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Original Research

Effects of Watering/Steaming of Large Square Hay Bales on Particulate Matter Generation

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ABSTRACT

One of the factors strongly influencing air quality in horse stables is the release of airborne particulate matter (APM) from roughage. This study examined the effects of a new system of steaming whole hay bales on the release of APM from hay. The hay bales were first watered from above and then placed in a specially constructed box and steamed with water vapor. To determine the effect of steaming the bales on the release of APM <10 μm (PM 10) and <2.5 μm (PM 2.5), samples of untreated and treated (watered and steamed) hay were examined under standardized conditions using a gravimetric particle analyzer (TEOM 1400a). In addition, the moisture content of the samples was measured. The average moisture content of the untreated samples was 13%. After watering/steaming the average moisture content rose to 31%, with a gradient from the surface to the center of the bale. Compared to untreated hay, watering/steaming of whole hay bales showed a nearly 90% decrease in PM 10 and PM 2.5 release and a mean decrease in bacteria and mold content in the hay dry matter (DM) of 49.70% and 34.53%, respectively. However, the quality of the watering/steaming process and hay bale texture has to be considered. Furthermore, an exponential relationship between the moisture content of the hay samples and their PM 10 and PM 2.5 release could be shown. A reduction in PM 10 and PM 2.5 release was determined for a moisture content of up to 25%.

1. Introduction

A large number of horses are afflicted by airway diseases. Common disorders are inflammatory airway disease and recurrent airway obstruction, which are usually subsumed under the term “equine asthma” [1], due to the similarity of some of their symptoms to asthma in humans [1,2]. Airborne particles in the stables (i.e., dust, endotoxin, molds, etc.) are regarded as one of the causative factors for these disorders [1–4].

Apart from knowledge of the sources releasing airborne particulate matter (APM) (bedding, feed, skin squames of the animals) in the stables [5], avoidance of high APM concentrations in stable air is of great importance.

It is well known that roughage (hay) can contain high levels of respirable particles [6] and thus represents a further source of APM in stables. Transport of roughage into the stables and active contact of the horses with the roughage while feeding both lead to a massive release of APM into the stable air. It can be assumed that the amount of APM released from the roughage is of great significance for the quality of the stable air.

Technical studies have shown that the concentration of APM (respirable dust particles and viable spores) (i.e., *Aspergillus fumigatus, Saccharopolyspora rectivirgula* [formerly named as *Faenia rectivirgula*] and *Thermoactinomyces vulgaris*) released from roughage varies according to the type of roughage used (hay vs. haylage/silage) [7,8] and cutting time (first cut/second cut) [7]. In addition, the method of presentation (on the ground/in a haynet) [3,9] has a significant influence on the respirable endotoxin and APM (respirable and inhalable particulates) concentration in the breathing zone of horses, which in turn has a significant impact on the respiratory health of the horses.

If hay is to be fed to horses suffering from respiratory disorders, without concerns about detrimental effects it might have on their health, the hay should be processed to reduce its content of particles.

Animal welfare/ethical statement: Gesche Claußen testify on behalf of all co-authors that the article submitted to Journal of Equine Veterinary Science.

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Several studies have shown that soaking [6,10–12], steaming [6,10,12–15], and treating the hay in a particle separation machine [16] significantly reduces APM release.

Furthermore, Moore-Coyler et al. [12] and Blackman et al. [10] show that steaming hay does not negatively influence the content of Ca, Mg, Na, P, Cu, Mn, N, K, Zn, and crude proteins. However, the water-soluble carbohydrate (WSC) content in hay can be reduced by steaming [12,14,17].

All these methods currently still involve complex management issues and provide only small amounts of particle-reduced roughage. At present, supplying several horses or a whole equestrian business with such feed involves high personnel costs.

To supply larger amounts of low-particle hay for horse keeping, OMT-Engineering GmbH developed a prototype of a steamer for whole square bales. The objective of the present study was to investigate the effect of watering/steaming square bales on the release of the environmentally relevant dust fractions PM 10 and PM 2.5 from hay under standardized conditions, with the aim of obtaining conclusions regarding the efficiency of the steamer in reducing the APM release from hay.

According to the US EPA [18] and DIN EN 12341 [19], the PM 10 and PM 2.5 fractions involve particles that pass through a size-selective air inlet with a 50% efficiency cutoff at 10 μm or 2.5 μm aerodynamic diameter. But to be able to draw conclusions about the relevance of PM 10 and PM 2.5 to health, the depth of respiratory penetration into the lungs is of vital importance. In this regard, the BS EN 481 [20] defines airborne particles according to their aerodynamic diameter and consequently their depth of respiratory penetration into the lungs in the following three fractions: inhalable fraction (aerodynamic diameter size [ADS] $\leq$ 100 μm; particulate matter [PM] 100), thoracic fraction (ADS $\leq$ 10 μm, PM 10), and respirable fraction (ADS $\leq$ 4 μm, PM 4).

2. Materials and Methods

2.1. Experimental Setup

2.1.1. Steaming Box

An industrial steam generator (WIGREX EcoTEC GmbH, Grefrath, Germany), a specially constructed steaming box and a controller unit (OMT-Engineering, Schwabhausen, Germany) were used to steam the hay bales. Because of the interior measurements of the steaming box (2.7 × 0.9 × 1.3 m; width × height × depth), whole square bales of hay can be steamed without removing the twine holding the bales together (see Fig. 1).

The interior of the steaming box was lined with panels of extruded polystyrene foam for thermal insulation.

To ensure uniform distribution of steam in the box and thus uniform steaming of the hay bales, a steam grate was placed on the bottom panel of the box, consisting of 5 tubular braces with 12 steam nozzles of 2 mm (diameter) each. Excess water from watering and steaming of the bales was able to escape unhindered through the gaps on the short sides of the steaming box and was collected using buckets. The hot water vapor necessary for steaming the hay was produced by an industrial steam generator placed next to the steaming box. The generator provided approximately 11 L/hour of steam with a temperature >110°C and a pressure of 10 bar. A connecting pipe transports the steam from the steam generator to the steaming box.

2.1.2. Determination of APM Release

The release of APM from the hay samples was ascertained with the gravimetric particle analyzer TEOM 1400a (Rupprecht & Patashnick Co., Franklin, MA, USA). The mass sensor contained in the monitor unit records the mass of APM collected by a filter continuously in real time. The concentration of APM released was measured using the sample inlet for PM 10 and PM 2.5.

The sensor unit itself was placed in a closed measuring chamber of 1.5 × 1.0 × 1.0 m for APM determination (see Fig. 2).

The measuring chamber is equipped with a semicircular bowl (30 × 39 × 50.5 cm; height × width × depth) attached to the rear wall, in which the samples are placed, and a paddle (10 × 33 cm; height × width) to agitate the samples.

The front wall of the measuring chamber can be completely opened to place the samples in the bowl and to clean the chamber after each measurement.

2.2. Experimental Procedure

Treatment (watering/steaming) of the hay bales took place from December 2015 to February 2016 under real-world conditions in

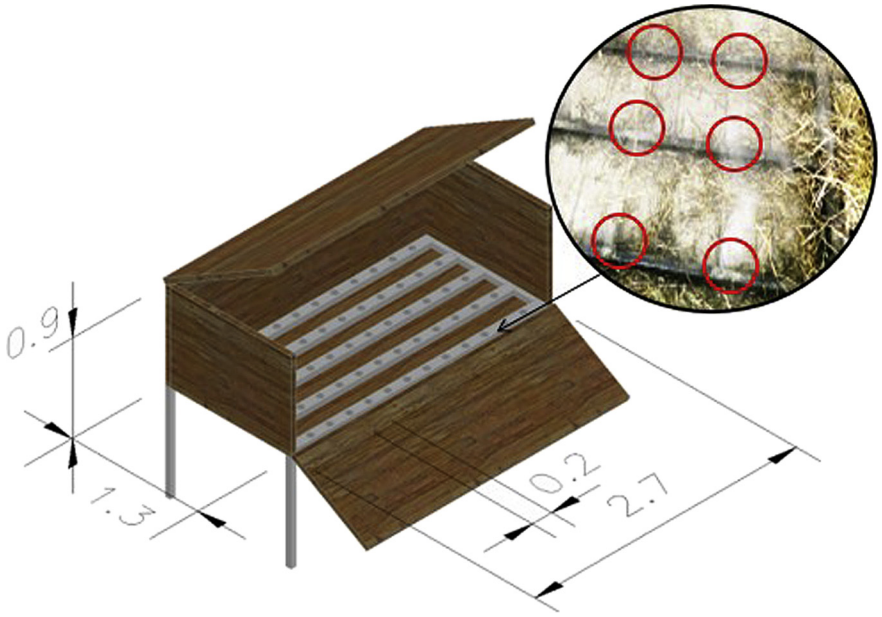

Fig. 1. The open steaming box. Inset shows the grate inside the box and the individual steam nozzles (circled in red).