Measurement of air flow through MSW-sewage sludge compost

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Mu, R. and Leonard, J. 1999. **Measurement of air flow through MSW-sewage sludge compost.** Can. Agric. Eng. **41**:093-097. Tests were carried out on an immature municipal solid waste (MSW) and sewage sludge compost to determine the resistance to airflow through this material. The material was contained in a three-section, plywood column with a 0.36 m^2 square cross section. Air was blown through the material using a 1.5 kW centrifugal fan at varying rates and the pressure drop across the material was measured with a simple u-tube manometer. Three depths of material were tested: 680mm, 1450mm, and 2200mm. At each depth, the pressure drop was a power function of flow rate and the coefficients and exponents varied linearly with depth of material. The general equation describing all the data was:

$$\Delta P = (101637H + 173473)Q^{(0.0126H + 1.1998)}$$

where ΔP, Q, and H are pressure drop (Pa), flow rate (m^3/s), and depth (m), respectively. Limited tests were carried out on material that had been allowed to stand in the column for two weeks. During this time, the material settled by about 10% of its original depth and the flow resistance was increased substantially. This points to the need to turn or loosen the material in order to maintain porosity and facilitate airflow. In addition to measuring flow resistance, flow uniformity was also investigated. This was done by measuring the velocity of air passing through holes in a plywood plate laid on the surface of the compost. These measurements indicated that flow uniformity over the column cross-section increased with flow rate and depth of material.

Des essais ont été faits sur un compost immature d'ordures ménagères et de boues d'égout afin de déterminer la résistance à l'écoulement de l'air à travers ce matérial – contenu dans une colonne de contreplaqué à trois cellules à section carrée de 0,36 m^2. Le soufflage d'air a été effectué au moyen d'un ventilateur centrifuge de 1,5 kW à des vitesses variables et la chute de pression a été mesurée avec un simple manomètre à tube en U. Trois profondeurs de matérial a été soumies aux essais: 680 mm, 1450 mm et 2200 mm. À chaque profondeur, la baisse de pression était une fonction de la puissance du débit d'air, et les coefficients et les exposants variaient linéairement avec la profondeur du matériau. L'équation générale décrivant toutes les données était :

$$\Delta P = (101637H + 173473)Q^{(0.0126H + 1.1998)}$$

dans laquelle ΔP, Q et H sont la chute de pression (Pa), le débit (m^3/s) et la profondeur (m), respectivement. Des essais limités ont été effectués sur le matériau qu'on avait laissé reposer dans la colonne pendant deux semaines. Durant cette période, le matérial s'est tassé d'environ 10 p. 100 de sa profondeur originale et la résistance à l'écoulement de l'air a considérablement augmenté. Ceci souligne la nécessité de tourner ou de décompacter le matériau pour en préserver la porosité et faciliter le passage de l'air. En plus de mesurer la résistance à l'écoulement de l'air, nous avons aussi examiné régularité du débit en mesurant la vitesse de l'air à travers les trous d'une plaque de contreplaqué posée à la surface du compost. Ces mesures indiquent que la régularité du débit sur la section transversale de la colonne augmentait avec le débit d'air et la profondeur du matériau.

INTRODUCTION

In the secondary processing phase of the proposed City of Edmonton co-composting facility, one possible scenario was for air to be blown upwards from the floor of processing channels through the composting municipal solid waste (MSW) and sewage sludge mixture. Preliminary work had indicated that the oxygen demand of this material was high and that, without adequate aeration, conditions within the channels would become anaerobic very quickly. This, in turn could lead to the production and accumulation of undesirable products of anaerobic decomposition such as methane. The preliminary work also indicated the need for aeration to cool the compost and keep the process temperature at optimum levels. Therefore, it was important to ensure that air supply equipment was adequately sized and specified and, to do this, information was required on the airflow resistance characteristics of the material concerned.

Some data on airflow through compost are available in the literature (Snell 1957; Singley et al. 1979; Taraba and White 1987; Keener et al. 1993; Das and Keener 1995) and these could be used as a guide. However, most of these studies did not look at deep beds of material and none of them used MSW /sewage sludge compost. In view of the importance of adequate aeration to the to the process, data using deep beds of MSW/ sewage sludge compost was considered to be desirable.

Thus, the primary objective of this work was to determine the relationship between pressure and flow for air blown through compost at depths greater than 2 m. A secondary objective was to evaluate the uniformity of air distribution through the compost, particularly when air was introduced from a point source.

METHODOLOGY

Material

The compost material was derived from a mixture of sewage sludge and unsorted MSW collected in Edmonton during December. This mixture was processed for seven days in a rotating drum digester and, after this primary digestion, oversized material was removed with an expanded metal mesh screen. The diamond-shaped perforations in the screen measured approximately 25 mm by 13 mm. The material was then frozen by spreading it out and storing it outside under a plastic sheet. The daily mean ambient temperatures during the two-month storage period were approximately -10°C and there were no temporary thaws during this time.

Table I. Summary of test conditions.

Depth of compost (mm)	Mass of compost (kg)	Mean wet bulk density (kg/m^3)	Range of flow rates		Number of measurements
			(m^3/s)	(10^{-2} m^3 s^{-1} kgDM^{-1})	
680	213	870	0.004 - 0.018	0.004 - 0.019	7
1450	419	800	0.003 - 0.015	0.002 - 0.008	9
2200	569	720	0.003 - 0.013	0.001 - 0.005	9

Prior to carrying out tests, the frozen material was brought inside, covered with a plastic sheet to minimize moisture loss, and thawed at room temperature (20°C) for two weeks. The moisture content of the material as used was 55% (wet basis). Bulk density determinations were made as the material was used (Table I) and these are an indication of porosity. Characterization of actual porosity would require measurement of particle density but, because of the highly non-homogeneous nature of the material, this was considered impractical. The material was not source separated, and included particles of glass, plastic, metal, etc. of varying dimensions as well as decomposable organic matter. The presence of these particles, meant that a conventional particle size analysis (mass fractions retained on different sieves) might not be valid due to the possibility of the higher density particles skewing the results.

Apparatus

The apparatus constructed for use in these tests is shown in Fig. 1. The compost was contained in a three-section column made from plywood in a steel frame. The cross section of the column measured 600 mm x 600 mm and each section was 760 mm high. A door was cut in one side of each section to facilitate emptying and filling of the column. Joints between column sections and around the doors in each section were sealed with duct tape. Air was introduced through a 102 mm-diameter circular hole at the centre of the floor of the bottom section. This hole was covered with a steel mesh screen to prevent material dropping into the air supply duct.

The air supply duct was made of 102 mm I.D black PVC pipe. A four-point pressure tap was installed immediately before the entrance to the column and this was connected to a simple U-tube manometer to measure air pressure. Two holes were drilled in the duct, at right angles to each other, to allow velocity readings to be made with a hot-wire anemometer (Velocicalc 8350, TSI, St. Paul, MN). Both holes were at the same cross section of the duct and were located in a straight section such that effects of the fan, transition section, and delivery elbow would be minimized (Jorgenson 1983). A set of 150 mm-long flow straightening vanes as installed immediately downstream of the transition section to help stabilize the flow before the velocity measurement location. The mean flow velocity in the duct was calculated from velocities measured in 7-point traverses across the duct in the horizontal and vertical planes (Jorgensen 1983). The velocities determined from the horizontal and vertical traverses were averaged to give a final mean velocity in the duct. This was multiplied by the cross-sectional area of the duct to give the volumetric flow rate.

A centrifugal fan (Model 15000, Keho Alta Products Ltd., Barons, AB) was used to supply the air. This fan was powered by a 1.5 kW electric motor and was capable of developing delivery pressures of up to 2 kPa (PAMI 1984). The outlet from the fan had a rectangular section and so a transition section was required between the fan and the circular duct. This was fabricated from plywood and the joint between the transition section and the duct was sealed with duct tape.

To vary the flow rate, a hole was cut in the transition section and fitted with a sliding gate. By opening the gate, a portion of the fan delivery could be bled off, thereby varying the amount of air delivered to the compost.

To assess the uniformity of flow through the compost, a flow measurement plate (Fig. 2) was fabricated from plywood. This consisted of a sheet of the same size as the column cross-section in which nine 50 mm holes had been drilled. Plywood partitions were attached to the underside of the sheet to divide the flow through the column. The whole assembly was placed on top of the material in the column and the partitions were pressed gently into the surface of the material so that flow

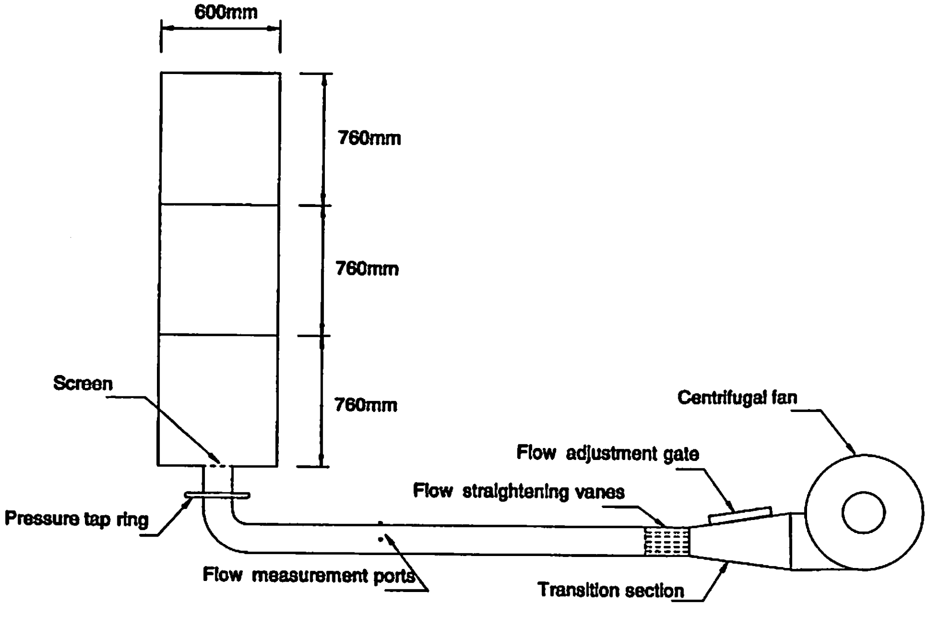

Fig. 1. Flow measurement apparatus.

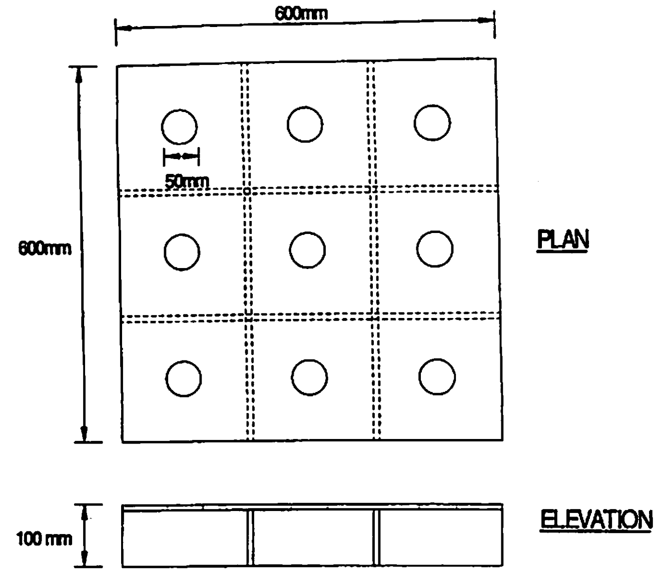

Fig. 2. Flow uniformity measurement plate.

was divided and directed through the holes in the sheet. Because these holes had a smaller total area than the column cross section, air velocities through them were higher and could be measured more easily. This was done using the same hot-wire anemometer as mentioned above. Air velocities through the holes were the averages of three readings taken across hole diameters.

Methods

Tests were carried out using three depths of compost corresponding to the three sections of the column described above. Initially, the first section of the column was filled to a depth of 680 mm with 213 kg of compost material. Air was blown through this at seven different flow rates varying from approximately 0.004 to 0.018 m^3/s (0.004×10^{-2} to 0.019×10^{-2} m^3/s per kg of dry matter). At each flow setting actual flow velocity was measured in the delivery duct and pressure was measured using the manometer connected to the inlet pressure tap. The flow rates used correspond closely with the rate, recommended by Rynk (1992) for temperature-controlled aeration, of 0.005×10^{-2} m^3/s per kg of dry matter.

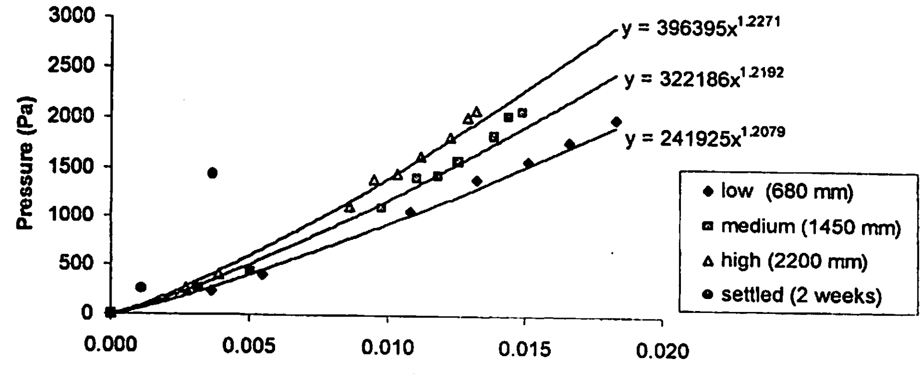

Fig. 3. Pressure drop through the column vs flowrate.

The above procedure was repeated with total depths of material of 1450 mm and 2200 mm. The conditions for these tests are summarized in Table I. As this table shows, difficulty was experienced in loading the column to maintain a uniform bulk density throughout. Consequently, the mean wet bulk density of the material in the column became lower as the depth of material increased.

The material was left in the column for two weeks, during which time it settled by about 230mm due to continued biological activity and consolidation of the material under its own weight. To check the effect of this settlement on flow characteristics, two additional tests were carried out at different flow rates (.001 m^3/s and .004 m^3/s).

RESULTS

The pressures measured at each flow rate for each of the three compost depths are plotted in Fig. 3. The data were fitted to curves of the form:

$$\Delta P = aQ^n \tag{1}$$

where:

ΔP = pressure drop over the column height (Pa),
Q = flow rate of air (m^3/s), and
a,n = constants for each curve.

These curves are shown in Fig. 3 together with their equations. The R^2 values for all three regression equations shown were above 0.999. Also shown in Fig. 3 are the two points resulting from the measurements taken after material had been in the column for two weeks.

Figures 4 and 5 show graphs of the airflow velocities measured at the holes in the plate placed on top of the compost for two contrasting situations. Figure 4 shows results for a low flow rate at the lowest depth of compost, while Fig. 5 shows results for a high flow rate at the greatest compost depth. Similar graphs were obtained for other depth and flow combinations but the cases shown illustrate the extremes of observed velocity distributions. In general, the uniformity of air distribution improved with both compost depth and flow rate. The coefficients of variation for the velocities shown in Figs. 4 and 5 are 23.6 and 3.5%, respectively.

DISCUSSION

Flow Resistance

Examination of the equations to the curves shown in Fig. 3 indicated that the constants a and n in Eq. 1 varied with depth of compost. Consequently, these constants were plotted against depth and subsequent regression analysis showed that both were linear functions of depth (R^2 = 0.999). Thus, Eq. 1 can be re-written:

$$\Delta P = (bH + c)Q^{(dH+e)} \tag{2}$$

where:

H = height of compost column (m), and
b,c,d,e = constants.

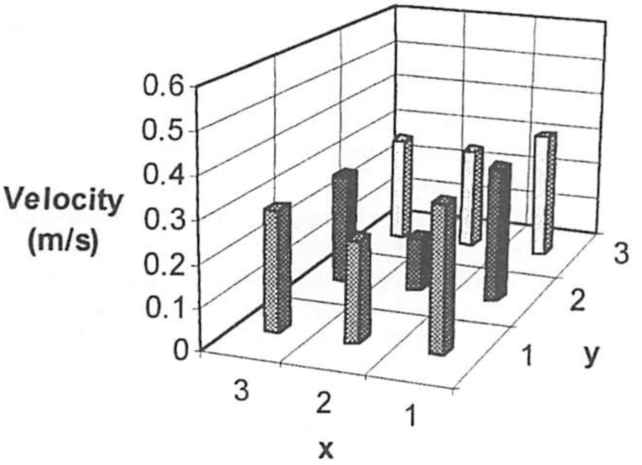

Fig. 4. Exit flow distribution for lowest depth (680 mm) and low flow rate ($Q = 0.0037\ m^3/s$; $V = 0.01\ m/s$).

Substituting values from the regression equations, Eq. 2 can be written as:

$$\Delta P = (101637H + 173473)Q^{(0.0126H+1.1998)} \tag{3}$$

Although the methods used and the form of Eqs. 2 and 3 are widely applicable, it should be emphasized that the values of the constants given in Eq. 3 are only applicable for the specific material used at the time of the tests.

This limitation is illustrated by the fact that the two points obtained after the same material had been left in the column for two weeks cannot be represented by Eq. 3. The best-fit regression equation of the power-law curve through these points and the origin is given by: $\Delta P = 2\text{x}10^7 Q^{1.6954}$ ($R^2 = 0.9999$). At any flow rate, this gives pressure values an order of magnitude greater than Eq. 3.

During the two-week residence time, the material consolidated under its own weight and, although aeration was not maintained during this period, the material would have continued to decompose. This would result in decreased porosity as particles decomposed, and increased moisture content due to microbial metabolism. This combination would result in increased airflow resistance. The higher airflow resistance measured after this period of consolidation highlights the need for regular turning or loosening of material to maintain porosity and facilitate air movement.

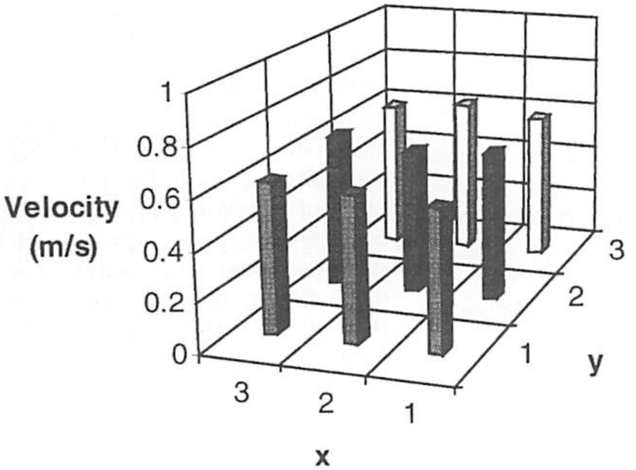

Fig. 5. Exit flow distribution for highest depth (2200 mm) and high flow rate ($Q = 0.013m^3/s$; $V = 0.036\ m/s$).

Table II. Equations describing pressure gradient, P' (kPa/m) as a function of mean flow velocity, V (m/s).

Compost depth	Equation	R^2
Low (680 mm)	$P' = 103.57\ V^{1.2079}$	0.9999
Medium (1450 mm)	$P' = 56.165\ V^{1.1832}$	0.9998
High (2200 mm)	$P' = 41.680\ V^{1.1709}$	0.9999

While Fig. 3 provides a clear representation of the observed results, it is not directly comparable to some of the data available in the literature. For instance, Higgins et al. (1982) and Keener et al. (1993) express pressure drop as a function of mean flow velocity through the material. This velocity can be obtained by dividing the flow rate by the cross-sectional area of the flow. Other researchers such as Taraba and White (1987) and Das and Keener (1995) have used pressure gradients to take account of material depth. In most cases, sufficient information was supplied by these authors to enable conversion of their data to whatever system of representation is appropriate.

The data in Fig. 3 can be expressed in the form of a slightly different equation:

$$P' = jV^k \tag{4}$$

where:

P' = pressure gradient (kPa/m), and

V = mean flow velocity through the material (m/s).

When the data presented in Fig. 3 are transformed to the form of Eq. 4, the resulting regression equations are those presented in Table II.

The exponents of V (i.e., values of k) in the equations of Table II are very similar to those reported by both Higgins et al. (1982) and Keener et al. (1993). The coefficients of V are not directly comparable to those reported by previous authors because of the use of different systems of units. However, the pressure gradients measured are of the same order of magnitude as those that have been reported by (or that can be calculated from the data of) Snell (1957), Singley et al. (1979), and Taraba and White (1987). Pressure gradients of similar magnitudes were measured by Das and Keener (1995) but these were obtained at higher flow rates and with material subjected to compressive stresses of up to 21 kPa.

Table II shows that the pressure gradients were higher at lower depths. The higher mean bulk density at lower depths of material (Table I) can largely account for this, but two other factors could have contributed.

An important difference between the measurements reported here and those reported previously is that these were carried out in a column where the air entered through a small hole in the base as opposed to entering via a plenum and being distributed over the entire column cross section. However, the equations in Table II are based on velocities calculated assuming that flow occupied the entire cross section. In the lowest section, close to the inlet orifice, the true flow area would be smaller than the full cross section and, consequently, measured pressure gradients should be associated with higher velocities. This would have the effect of making the equation for the lowest depth more similar to those of the other two depths.

Another factor to note is that lower depths of material provide less total resistance to flow and, therefore, higher flow rates and velocities can be achieved. This could result in more turbulence and, hence, higher pressure gradients. Snell (1957) indicated that, with ground garbage compost, the transition from laminar to turbulent flow occurred at about 0.015 m/s, which is in the middle of the range of velocities used here.

In general, the shape of the pressure curves obtained is in good agreement with previous work while the magnitude of the pressures measured is at the high end of values in the literature. This is to be expected since the material had a high bulk density, did not have any bulking agent added to enhance porosity, and was tested at a comparatively high moisture content.

Flow uniformity

The use of a perforated plate for evaluating flow uniformity was adopted because the low air velocities through the material made direct measurements of velocity at the surface of the compost impractical. The plate forced air to flow through a smaller area at higher, measurable, velocities. Thus, the values shown in Figs. 4 and 5 should not be interpreted as reflecting actual velocities within the compost but simply as indicators of the relative amounts of air leaving the column in the partitioned regions adjacent to holes in the plate.

At low compost depths and low flow velocities there appeared to be greater flow towards the outside of the column than in the centre. This could have been due to wall friction inhibiting compaction of material during filling and resulting in marginally greater porosity and less resistance to airflow towards the outside. At low flow rates, these differences would be apparent but would become insignificant at higher pressures and flows. Also, as more material was added to the column, compaction at the lower layers would become more uniform and would result in more uniform distribution of flow.

CONCLUSIONS

Airflow resistance of immature MSW / sewage sludge compost with a moisture content of 55% (wb) was measured in a 0.36 m^2 column for depths of 680, 1450, and 2200 mm of material and for flow rates up to 0.018 m^3/s. The pressure drop through the column was a power function of flow rate with both the coefficient and exponent of flow being linearly related to depth of material. After two weeks in the column, material settled by about 10% and two measurements of airflow indicated substantially higher flow resistance. This indicates the need for regular turning or loosening of the compost to maintain porosity.

To provide better comparisons with previous work, the data obtained were also expressed in terms of pressure gradient and mean flow velocity through the material. Again, a power law relationship applied and the measured exponents were in good agreement with published values. The pressure gradients measured were of the same order, but at the high end of previously measured values. Higher pressure gradients at lower depths of material were attributed to higher bulk densities and under-estimation of flow velocities at the bottom end of the column where flow was still spreading out from the entry orifice.

Flow uniformity was determined by measuring flow velocities through holes in a perforated plate placed on the surface of the compost. At low flow rates and depths, flow through the middle of the column was less than that towards the edges. As flow rate and depth increased, so did uniformity of flow across the column section.

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