exposure latitude of these materials is a great advantage for this type of work. With modern films, the grain structure of ISO 400 materials is not a problem at any reasonable degree of enlargement.

Colour slide films

6 It is a feature of all colour slide films that they have less exposure latitude than either colour or black and white negative films. Care is needed, therefore, to avoid exposure errors. Over-exposure, most likely to occur in the bright image of the cloud, causes detail in the cloud to be 'burnt out', and must be avoided.

7 All readily available colour slide films are balanced for daylight use, and the same considerations of colour temperature filtration apply, as in the case of colour negative films. Again, the use of high speed film, ISO 400 or more, will be found to be advantageous.

8 Professional colour slide films are available which are balanced for use with tungsten light, and these may be used in the photography of clouds in conditions where no daylight, or fluorescent lighting is used - as for example in a studio, or similar environment where all the lighting is under the control of the photographer.

9 Slides can be made from black and white negatives, black and white prints, and colour negatives. Special films are available for these applications, and these films must be used if satisfactory results are to be obtained. These services are provided by all good professional processing laboratories.

Exposure determination

10 The subject to be photographed will be a brightly lit particle cloud, against a dark background. Using the high light output of photographic lamps, the required contrast frequently arises naturally due to the relatively low level of ambient lighting in many workplaces. When high background brightness does result in serious loss of contrast, it may be necessary to erect a temporary dark background. The correct exposure for this kind of subject is that which reproduces all the gradations of brightness within the illuminated particle cloud, and at the same time produces a sharp image free from severe blurring due to the movement of and within the particle cloud. Fill-in flash may be useful to give a record of the general area, at the expense of contrast.

11 The method of choice for exposure determination for this type of subject is by the use of a spot exposure meter, from the camera position, measuring the brightness of the particle cloud at its brightest part, and using this measurement as a highlight reading to compute the exposure required. This method requires the availability of a spot exposure meter and a camera which allows the exposure to be set by the user.

12 The single lens reflex (SLR) camera, with through the lens (TTL) metering and manual exposure facility, will produce good results when used with care. The exposure can be measured when the illuminated dust cloud is made to fill the field of view, either by the use of a zoom lens, or by moving the camera close to the cloud to make the measurement. Having noted the indicated exposure, the subject is then framed in the viewfinder as is required in the final shot, either by moving the camera, or re-setting the

zoom lens. The exposure actually required is somewhat more than that indicated by the measuring process described, so exposures are actually made using twice, and four times that indicated, usually referred to as exposure compensation of +1 and +2 stops. Some cameras have controls calibrated in this way for this purpose. If the camera in use has no exposure compensation control, the required effect can be produced by down-rating the film speed. In the case of ISO 400 film, for example, setting the film speed at ISO 200 will give compensation of +1 stop, while +2 stops will be obtained by setting the film speed at ISO 100. Exposures indicated, when the film speed has been down-rated, are the actual exposures required. This compensation is required because the area measured is the highest brightness to be recorded, but the camera exposure meter will not be calibrated for this type of measurement.

13 It is as well to make a number of exposures of each shot, noting the degree of over-exposure given in each case so that the final pictures can be evaluated and the optimum exposure correction found. Use of printed numbers at the edge of field of view will be useful to identify the negatives.

Use of automatic exposure systems

14 Because of the nature of the image produced by the dust lamp (high brightness in the area of interest with much lower brightness in other areas of the frame), it can be difficult to produce good results using automatic exposure systems in dust cloud photography. Practical trials are the only reliable way of testing the suitability of any given automatic camera for this type of work. Those cameras which enable the user to exert some control over camera function, particularly any form of exposure compensation facility, either by the use of a calibrated compensation control or by setting reduced values for the film speed, are likely to be most useful.

15 The built-in flash needs to be switched off, or obscured by opaque black tape if the camera has no facility for stopping the flash firing. The use of high speed film is essential to avoid the automatic exposure system making over-long blurred exposures.

16 In the case of compact cameras it may be necessary to use ultra high speed films, such as Kodak Ektapress ISO1600, to obtain satisfactory results, due to the limited lens aperture of the compact camera.

17 The area of the frame covered by the brightly lit particle cloud will have a profound influence on the exposure given by the automatic exposure system. A bright area nearly filling the frame will be under exposed, while a small bright area in an otherwise dimly lit situation will be over exposed, with the loss of internal detail. The optimum size of the particle cloud image in the frame to give the best result may be found by experiment for a particular camera.

18 The use of the spot metering facility provided on some compact cameras is only useful for particle cloud photography if there is also an exposure compensation

facility as well to enable the required compensation of up to +2 stops to be made. Without the exposure compensation, the use of the spot meter will produce under-exposed pictures.

Video recording of particle clouds

19 The advent of the small video camcorder has made the dynamic study of particle emissions from industrial processes easier than ever before, providing instant playback of high quality colour images. It is not always easy to accurately judge the quality of the image from the small black and white image in the camera viewfinder. A small colour monitor connected to the video output of the camera will be found to be a worthwhile item in the kit. It will be found particularly useful when setting up camera and lighting, when the effect of small changes in lamp or camera position can be studied and the optimum set up for a particular situation established quickly.

20 The essential feature of the method is the presentation of a high brightness image of the particle cloud to the video camera without glare from the lamp. This is achieved by having the lamp as near as possible on the axis of the camera lens, but screened from the camera by any convenient part of the process machinery in shot, or by the body of the process operator after it has been established that no large movements are made by the operator during the normal working cycle.

21 There is rarely any advantage to be gained by the use of high camera angles, as the reflections from working surfaces and other equipment usually cause problems. When studying particle-producing processes taking place on a bench, for example, the best results are likely to be obtained by the use of a camera mounted at the level of the bench top, and the lamp at the opposite side, at, or slightly below, bench level.

22 Care should be taken to avoid close lamp positions which cause any discomfort and distraction to the process operator. The camera can be positioned some distance from the action, if space permits, the zoom lens being used to frame the shot as tightly as required. The advantages of the use of a distant camera position are that most zoom lenses produce their best images in the middle to long focus part of their range, the camera operator will not hamper the normal work of the process being studied, and will not distort the normal air movement around the work station. Contamination of the camera will also be reduced if close camera positions can be avoided.

23 It is essential that the particle cloud should be very much brighter than the background to achieve the contrast required to show the extent of the cloud, and any movements due to extraction systems, for example.

24 Using the high light output of photographic lamps, the required contrast frequently arises naturally due to the relatively low level of ambient lighting in many workplaces. When high background brightness does result in serious loss of contrast, it may be necessary to erect a temporary dark background.

25 If a dark background cannot be erected, or the operation being studied is too large to make a dark background of sufficient size a practical proposition, one can use a more powerful lamp, or two small ones side by side.

26 Prolonged or repeated exposure to a dusty environment may cause damage to the mechanism of the camera. The use of a rainshield or some other means will provide some protection, but care must be taken to avoid scratching the plastic window over the camera lens when removing deposited dust.

27 Alternatively the camera can be enclosed in a transparent polythene bag of sufficient size. The camera lens is positioned at the bottom of the bag, where a hole is cut to allow the lens to poke through. The lens needs to be fitted with a haze filter, and a screw in lens hood, to which the plastic bag is sealed using an elastic band, or adhesive tape.

28 A similar arrangement allows the viewfinder to protrude from the bag, and the normal opening of the bag gives access for battery changing, this opening being closed by the use of paper clips when not in use. The camera controls can easily be operated from outside the bag. If it is required to hand hold the camera, the hand grip retaining strap will need to be brought out through a slit in the plastic bag, which is then sealed with adhesive tape. This device is easy to make and, in use, limits the dust contamination to only the haze filter on the lens and the viewfinder eyepiece, from where the dust can be removed using a compressed gas canister

APPENDIX 5 SUPPLIERS

(NOTE: inclusion in the list should not be taken as a recommendation. Lamps may also be available from other suppliers.)

Suppliers of some of the battery powered lamps tested

TB/100
Tyndall Beam Dust Detection Lamp
A&G Marketing
Bridle House
Brent Pelham
Buntingford
Herts SG9 0HE
tel: 01279 777444

CLULITE CLUBMAN DELUXE LAMP
Cluson Engineering Ltd
Unit 6, Bedford Road
Petersfield
Hampshire GU32 3LJ
tel: 01730 274672
fax: 01730 260475

COLEMAN NIGHTSIGHT 800 000 CANDLEPOWER LAMP

Coleman UK Inc
Parish Wharf Estate
Harbour Road
Portishead
Bristol BS20 9GG
tel: 01275 845024
fax: 01275 849255

The Coleman Company Inc
250 North St Francis
Wichita
Kansas 67202
USA

CIBIE 'SUPER OSCAR' LONG RANGE DRIVING LAMP
The lamp is supplied for motor car use and not in the form of a hand-held dust lamp.

LECTRO SCIENCE 'NITE TRACKER' LAMP
Target Sports
486 Halliwell Road
Bolton
Lancs BL1 8AN
tel: 01204 496008

Lectro Science Inc
6410 West Ridge Road
Eire
PA 16506
USA

CENTAUR 'CENLITE' LAMP
Tensor Marketing Ltd
Lingfield Way,
Yarm Road Industrial Estate
Darlington DL1 4XX
tel: 01325 469181
fax: 01325 381386

Amateur video lamps (mains operated)

CYGNET PHOTOGRAPHIC
PO Box 306
High Wycombe
Bucks HP13 6EF
tel: 01494 436783
fax: 01494 436108

Suppliers of 'REFLECTA' lamps made in Germany, 1000 and 2000W units; also a 24 volt 250W battery operated hand lamp.

LASTOLITE LTD
8 Vulcan Court
Hermitage Industrial Estate
Coalville
Leicestershire LE67 3FW
tel: 01530 813381
fax: 01530 510156

Suppliers of HEDLER lamps, made in Germany. Mains operated lamps up to 2500W.

Professional lighting equipment suppliers

STRAND LIGHTING LTD
Grant Way
Isleworth
Middlesex TW7 5QD
tel: 0181 560 3171
fax: 0181 568 2103

Suppliers of lighting equipment to the film and television industry. The 800w 'REDHEAD', and the 2000w 'BLONDE' portable lamps from this supplier have been used for the photography and video recording of particle clouds. A 24 volt 250w battery operated hand lamp is also available.

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