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Hygroscopic expansion of biofilter media consisting of woodchips

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Abstract

Increasing the moisture content of woodchips in a biofilter bin causes the material to expand, thereby imposing hygroscopic pressure on the bin wall. A swell test was conducted using a modified oedometer apparatus to determine the change in volume of bulk pine woodchips due to changes in moisture content. Water was added to the oedometer containing woodchips having initial moisture contents of 38, 49, 58, and 71%. Dial readings were recorded manually at regular intervals up to 24 h following the addition of water. The relationship between dial reading and the logarithm, to base 10, of time was linear for each of the five initial moisture contents tested. Change in volume of woodchips was directly proportional to change in moisture content with a constant of proportionality of 1 x 10^{-6} m^3. The maximum volume change observed was 1.31×10^{-4} m^3.

Keywords: biofilter, moisture content, oedometer, swell test, volume change, wall pressure.

Introduction

Over the years, researchers have focused on the functional parameters of biofilter operation such as removal efficiency and elimination capacity. Much is known of the environmental parameters that influence biofilter performance. Biofilters are seen as suitable technology for treating the odours associated with livestock production and numerous attempts have been made to design low-cost biofilter units to retrofit to existing livestock barns. Biofilter units, such as those that have been designed for livestock barns, can be classified as "bulk material storage structures" because they are storage structures that contains bulk woodchips (or a mixture containing both woodchips and compost). Bulk material storage structures, in general, are susceptible to structural failure. Garlinski and Mann (2005) observed bulging walls in a small biofilter unit constructed on a university research farm. To adequately design the structure to avoid structural failure, it is necessary to study the lateral pressures caused by bulk woodchips used inside a biofilter. Although a biofilter can be classified as a bulk material storage structure, there is one important distinction between biofilters and most other bulk material storage structures. Most storage structures store dry materials. To be effective at removing odour, however, the woodchips in a biofilter must be wet. Moisture content is important because the microorganisms that carry out the biodegradation process require a moist environment for their growth and metabolism. The recommended moisture content range for optimum biofilter operation is 40-80% by weight (Devinny et al., 1999). Ima and Mann (2008) studied the lateral pressure caused by wet woodchips in a model biofilter bin and reported that increasing the moisture content of woodchips increased lateral pressure on the biofilter wall. Increased lateral pressure was attributed to change in volume of the woodchips that occurred due to moisture absorption. As individual woodchip particles were wetted, they swelled causing the entire woodchip bulk to expand. Expansion of the woodchip bulk imposes additional pressure, termed hygroscopic pressure, on the bin wall. The concept of hygroscopic expansion is not new. It is a well-known concept to geotechnical engineers because clay soils are known to expand with increase in moisture content. Several researchers (Blight, 1986; Britton et al., 1993; and Zhang and Britton, 1995) studied moisture-induced (or hygroscopic) loads in grain bins; their research indicated that increased moisture content caused an increase in pressure exerted on the bin wall. There is also a body of literature that has reported hygroscopic expansion in building materials such as plywood and oriented strandboard (Lang and Loferski, 1995). Based on the fact that hygroscopic expansion has been observed in clay soils, cereal grains, and wood-based building materials, it is reasonable to assume that hygroscopic expansion will also be present in bulk woodchips exposed to water. Hygroscopic expansion, or change in volume, is proportional to change in moisture content and can be expressed mathematically as:

$$\Delta v \, \alpha \, (\Delta mc)^n \qquad \text{Eq. 1}$$

$$\Rightarrow \Delta v = k(\Delta mc)^n \qquad \text{Eq. 2}$$

where, Δv = change in volume of media material, m^3, k = constant of proportionality , Δmc = change in moisture content of media material , n = constant of power. Determining the values of k and n in Eq. 2 for a specific media material would be useful in predicting the change in volume of the material that could occur as the media moisture content changes. Change in volume of the material would, in turn, be necessary in estimating hygroscopic load on the biofilter wall. Thus, the objective of this study was to determine the values of *k* and *n* for bulk woodchips such as would be present in an agricultural biofilter.

Materials and methods

Test apparatus

A swell test (ASTM 1996 - D4546) was conducted with a modified oedometer apparatus (Figure 1). A modified oedometer apparatus was used because the standard oedometer apparatus (ASTM 1996 - D2435) is not suitable for the physical properties of woodchips. A standard oedometer apparatus is typically used for determining the swelling and consolidation properties of soils (e.g., clay soil). Soils have finer particles than woodchips. Thus, the apparatus has a small sized cylindrical cell, which contains the soil during the experimental process. This size of cell would not allow the use of a good representative sample of the woodchip material given that woodchips have larger particles than soil. Furthermore, much lower loads were needed for woodchips than are needed for clay soils. The modified apparatus consisted of a cylindrical model bin, dial gauge, and nominal weight. The bin was made of polyvinyl chloride material and was 254 mm by 533 mm by 13 mm in diameter, height, and thickness, respectively. The bottom of the bin was sealed permanently with a plate. The top cover plate of the bin was attached to the remaining structure by means of screws. Thus, the cover plate could be removed whenever necessary. Two holes, 10 mm each, were created on the top cover plate. One hole (the center hole) was located at the center of the plate while the other hole (the side hole) was located 51 mm from the edge of the plate. The center hole provides a free passage for an aluminum rod, which forms a part of the nominal weight. The side hole was used for pouring water into the bin through a funnel during testing. The nominal weight constituted the seating pressure. It consisted of an aluminum rod (10 mm in diameter and 711 mm long) and a perforated pvc plate (250 mm in diameter and 13 mm thick) attached to the base of the aluminum rod. The dial gauge was attached towards the other end of the aluminum rod. During tests, upward movement of the plate as a result of swelling of the woodchips caused displacement to occur in the dial gauge. The amount of displacement that occurred in the dial gauge is an indicator of change in volume of the material.

Physical properties of woodchip material

Woodchips were purchased from a local landscape supplier. They were described as being pine woodchips, however, the specific type of pine wood was not known. The particle-size distribution of the woodchips was determined by sieving and expressed as a percentage of total wet mass as follows: <2 mm (4.9%); 2 to 2.4 mm (2.5%); 2.4 to 3.4 mm (4.5%); 3.4 to 6.7 mm (14.2%); 6.7 to 19 mm (49.9%); 19 to 25 mm (9.5%); > 25 mm (14.4%) (Ima and Mann, 2007). Initial physical properties of the woodchips are as follows: porosity (63%), bulk density (281 kg/m^3), angle of repose (34°), and coefficient of friction (0.47). Material properties were determined using the methods described by Ima and Mann (2007) when the moisture content was 26% (wet mass basis).

Experimental procedure

A woodchip sample of known moisture content was poured into the bin. The perforated plate at one end of the nominal weight was placed on the surface of the sample and the bin was covered with

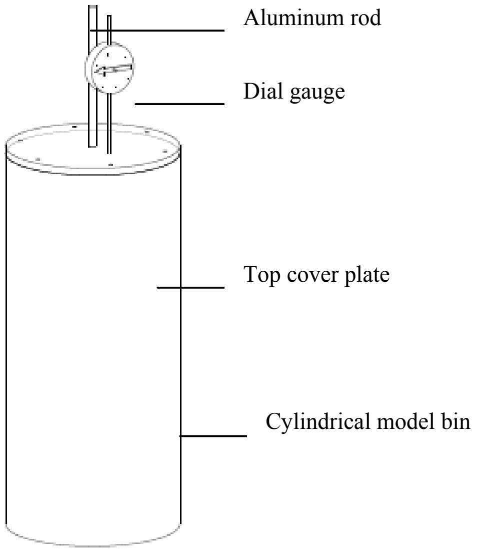

Fig 1. Modified oedometer apparatus

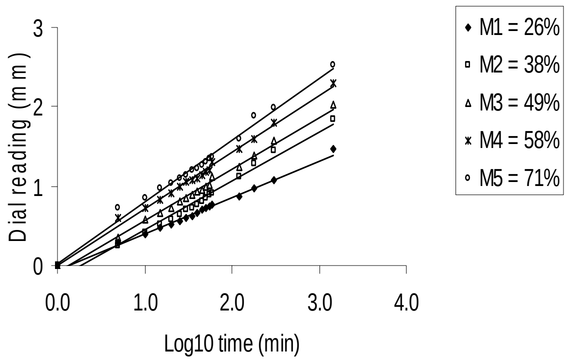

Fig 2. Swelling of woodchips with time for five woodchip samples having different moisture contents

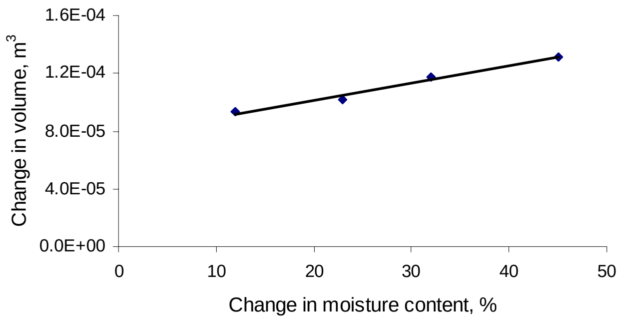

Fig 3. Swelling potential of woodchips

the top cover plate. The dial gauge was put in place and 1.5 L of water was poured into the bin through the side hole created on the top cover plate of the bin. As swelling of the material occurred, dial gauge readings were recorded at 5 min, 10 min, 15 min, 20 min, 25 min, 30 min, 35 min, 40 min, 45 min, 50 min, 55 min, 1 h, 2 h, 3 h, 5 h, and 24 h. Recording was stopped at the 24 h reading because preliminary tests conducted with a similar sample showed that swelling was completed within 24 h of commencing the test. The overall volume change for the sample was recorded at the end of the test. The recorded displacement observed from the dial gauge was used to calculate change in volume of woodchips. At the end of a test, the top cover plate of the oedometer apparatus was removed to change the woodchip sample for the next test. Five trials were completed with woodchip samples having initial moisture contents of 26, 38, 49, 58, and 71%. The initial volume of sample prior to moisture addition was kept constant in all tests. Final moisture content of the woodchip samples was determined on a wet basis by oven dry method (ASAE, 2003).

Results and Discussion

The relationship between dial reading and the logarithm, to base 10, of time was linear (Figure 2) for each of the five initial moisture contents tested. This result indicates that the degree of expansion increases as the moisture content of the woodchips increases. The swelling potential of woodchips is shown in Figure 3. Swelling potential refers to the change in the volume of woodchips that could be obtained for any change in moisture content of woodchips. In general, change in volume increased as change in moisture content of woodchips increased. The maximum volume change observed was $1.31x10^{-4}$ m^3. This result indicates that the wetter the woodchip particles, the greater the amount of expansion of the woodchip bulk that could take place due to swelling of the individual particles. Zemenu et al. (2009) reported that the degree of swelling for a clay sample depended upon its initial conditions (both moisture content and dry density) and the load applied. Kebeli et al. (2000) studied changes in pressures and loads in grain bins caused by increases in moisture content of the grain bulk stored inside those grain bins. They observed substantial changes in the observed pressures and loads that were attributed to "grain expansion" that took place as the moisture content increased. Lang and Loferski (1995) confirmed that wood products also exhibit hygroscopic behaviour. Their experimental work led to the calculation of "in-plane hygroscopic expansion coefficients" that were ultimately used to predict the dimensional stability of structural panels when exposed to environments of varying relative humidity. In other words, structural panels will expand as relative humidity increases. Therefore, the observed swelling of small wood particles (i.e., woodchips) with elevated levels of moisture is consistent with previous findings with clay soil particles, bulk grain, and structural wood products. Figure 3 indicates a linear relationship (R^2 = 0.9853) between volume change and change in moisture content of woodchips. The slope of the relationship represents the constant of proportionality, *k*, between volume change and change in moisture content for the woodchips. Thus, the values of *k* and *n* in Eq. 2 for woodchips are $1x10^{-6}$ m^3 and 1, respectively. Equation 3 shows the observed relationship for hygroscopic expansion of bulk pine woodchips.

$$\Delta v = 1x10^{-6}(\Delta mc) \qquad \text{Eq. 3}$$

Conclusions

Wetting of woodchips causes individual particles to swell and the entire bulk to expand. Expansion of the bulk, in turn, imposes additional pressure, termed hygroscopic pressure, on the bin wall. Knowledge of the swelling potential of the material is important in predicting the change in volume of the material that could occur for any change in moisture content. A swell test conducted for pine woodchips showed that change in the volume of woodchips is linearly proportional to a change in its moisture content, with a constant of proportionality of $1x10^{-6}$ m^3.

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