Model for Constant Drying Rate Period during Sludge Composting and Drying

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1. Introduction

Air introduced into a reactor system for composting supplies oxygen to the microbes and removes moisture and heat. The important mechanisms of heat removal in the composting process are vaporization and dry air convection. Since drying and decomposition of organic matter are inter-related via heat output and vaporization, the dual purpose of water removal as well as organic matter destruction can be achieved for high moisture content materials like dewatered sewage sludge by controlling aeration rates. Thus, a study of the process of drying under various simulated conditions of composting and aeration rates was done in the laboratory.

2. Material and Methods

The laboratory scale experimental set-up used for the investigation is shown in Figure 1. Glass pans having the same surface area (56.75 cm^2)but of varying thicknesses are packed with raw dewatered sludge. Assuming the porous space within the sludge to be negligible after packing, each pan can be considered to be a piece of sludge having the same thickness as that of the pan. The pans are placed in a cylinderical vessel placed horizontally. The cylinderical vessel is placed in a wooden box provided with a heat source which is connected to a temperature controller. The temperature controller probe is placed inside the cylinderical vessel. Thus necessary temperatures can be maintained in the cylinderical vessel containing the pans.

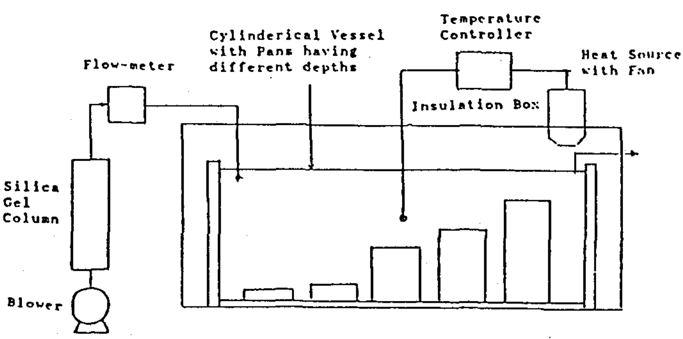

Figure 1 Schematic of Experimental Apparatus

The experiments (termed 'Pan Experiments') done, involved passing air having a specific relative humidity, at a particular velocity, across the series of pans of varying thicknesses packed with raw dewatered sludge. The pans are removed at regular intervals of time and their weights determined. Thus, from the moisture loss data, the drying curves (moisture content versus time) for each set of constant conditions of temperature, air relative humidity and air velocity were obtained.

The experimental conditions used were as follows:

Sample: raw dewatered sludge (lime treated) containing 70-75% initial moisture content and 40-43% volatile solids.
Pan Thicknesses: 1.3 cm, 1.6 cm, 3.5 cm, 5.7 cm, 8.7 cm.
Aeration Velocity: 0.058 cm/s, 0.29 cm/s, 0.58 cm/s
Temperature: 30°C, 40°C, 50°C, 60°C
Air relative humidity: varied between 0% and 70%

3. Results and Discussion

Figure 2 is an illustrative plot of the moisture content (dry basis) as a function of time. Figure 3 has been derived from Figure 2 by taking

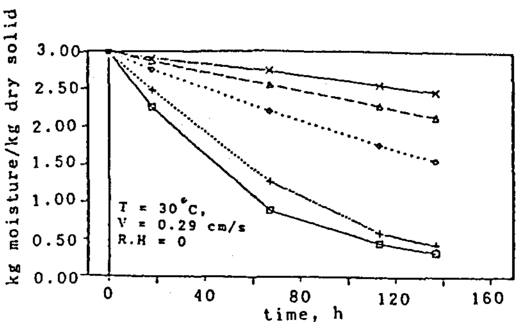

Figure 2 Illustrative Plot of Moisture Content versus Time

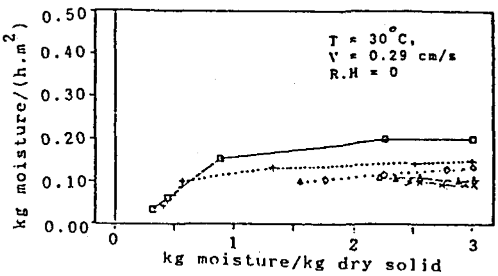

Figure 3 Illustrative Plot of Drying Rate versus Moisture Content

the slopes over short periods of time, and calculating the rate in kg moisture/(h.m^2) by multiplying the slope by (S_s/A). Here, S_s is the mass of dry solid and A the wet surface area over which evaporation occurs into the flowing air stream. In case of sludge, shrinkage occurs with increased drying, and A does not remain constant. A has been approximated by the arithmetic mean of the values at the beginning and end of the time period under consideration.

As seen in Figure 3, there is a constant drying rate period and a falling drying rate period. The critical moisture content(wet basis) at which the drying rate begins to fall was determined to be between 40% and 50% from the experimental curves.The falling rate period is difficult to analyse due to changing drying conditions in various pans due to sludge compaction. Here in this paper, drying rate during constant period is discussed.

Figure 4 is an illustrative plot of the drying rate versus thickness of sludge particles. From Figure 4, it is evident that the drying rate is not related to the thickness of the sludge particle for particle thickness below 8.7 cm.

Figure 5 shows that the drying rate in the constant rate period varies linearly with air velocity.

Figure 6 is an illustrative plot of the initial drying rate versus (H_s - H) on a logarithmic scale. Here, H_s is the saturation humidity (kg moisture/kg dry air) at a particular temperature, while H is the relative humidity (kg moisture/kg dry air) of the inlet air. A drying model for the constant rate period was formulated, which related the drying rate with the aeration velocity and air specific humidity. The model is expressed as follows:

$$N = k(H_s - H)^n \quad \text{where } k = a + bV$$

Here, N is the drying rate in kg moisture/(m^2.h), V is the air velocity in cm/s, n, a and b are constants.

Figure 6 to 8 show the derivation of the above model from an analysis of the experimental data.

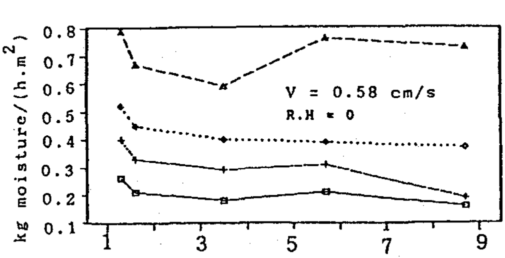

Figure 4 Illustrative plot of Drying Rate versus Thickness of Sludge

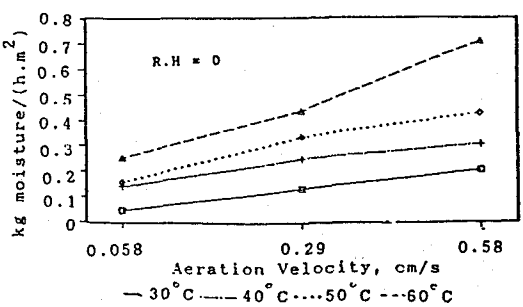

Figure 5 Initial Drying Rate versus Aeration Velocity

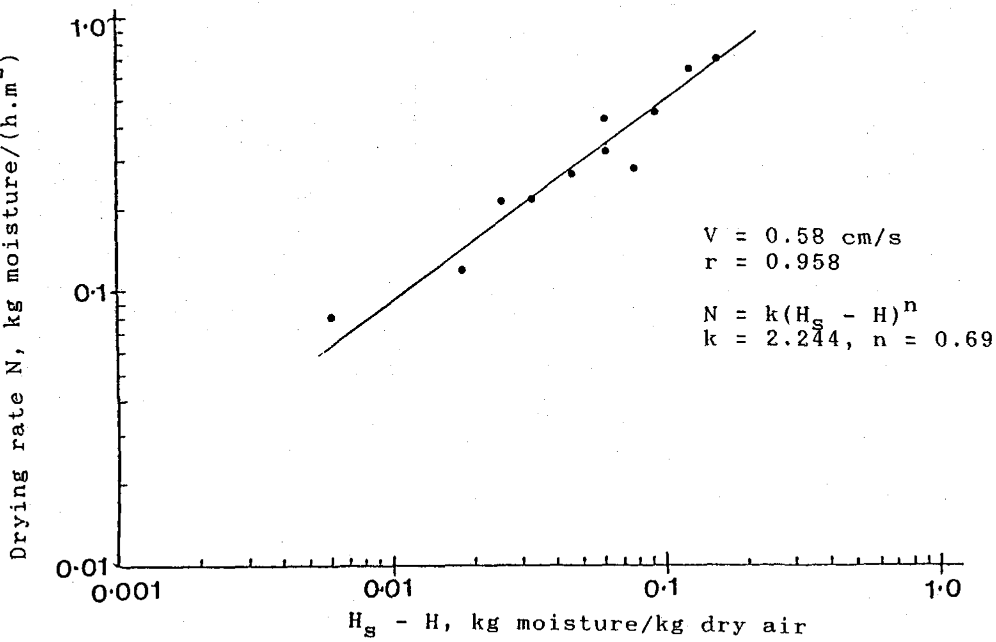

Figure 6 Initial Drying Rate versus (H_s - H)

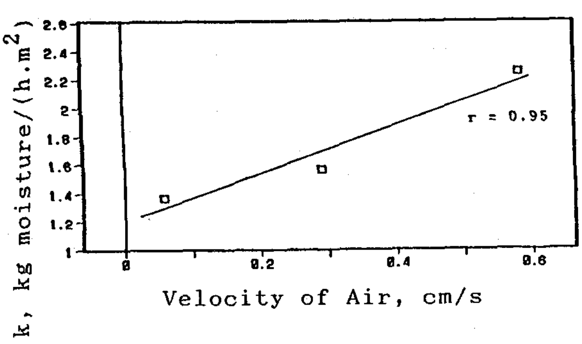

Figure 7 k versus Velocity of Air, V

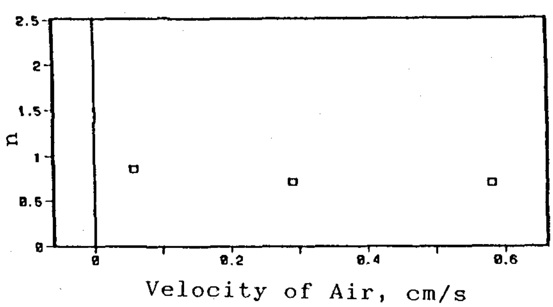

Figure 8 n versus Velocity of Air, V

4. Conclusions

1. In the drying of dewatered raw sludge under typical conditions of composting, there is a constant drying rate period followed by a falling rate period. The critical moisture content (wet basis) at which this transition occurs was determined to be between 40 and 50%.
2. The drying rate of the sludge in the constant rate period depends on the velocity, specific humidity and temperature of the air flowing across it. In the constant rate period, the drying rate is independent of the moisture content or thickness of the sludge particle.
3. A model was formulated which related the drying rate in the constant rate period with the air velocity, air specific humidity and air saturation humidity (which is dependent on temperature).