Respirable dust control in a scale-model horse stable using filtration and mechanical ventilation

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Dunlea, A.P. and Dodd, V.A. 1996. Respirable dust control in a scale-model horse stable using filtration and mechanical ventilation. Can. Agric. Eng. 38:215-221. Respirable dust levels were studied using a model stable in which mechanical ventilation, filtration, and designed air flow were used for respirable dust control. Various inlet ventilation and exhaust fan operating levels were tested. Different bedding materials and stable door configurations also were tested. The model was adapted to include an inlet distribution ceiling attic to diffuse the inlet air in a downward direction throughout the stable. The inlet air was delivered through a series of filters by an axial inlet fan to the distribution attic. Two exhaust fans were located at the side walls of the chamber near the floor. Tests showed that the respirable dust levels within the stable remained low (<10 counts/mL) although the respirable dust levels at the incoming inlet ventilation position varied widely. Bedding of straw, shredded paper, and wood shavings was evaluated by agitating the individual bedding material and recording the level of respirable dust at 3 min periods. The control system reduced to low levels (<10 counts/mL) within 12 min for both straw bedding and shredded paper. Wood shavings produced little respirable dust.

Des expériences ont été réalisées afin d'analyser le niveau de poussière respirable dans un étable modèle dans laquelle étaient installés un système de ventilation mécanique, un système de filtration et un système de circulation d'air créé spécialement pour l'expérience. Plusieurs systèmes de ventilation -admission et échappement d'air- ont été testés à des niveaux opérationnels différents. Des matériaux tityres ainsi que plusieurs formes de portes d'étable ont été également vérifiés. L'étable modèle a été adaptée pour inclure un plafond de grenier avec un système de distribution d'air permettant de diffuser l'air d'admission vers le bas à travers l'étable. L'air d'admission a ainsi été transporté à travers une série de filtres grâce à un ventilateur axial qui a inspiré l'air pour l'emmener jusqu'au grenier de distribution. Deux ventilateurs d'échappement ont été postillonnés sur les murs latéraux le long de la chambre à côté du sol. Les expériences ont montré que le niveau de poussière respirable restant à l'intérieur de l'étable était resté bas (<10 mL/chronométrage) même si le niveau de poussière respirable variait largement au niveau du ventilateur d'admission d'air. Les litières de paille, de papier déchiqueté et de copeaux de bois ont été évaluées en agitant le matériel de litière individuellement et en enregistrant le niveau de poussière respirable par intervalle de trois minutes. Pour la litière de paille et de papier déchiqueté, le système de vérification a réduit le taux de poussière à des bas niveaux (<10 mL/chronométrage) en moins de 12 minutes. Quant aux copeaux de bois, ils ont produit très peu de poussière pouvant entrer dans le système respiratoire.

INTRODUCTION

The problems of dust associated with the stabling of horses has been discussed in a previous paper, Dunlea and Dodd (1995), and the necessity to achieve a clean environment within the horse’s stable has also been advocated by other authors.

Much has been written concerning the threshold limit values of dust for humans with particular reference to 'farmers’ lung'. A figure of 10 mg/m³ as the threshold limit value for total dust has been cited by many authors including ACGIH (1986), Wathes et al. (1983), Crichlow et al. (1980), and Woods et al. (1993). A figure of 5 mg/m³ of respirable dust was referenced as a threshold limit value (TLV) by Maghirang et al. (1991). Little research has been conducted on the threshold limit value for horses. McPherson and Thomson (1983) suggested that “a retrospective diagnosis may be made by assessing a horse’s response to a controlled environment”. Webster et al. (1987) stated that “McPherson et al. (1979) were able to induce acute increases in intrathoracic pressure changes during respiration (indicative of Chronic Obstructive Pulmonary Disease (COPD)) by exposing sensitive horses to 12 mg of A. fumigatus or M. faeni aerosol over 20 min. Assuming as a first approximation that an aspergillus spore weighs 3.6 x 10⁻⁸ mg and that a quarter of the spores generated by McPherson et al. (1979) reached the lower respiratory tract, their horses were being challenged by 0.15 mg or 4 x 10⁶ particles/min. This corresponds to 33 counts/cm³ air and may, pending better evidence, be taken as a somewhat arbitrary threshold limit value for particles in stable air”. This tentative threshold limit value proposed by Webster et al. (1987) should be interpreted taking account of the assumption that 28% (by weight) of spores in the intake air reached the lower respiratory tract, an inhalation rate of approximately 90 L/min and a unit density of spores of 3.6 x 10⁻⁸ mg/spore. Clarke (1993) also commented on the work of McPherson et al. (1979) stating that the exposures of experimental animals to the spores, although capable of inducing disease were not threshold limit values.

“Furthermore, the TLV of stable dust which will induce COPD in an asymptomatic horse should be seen as a value separate from the TLV for stable dust which will sensitise or establish an allergy in a horse to stable dust” (Clarke 1993). Clarke (1993) further stated that it was not possible to relate
the TLV for humans to that for horses as the stable horse may be exposed to the challenge of dust for 22 - 23 hours per day, seven days a week, a view also shared by Woods et al. (1993). The tentative TLV of 33 counts/mL proposed by Webster et al. (1987) is to date the only figure suggested for horses.

The control of dust within the horse’s stable by means of natural ventilation has been advocated by Webster et al. (1987) while Woods et al. (1993) discussed the advantages of dust clearance using mechanical ventilation. Little consideration has been given to the quality of the outside incoming air with respect to its dust concentration. Webster et al. (1987) assumed that the concentration of respirable particles in incoming air was 5 counts/mL. Little consideration was also given to the airflow pathway by which ventilated dust left the horse’s stable. Natural ventilation allows the dusty ventilated air to pass the breathing zone of the horse. Woods et al. (1993) made little reference to the airflow pattern associated with the mechanical ventilation system, however much emphasis was placed on the breathing zone of the horse with regard to the inhalation of respirable dust.

A model stable (approximately one half scale to the normal stable size) allowed testing of a dust control system using different bedding material as sources of dust within the chamber. The dust control system incorporated a designed airflow pattern by means of mechanical ventilation and inlet air filtration. The use of inlet air filtration was considered a necessary part of the dust control system as outside incoming air may contain high levels of respirable dust, Dunlea and Dodd (1995).

Conventional thinking regarding dust control for horse stables has been mainly reliant on natural ventilation; however, the results presented by Dunlea and Dodd (1995) showed that the outside incoming air may contain levels of respirable dust far in excess of a desired internal horse stable level. The effect of conventional bedding materials on the dust level within the stable using this integrated dust control system was tested as most conventional bedding materials produce dust. The concept of combining inlet air filtration with a designed air flow pattern to ensure that the normal breathing zone of the horse will be supplied with filtered air and that any dust produced from the bedding material will be ventilated away from the breathing zone of the horse required investigation. The objective of this paper was to test the ability of this integrated dust control system to effect an internal stable environment of low dust levels and to consider the effects of inlet ventilation rate, outlet fan activity, bedding material, and stable door configuration on such dust levels. This paper reports results of this dust control system using air filtration and mechanical ventilation.

MATERIALS AND METHODS

Model stable set up
Figure 1 shows the outline of the model stable together with the dust control system. The chamber measured 4200 mm long, 2450 mm wide, 1800 mm to the eaves and 2080 mm to the apex from the floor. Two sides of the chamber were constructed of 19 mm marine plywood and two were constructed of 7 mm plexiglas. The structure was supported externally by 95 mm x 70 mm wood beams. A door was located at one end wall and measured 720 mm x 1480 mm. The door could be adjusted to three positions: open, half open, and closed.

The sampling point within the model stable was located 1.0 m above the floor and in the centre of the model chamber floor (Fig. 2). The incoming air was monitored by placing a sampling tube at the inlet position upstream of the inlet fan and filters. Figure 2 shows the sampling positions within the chamber.

Fig. 1. Model stable (chamber) and dust control system.
Instrumentation

The respirable dust levels within and outside the model stable were monitored using the same system as described by Dunlea and Dodd (1995) which included a particle counter (Hiac Royco Model 1200 Pacific Scientific, Menlo Park, CA). This instrument enabled detection of particles with an aerodynamic diameter of greater than 0.5 μm. The particle counter model was selected to cope with the large volume of dust in the horse stable environment. A flow rate of 2.8 L/min was used. The low flow rate allowed the counting of large particle numbers and avoided the possible problem of multiple imaging. The counter was controlled by a mainframe (Hiac Royco Model 4150 Pacific Scientific, Menlo Park, CA). The mainframe also controlled a scanner (Hiac Royco Model 160 Pacific Scientific, Menlo Park, CA) which allowed air samples to flow through a manifold (Hiac Royco Model 161, Pacific Scientific, Menlo Park, CA). Up to ten different sample ports were available using the manifold and the scanner. Data were recorded on a data logger (Model Tracker 1350 Data Track Technology Ltd., New Milton, Hampshire, UK). Air samples were obtained using 12 mm plasticized vinyl tubing with a high purity inert internal liner of Hytrel polyester.

Air was sampled for 1 min at each sampling point with another minute of purging of the sampling tube prior to the recording of the data. The sampling of long duration tests was done every hour while short duration tests were done every 3 min.

Method

A perforated ceiling tent was used to diffuse the incoming filtered air throughout the chamber. The tent was sealed to form a triangular cross-section with a 178 mm diameter inlet at one of the eaves. The other eave side of the ceiling tent was sealed. The underside of the tent was perforated with 14 mm diameter holes evenly spaced to form a lattice of holes 300 mm by 150 mm. The tent was suspended by its ridge from the underside of the apex of the chamber and the perimeter of the tent was attached to the sides by means of hooks secured to the sides of the chamber. These hooks ensured that the underside of the tent could be stretched to form an even surface as a perforated ceiling. Galvanized wire (2 mm diameter) was stretched across the ceiling every 500 mm to ensure that the ceiling did not sag. Figures 1, 2, and 3 show the position of the perforated ceiling tent.

The incoming air was filtered by a series of filters using a bag filter model HI FLO 95 and secondly by an absolute filter model ABSOLUTE (both by Sofiltra-Camfil, Clonshaugh Industrial Estate, Dublin, Ireland) and were housed in type FC-HF and FC-A housing units, respectively (Sofiltra-Camfil, Clonshaugh Industrial Estate, Dublin, Ireland). The filter housing was connected to the diffusion tent by a 178 mm diameter flexible duct.

The inlet air was forced through both filters by means of a 510 mm diameter, 0.58 kW axial fan (Model E500/4 New Euroseries Zeihl Abegg, Roof Units Group, Dudley, West Midlands, UK). This fan unit was controlled by a variable speed controller (Model SPC 5050, Dan Chambers Ventilation, Glassnevin, Dublin, Ireland.) The location of this fan is shown in Fig. 1.

Two 260 mm diameter 39 W axial fans (Model E200/4, New Euroseries Zeihl Abegg, Roof Units Group, Dudley,
West Midlands, UK) were used for exhaust air. These fans were controlled by a step controller (Model RE26, Zeihl Abegg, Roof Units Group, Dudley, West Midlands, UK). The fans were located approximately 500 mm above the floor of the unit midway along the front and rear sides of the chamber (Fig. 1).

The sizing of the inlet and outlet fans and the filters was selected to enable full scale testing at a later stage that requires a minimum ventilation of 2 air changes/h and a maximum of 40 air changes/h. The maximum exit velocity at the openings in the perforated ceiling was 5.0 m/s, which would be considered high. However, this high exit velocity was quite low when monitored 0.3 m from the perforated ceiling openings using a hot-wire anemometer (Solomat MPM 500e, Neotronics N.A., Norwalk, CT).

The volume of the model stable was 18.5 m$^3$ and the varied parameters tested are shown in Table I.

Different bedding materials, straw, shredded paper (Fig. 2), and wood shavings (Fig. 3) were tested over periods of time. Zero bedding condition was also tested over extended periods of time. The chamber door was operated in different configurations, half closed or fully closed.

**RESULTS AND DISCUSSION**

The effect of zero bedding on dust level is shown in Fig. 4. The inlet air and the chamber were sampled every hour for 23 h at the stated operating conditions of 1.12 m$^3$/s with the outlet fans off and the chamber door half closed. The outside

![Fig. 4. Respirable dust levels in chamber with zero bedding, inlet ventilation rate of 1.12 m$^3$/s, outlet fans off, and door half closed using outside air and inside air.](image-url)

| Table I: Summary of parameters tested in the model stable |
|---------------------------------|---------------------------------|-----------------|-----------------|
| Inlet ventilation rates         | Outlet fan activity             |
| m$^3$/s                        | Air changes/h                   | Off/On/On Fast  |
| 0.67                           | 130                             |                 |
| 1.12                           | 217                             |                 |
| 1.67                           | 326                             |                 |
air quality varied throughout this 23 hour test whereas the level of respirable dust within the chamber remained at less than 5 counts/mL throughout the test period.

A similar result was recorded in Fig. 5 using a higher ventilation rate of 1.67 m³/s and the chamber door fully closed. Figure 5 shows results of the system operating at 1.67 m³/s with the outlet fans off. Almost negligible respirable dust levels were recorded within the chamber throughout the test period of 24 h even though the outside air recorded variable levels of respirable dust with a maximum of approximately 48 counts/mL.

Operating the outlet fans showed little effect on the level of respirable dust within the chamber (< 5 counts/mL) with the chamber door half closed and a ventilation rate of 1.67 m³/s as shown in Fig. 6. Under these conditions, levels of outside respirable dust levels were considerably lower than the previous tests and, after approximately 12 h, the level of respirable dust outside the chamber was very similar to the level of dust within the chamber.

The emphasis must be placed on the consistent low level of respirable dust inside the chamber rather than the variable level of respirable dust in the outside air as it is the level of respirable dust within the stable that will effect the health of the horse.

Figure 7 shows the effect of generating a high level of respirable dust within the chamber by agitating the straw bedding material violently. This action simulated the mucking out process in a stable. The ventilation systems were activated as of time zero and had a marked effect on the level of respirable dust within the chamber. The high initial level of respirable dust was reduced to a low level within approximately 9 min when the inlet ventilation was 1.12 m³/s and the door half closed. Once a steady state was achieved within the chamber, there appeared to be little difference between the three different operational parameters. The initial respirable dust levels also varied between each other as this may have been due to the level of agitation of the straw bedding associated with each test.

The use of a higher inlet ventilation rate of 1.67 m³/s, with the chamber door fully closed (Fig. 8) gave results similar to those reported previously. Similarly a steady state of low respirable dust level was achieved after approximately 9 min post agitation of the straw bedding. Again there was very little difference between the the outlet fans activities and their effect on the level of respirable dust in the chamber. The magnitude of the initial respirable dust level at agitation was different for all tests in both Figs. 7 and 8, as levels of almost 180 counts/mL were recorded in Fig. 8.

The use of shredded paper as a form of bedding for horses has become popular in recent years. High levels of respirable dust were generated during its agitation. Figure 9 shows the effect of operating the system at an inlet ventilation rate of 1.67 m³/s with the door half closed and the outlet fans on. A maximum level of respirable dust of approximately 240 counts/mL was recorded during agitation of the shredded paper bedding. Negligible levels of respirable dust were re-
Fig. 8. Respirable dust levels in chamber with straw bedding, inlet ventilation rate of 1.67 m$^3$/s, and door fully closed with outlet fans off, on, and on fast.

Fig. 9. Respirable dust levels in chamber with shredded paper bedding, inlet ventilation rate of 1.67 m$^3$/s, door half closed, and outlet fans on.

Fig. 10. Respirable dust levels in chamber with shredded paper bedding, inlet ventilation rate of 1.12 m$^3$/s, door fully closed, and outlet fans off.

Fig. 11. Respirable dust levels in chamber with wood shavings bedding, inlet ventilation rate of 1.12 m$^3$/s, door half closed, and outlet fans on.

during agitation of the wood shavings. A maximum level of approximately 28 counts/mL was recorded in Fig. 12 during agitation of the bedding material. Lower levels of respirable dust were recorded some 12 min after agitation of the bedding material in both figures.

These results show an encouraging level of respirable dust control within the chamber and require further investigation using full scale stables with horses. The present preferred method of dust control for horse stables recommends the use of natural ventilation to clear any dust arising from within the stable and in particular arising from bedding material (mainly straw). Natural ventilation as a means of dust control has the disadvantage of clearing respirable dust from the stable past the breathing zone of the horse and thus exposing the animal to potentially unnecessary levels of dust. Natural ventilation also relies on the incoming air to be dust free; this assumption has been shown to be unreliable in some locations. A novel approach to solving this problem was addressed by the authors and the results show enough potential to proceed to
The scale model has also indicated that the continued use of straw as the preferred bedding material is also attainable without associated dust problems. The use of this system incorporating incoming air filtration and a designed airflow pattern ensures that the breathing zone of the horse will not be unduly exposed to contaminated air produced from bedding material and that the incoming air quality is not important.

SUMMARY AND CONCLUSIONS
1. The unit achieved low levels of respirable dust within the chamber despite varying levels of respirable dust in the outside air. These low levels of respirable dust within the chamber were maintained for long periods of time.

2. Respirable dust levels increased within the chamber during agitation of the bedding material; however, this increased level of respirable dust was quickly reduced to a low level within approximately 12 min by the continuous use of filtered ventilation.

3. The inlet ventilation rate appeared to have an effect on the rate of decrease of the respirable dust level within the stable; however, due to the limitation imposed by the size of the inlet fan, lower ventilation rates were not assessed.

4. The effect of the chamber door configuration was negligible as was the activity of the outlet fans during the testing at the high inlet ventilation rates.

5. The bedding type showed variation in the level of respirable dust produced during agitation. It was not intended to discuss the merits of the different bedding materials with respect to the amounts of respirable dust produced from each bedding material. To test the different types of bedding materials for their respirable dust production levels, a more comprehensive sampling of bedding material would have been carried out.

6. These tests were limited by the size of the chamber and the possible effect of a horse's movement within a stable were not assessed. These shortcomings will be addressed in a future paper which will report on the results from a full scale operational unit accommodating horses.

REFERENCES


