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Real-time measurement of dust in the workplace using Video Exposure Monitoring: farming to pharmaceuticals

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Abstract. Real-time, photometric, portable dust monitors have been employed for video exposure monitoring (VEM) to measure and highlight dust levels generated by work activities, illustrate dust control techniques, and demonstrate good practice. Two workplaces, presenting different challenges for measurement, were used to illustrate the capabilities of VEM: (a) poultry farming activities and (b) powder transfer operations in a pharmaceutical company. For the poultry farm work, the real-time monitors were calibrated with respect to the respirable and inhalable dust concentrations using cyclone and IOM reference samplers respectively. Different rankings of exposure for typical activities were found on the small farm studied here compared to previous exposure measurements at larger poultry farms: these were mainly attributed to the different scales of operation. Large variations in the ratios of respirable, inhalable and real-time monitor TWA concentrations of poultry farm dust for various activities were found. This has implications for the calibration of light-scattering dust monitors with respect to inhalable dust concentration. In the pharmaceutical application, the effectiveness of a curtain barrier for dust control when dispensing powder in a downflow booth was rapidly demonstrated.

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1. Introduction

Real-time dust monitors are employed by occupational hygienists for tasks such as walk-through surveys, background sampling, site dust measurements, assessment of the effectiveness of dust control systems and measurement of indoor air quality [1]. They also form part of Video Exposure Monitoring (VEM), the combination of video and synchronized real-time exposure data [2], to illustrate dust control techniques and highlight dust levels generated by work activities. VEM can also play an important role in exposure risk communication by demonstrating good practice.

In VEM, dust monitors are used qualitatively and semi-quantitatively. For qualitative measurements, the relative effect of changing controls on exposure is measured. For quantitative measurements, the real-time monitors must be calibrated with respect to the respirable and, if required, inhalable dust concentrations [3,4,5]. Quantitative data can place the exposure in context by reference to control and exposure limits, although the exposure data will only be semi-quantitative because of uncertainties due to sampling and, particularly for aerosols, calibration associated mainly with the real-time instrument response which is a function of particle characteristics, e.g. size distribution and other scattering properties [6].

Two workplace examples, at opposite ends of the spectrum in relation to the working environment, are described here to illustrate the role of VEM with real-time dust monitors for the measurement of
respirable dust concentration and, by inference, inhalable dust concentration, arising from (a) poultry farming activities and (b) powder transfer operations in a pharmaceutical company. They present different challenges for measurement, and particularly for VEM: low light, dusty farming conditions with a highly mobile workforce contrasting with ultra-clean pharmaceutical operations where dust levels are typically very low.

2. Poultry farming

2.1. Background

Recent research into the incidence of ill health in agriculture in Great Britain [7] concluded that there is very little current information available on the incidence or prevalence of occupational ill health in the agricultural industry. However the data indicated that respiratory disease generally and upper respiratory tract infection symptoms in particular were high, and reported by just under 40% of farm workers exposed to organic dusts. The prevalence of chronic bronchitis amongst agricultural workers is reported to be 6.5%. The agricultural workforce totals about 400,000 with the majority exposed to organic dust during the course of their work. The figures would therefore suggest that up to approximately 162,000 workers could be suffering from respiratory symptoms at any one time and 27,000 suffering from bronchitis.

A specific group of farm workers, those in poultry farming, can be exposed to significant amounts of dust produced from poultry dander, feathers and dry wastes during their work activities. While other studies [8] have focused on identifying the scale of the risk through more comprehensive exposure measurements, in this work VEM was used to provide information on the hazard and its control which could form part of a package of electronic training material. Such risk management guidance for managers and safety representatives of large poultry farms and trade associations can then be disseminated in a suitable form to employees and contract workers.

2.2. Poultry farm activities

Various tasks in a commercial poultry farm, identified from previous work [8], were targeted for action as part of the investigation. The cycle of poultry rearing can be simplified to:

- Laying new litter;
- Repopulation (introducing new chicks);
- Growing the birds to adult size;
- Depopulating (removing the birds);
- Litter removal; and
- Cleaning and disinfecting.

All the above activities, apart from the growing phase, were identified as producing significant dust levels and suitable for VEM. At the farm, these activities can be described as follows:

- Laying new litter: The central part of the Rearing Shed is fenced off and bags of white wood shavings are opened and spread over the concrete floor using forks.
- Repopulation: Recently hatched chicks are introduced into the Rearing Shed under subdued lighting (the chicks are attracted to and congregate under hanging red lights, hanging gas burners heat the same areas).
- Depopulation: Removal of all of the young adult birds. Batches of a few hundred birds are herded to one end of the Rearing Shed, corralled and collected by poultry catchers, inoculated, then removed to cages on a lorry to be transported away.
- Litter Removal: Once the shed is emptied of birds, the used litter is removed. A ‘Bobcat’ type vehicle (a small, quick, manoeuvrable loader) is used to shovel up the litter into a pile at one end of the shed, then load it into a tractor/trailer. Shovelling and brushing by hand is needed.
around the edges of the shed and the supporting pillars. A mechanical rotating brush attached to the ‘Bobcat’ shovel enables the floor to be swept clean.

- Cleaning and disinfecting: A power-washer with hand ‘gun’ is used to wash everything from the top down (roof, roof mounted ventilation, walls, bird feeder containers and floor). Following washing, a disinfectant is mixed with the water and the same equipment (with a long lance replacing the hand ‘gun’) and technique is used to disinfect all of the surfaces.

2.3. Materials and methods

The VEM technique (Exposure Level Visualization - ‘ELVis’) involves real-time, personal monitoring while simultaneously videoing the worker and combining the exposure profile with the video image on a computer; it has been described previously [2]. Radio telemetry was not used in this case for transmission of the real-time monitor data in order to simplify the kit and minimize the weight carried by the subject. The data was simply stored on the real-time monitor’s datalogger. The real-time monitor (1 s logging period) and the camera clocks were synchronized with the PC clock and a digital radio-controlled clock respectively. Then the real-time monitor’s clock was filmed alongside the radio-controlled clock to synchronize them to ‘real’ time. The video and data files were joined to display on one screen as illustrated in figure 1. Here, one subject was monitored and carried the monitor in a harness with gravimetric samplers located immediately adjacent to the monitor.

![Figure 1. Example of the VEM screen display showing spreading of new litter over the concrete floor of the rearing shed. The complete exposure profile is shown at the bottom and a detailed window, either side of the moveable cursor, is displayed at the upper right of the screen. The real-time monitor is calibrated with respect to inhalable dust.](image-url)
A camcorder (Sony Handycam) was used to video activities. Although it was able to work in low light, depopulation and repopulation occurred in very low light levels and it was not possible to use natural light. Satisfactory footage was obtained by illuminating the subjects with infra-red from portable infra-red lights (Sony Battery IR Light) situated next to each camera, and by setting the cameras to ‘night-shot’. Reflective tape was affixed to the real-time monitor and the harness to further improve identification of the subject and instrument being filmed.

The real-time monitors (Thermo Personal DataRAMs - PDR) were located in a harness attachment sampling in the breathing zone towards the top of the chest (the poultry catchers bent forward a lot during their activities). Up to three real-time monitors were used during a visit: two subjects were monitored, each with a real-time monitor and gravimetric samplers; and a further real-time monitor with adjacent gravimetric samplers recorded the background dust level.

Personal gravimetric samplers (IOM head and cyclone samplers for inhalable and respirable fractions respectively) were also employed to obtain exposure data and retrospectively calibrate the real-time monitors. The samplers were operated according to the HSE reference method MDHS14/3 [9]. Each time-series of real-time monitor data was compared with its corresponding gravimetric samplers and the relevant calibration factors applied.

2.4. Results and Discussion

2.4.1. Inhalable dust concentrations

The exposure levels to inhalable dust determined from gravimetric measurements using the IOM head for three activities are shown in table 1. The workers were monitored for periods between 0.5 – 2 hr to determine exposure concentrations for the activities.

| Activity                  | n | Maximum (mg m⁻³) | Median (mg m⁻³) | Minimum (mg m⁻³) |
|---------------------------|---|------------------|-----------------|------------------|
| Depopulation              | 3 | 39.4             | 23.4            | 22.8             |
| Repopulation              | 2 | 4.4              | 4.4             | 4.3              |
| Litter/manure removal     | 3 | 7.9              | 3.0             | 0.9              |

Three other activities (routine cleaning, laying new litter and cleaning/disinfecting) were also measured but only one measurement was taken for each (this data was used in section 2.4.2).

The ranking of the activities in table 1 (with median values of exposure in mg m⁻³ in parentheses), albeit based on limited data, in terms of the inhalable dust exposure is:

depopulation (23.4) >> repopulation (4.4) ~ litter/manure removal (3.0).

Previous work [8] at another poultry farm reported different exposure rankings of activities (median values in mg m⁻³):

litter/manure removal (35.4) > repopulation (5.5) ~ depopulation (4.6).

There are various differences between the farm studied here and those used for the earlier work. In this work there were fewer data collected (11 samples compared to 60), the farm was a much smaller enterprise, processes were less mechanised and there were possibly less time constraints.

Larger farms require more materials and there is more product and waste to be removed. During litter removal at larger farms there may be two or more vehicles collecting manure compared with the one vehicle used in this study which would confer some control over where the dust is generated. Also, collecting damp with dry manure can reduce dust, as was performed at the farm studied here.
Petrol-engined blowers used at larger farms to clear remaining dust around stanchions can raise clouds of dust. At this farm, new litter was manually broken away from an opened bag, then distributed using a pitchfork. Laying new litter at larger farms is, however, largely mechanised and can include using a ‘hay-turner’ attachment to spread the litter.

Depopulation resulted in high inhalable dust concentrations in this study but fairly low concentrations at the other larger farms. Different types of bird feathers (eg from chickens, turkeys and ducks) may result in differing dust levels, as well as differences between the bird catchers’ technique (e.g. farm employees or contracted staff may operate differently). The use of powered and natural ventilation at larger farms tends to prevent accumulation of dust inside the shed. In other respects both depopulation and repopulation were carried out similarly at this and larger farms.

2.4.2. Comparison of monitors
The use of inhalable and respirable samplers and the PDR at the farm allowed comparisons to be made between the measurements; the results are shown in table 2.

| Activity         | n | Gravimetric inhalable/Gravimetric respirable | Gravimetric inhalable/PDR | Gravimetric respirable/PDR |
|------------------|---|---------------------------------------------|---------------------------|---------------------------|
| Depopulation     | 3 | 7.6 (1.1)                                   | 6.6 (1.5)                 | 0.9 (0.2)                 |
| Routine cleaning | 1 | 4.8                                         | 4.6                       | 1.0                       |
| Repopulation     | 2 | 21.8 (0.4)                                  | 18.4 (5.1)                | 0.9 (0.2)                 |
| Laying new litter| 1 | 12.1                                        | 26.1                      | 2.2                       |
| Litter removal   | 3 | 5.2 (2.1)                                   | 9.7 (0.9)                 | 2.1 (0.8)                 |
| Clean/Disinfect  | 1 | 2.9                                         | 14.4                      | 5.1                       |

There is a wide variation in gravimetric inhalable/gravimetric respirable ratio for the activities - a factor of approximately 8 between the maximum and minimum. The dust particle size profiles are therefore different for the activities measured, which necessitates the application of separate calibration (response) factors for each activity to each PDR. Repopulation and laying litter are the two activities which generate the greatest proportion of inhalable dust. The gravimetric inhalable/PDR ratios do not follow the same ranking as the gravimetric inhalable/gravimetric respirable ratios, although the statistics do not allow detailed analysis. The range of gravimetric respirable/PDR ratios is not as great as that for gravimetric inhalable/PDR (especially if the cleaning/disinfecting result is considered anomalous, ie the low gravimetric inhalable/gravimetric respirable ratio and the high gravimetric respirable/PDR ratio). Nevertheless, the respirable dust from the different activities still requires different PDR calibration factors, as is found for most dusts other than ‘standard’ silica (eg Arizona road dust) used to factory calibrate the instruments [4,5].

The accuracy of real-time dust monitors for workplace (and environmental) monitoring relies on the validity of the calibration, which is typically based on gravimetric samplers. Photometric (light scattering) dust monitors, which are commonly used for workplace air monitoring, including the PDR used in this study, have a response as a function of particle size quite similar to the respirable sampling convention and therefore to the standard cyclone sampler [6]. The real-time monitor can, however, only have an average response factor applied over the duration of the activity. Consequently, if there are any variations in the dust particle characteristics (size distribution, refractive index etc) over this period, then at any given instant there may be significant deviation from the average value. This situation could be exacerbated when the photometric (‘quasi-respirable’) real-time monitor is calibrated with respect to an inhalable reference derived from a gravimetric sampler. Here the respective particle size profiles of the monitors are very different which increases the chance of wider
deviations of the real-time monitor values from the ‘true’ values. For example, generated particles that are greater than 10 µm will be captured by the reference sampler, but not measured by the real-time monitor. Therefore, as the particle size increases above 10 µm the real-time monitor will increasingly underestimate the inhalable concentration.

The use of a portable TEOM [10] should help in deriving more accurate response factors for a real-time monitor. This is because its response is not subject to uncertainties in measurement caused by changes in particle size, colour, or shape and responds purely as a function of mass of dust sampled. The TEOM’s response time can be quite long for VEM depending on the concentration of aerosol being measured, typically tens of seconds compared to seconds for photometers including the PDR. It is, however, much shorter than the gravimetric sampling period (of the order of an hour). The use of the TEOM should thus be able to confirm that the response factor of the photometer monitor remains essentially constant over the measurement period or, if not, provide more accurate values for the periods where the response factor is significantly different. Further work is necessary to validate this approach for various types of dust and workplace activity.

2.4.3. VEM output
The results from the VEM were processed (using Adobe Flash media tools) for the occupational hygienists as shown in figure 2. The activities were highlighted on the chart and the corresponding exposure and video are viewed by moving the cursor (highlighted in figure 2 by arrow) over the chart and exposure profile. This information is suitable for adapting and incorporating into guidance such as Toolbox talks [11] which are short talks focused around specific health and safety issues and allow workers, safety professionals and managers to explore risks and develop strategies for dealing with them. It is the intention that Toolbox talks can help to demystify health and safety and to show the relevance of specific topics to particular jobs.

![Figure 2. VEM depicting poultry farming activities (moveable cursor highlighted by arrow)](image)

3. Pharmaceutical powder transfer operations
3.1. Background
In the pharmaceutical industry, there is potential for exposure to active agents during powder transfer operations. Various control measures can be adopted to minimise exposure risk, in particular, the use of a curtain barrier when dispensing in a downflow booth. VEM, using a non-pharmaceutically active powder (xanthan gum), was undertaken to show how improved control further reduced personal
exposure by monitoring with and without a curtain barrier. Moreover, this offered the opportunity for disseminating training information using the ‘ELVis’ software.

3.2. Materials and methods
The ultraclean environment required that all equipment be checked and wiped, and operators wore coveralls. Also, note that for clean applications such as this, separate instruments are used from those for ‘dirty’ applications as described in section 2. Both wireless instruments (radio telemetry - Satel Radiomodems) and wireless video (transmitter/receiver – Astrotel Communication Corp.) were employed. A dust lamp (HSE Tyndall beam dust lamp) was used to enhance the video footage by showing the suspended dust particles. Two cameras were employed for wide angle and close-up views. The real-time monitor (Casella Microdust) was chosen to allow periodic checks of the span as well as zero during the measurement period. A harness was adapted to fit the sampling probe (25 cm long) in the breathing zone of the worker. The monitor (based on the photometric light scattering principle) was factory calibrated with respect to total suspended particulate (TSP), which approximates to the inhalable fraction [4].

The activity to be monitored was simple and used as a test case for the technique. Powder was transferred in a downdraft booth from one receptacle to an adjacent one using a scoop (figure 3), when full the contents were bagged and transferred back and the process repeated. Monitoring was performed before and after installation of a curtain barrier - a clear plastic sheet fixed between opposite walls of the booth with two holes cut centrally for insertion of the operator’s arms. The operator carried out the same activities but behind the barrier.

![Figure 3. Powder transfer operations using a scoop](image)

3.3. Results and Discussion
Task analysis was undertaken, identifying three activities: scooping, emptying the bag and bulk transfer of the contents, and the results were analysed and displayed as in figure 4.
Figure 4. Task analysis for powder transfer operations derived from VEM using a Microdust dust monitor.

These data were then summarized and displayed as bar graphs as shown in figure 5. Emptying the bag resulted in the highest exposure while scooping and bulk transfer exposures were roughly similar.

Figure 5. Comparison of exposure (mg m\(^{-3}\) TSP) with and without the curtain barrier for the three activities.

The beneficial effect of the simple curtain barrier can be clearly seen and was demonstrated in a very short time – the exercise took a half-day with the actual measurement taking less than one hour.
4. Conclusions

Two contrasting examples of workplace environment have been used to illustrate how VEM with real-time dust monitors, calibrated with reference samplers, can transform task analysis data into useful information on the hazards of dust (poultry waste and pharmaceutical powder) and its control. The different environments placed different demands on the VEM measurement equipment, eg low light levels and very mobile workers at the poultry farm and the ultra-clean, sterile environment at the pharmaceutical production facility.

The calibration of the real-time monitors, which are essentially responsive to the respirable fraction, such that they read in inhalable dust concentration has been highlighted as an area where further work may be needed to (a) test the validity of such calibration over the measurement period for various dusts and activities and (b) develop real-time, portable inhalable monitors, possibly based on the TEOM.

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