



Investigating The Physical Properties of Vermicompost Fertilizer

Seyed-Amir Zaki ¹, Ezzatollah Askari Asli-Ardeh^{2*}, Mohammad Hossein Kianmehr ³,
Javad khazaei ⁴

¹Department of Biosystem Engineering, University of Mohaghegh Ardabili, Ardabil, Iran.

^{2*} University of Mohaghegh Ardabili , Ardabi , Iran.

^{3,4}Department of Agro Technology Engineering, Aboraihan Campus, University of Tehran, Tehran, Iran.

ABSTRACT

Organic waste can be processed in a variety of ways, such as burning, land filling in special places, and recycling. One of the best techniques is vermicompost production from powdered municipal waste and for processing it must be transported or stored; therefore, bulk density and flowability characteristics of these materials are important for transportation and storage. Particularly the discharge of these materials from the reservoirs may have serious problems due to their flowability. Considering the fact that moisture content and particle size affect the bulk density as well as the particle size in the angle of repose of vermicompost fertilizer, in this research, the moisture content of materials in five levels (10%, 20%, 30%, 40% and 50%) and particle size in three levels (0.3, 0.6 and 1.8) were investigated in line with the angle of repose and bulk density. The results showed that the bulk density decreases with increasing moisture content and also with increasing particle size from 0.3 to 1.18 mm, the bulk density decreases in the range of 0.80 to 0.60 grams per cubic meter. The results of the angle of repose indicate that with increasing the particle size, the coefficient of internal friction increases and the angle of repose increases. Particular effects of particle size and moisture content at 1% level on tab density and Hausner ratio are significant and with increasing moisture content the tab density decreased. Hausner ratio decreases by increasing the particle size from 1.30 to 1.14 that indicates an increase in the mass flow rate with increasing particle size. The coefficient of correlation between the angle of friction and the angle of mass is 0.99. Both the Hausner and Hel-Shaw ratio indices were used to determine the properties of each other.

Keywords: Vermicompost fertilizer, physical properties, The angle of repose, bulk density

Corresponding author: Ezzatollah Askari Asli-Ardeh

INTRODUCTION

Today, with population growth, industrial progress and development, urbanization, increased human welfare level and the consumption of food, waste and organic residues disposal have become a major environmental problem. If these waste materials are not disposed correctly, they can cause many problems for the environment and endanger the health of the human community. Organic waste processing is possible in various ways, including incineration, burial in certain places and recycling. These methods, in addition to the high cost, can also bring about environmental problems. However, recycling of waste in the environment and reducing pollution are very effective and can convert waste materials into a variety of useful materials. One of the most important methods for processing municipal waste is recycling them as vermicompost. As a result of this process, in addition to reducing health and environmental problems, significant quantities of organic fertilizers, called vermicompost, are produced (Arzanesh and Abbasi, 2011). Vermicompost is a

biological organic fertilizer that is produced by the means of constant and calm passing of decaying organic matter from the digestive tract of species of earthworms and excretion of these substances from the worm body (Gupta, 2003; Ismail 2003). These materials while passing through the body of worm will be smeared with mucus, vitamins and enzymes that ultimately they are enriched as an organic fertilizer and will be produced and consumed as very useful means for building and improving soil nutrients. Therefore, vermicompost is a worm extract with a percentage of organic matter and food and carbohydrate substrates (Sathe, 2005). Compost that is a mixture of processed organic matter, due to the unique and specific modification effects on the physical, chemical and biological properties of the soil and consequently growth and increase of the product, has been considered by farmers (Subler et al., 1998). For this reason, one of the lateral branches of the agricultural sector is the production of different types of compost from organic raw materials. Vermicompost in fact is the result of a semi-aerobic process which is carried out by a specific group of composting worms, with the help of some microorganisms, especially bacteria and actinomycetes (Manna, 2003). In order to be processed, powders and bulk materials are required to be transported or

stored. Therefore, the flowability characteristics of these materials are important for transportation and storage. Particularly evacuation of these materials from the reservoirs may be faced with serious trouble. To overcome these problems, it is necessary to pay attention to the flowability of these materials. Vermicompost flowability may be affected by physical, chemical, environmental changes; tools design defects, particle size, shape, surface structure, particle size distribution, moisture content, particle pressure conditions and storage time. Powder flowability also depends on the geometry of the equipment, because the equipment must be designed according to the properties and characteristics of particles and should not be based solely on the formulas obtained for a few powders (Freeman, 1976). The ISO 3435 standard describes the use of an angle of repose to quantify the bonding properties of granular materials. The angle of static repose is an angle that shapes the inclined surface of materials in the rotating cylinder with the horizon level and the angle of the dynamic repose is the angle that shapes an inclined surface in the bulk material of the rotating cylinder with the horizon (Cain, 2002). The tilted box and fixed cone method used to measure the angle of repose and since it is difficult to measure the angle of repose for adhesive materials, they used a mixture of materials with good flowability with these sticky materials. Determining the angle of repose with different compositions and predicting the combination angle diagram from the evidences, made the researchers able to obtain the theory of repose angle for sticky materials (Riley et al., 1978). In another method, a box is used to determine the angle of material repose. In this method first the box is filled to a certain height with the desired materials and then they open its slider door so the material flows through the valve. The angle of repose is obtained by measuring the angle of the materials after the flow inside the box with the horizontal level (Karababa, 2006). Finally, the condition of flowability is determined according to Table (1).

Table 1: Classification of powder flowability based on repose angle

The repose angle (degree)	Description
25-30	Very free flow
30-38	Free flow
38-45	Flow as smooth as possible
45-55	Sticky
>55	Very sticky

Given that the percentage of moisture content, particle size and bulk density, and the angle of repose of vermicompost as masses for storage and its conversion to pellet is very important, in this research, these are discussed.

Mass condensation was proposed as a flowability criterion for powder materials (Carr, 1965).

The Hausner ratio, which expresses the ratio of Tab density (TD) to Bulk density (BD), is calculated by equation (1) (Thalberg et al., 2004). The researchers in line with reviewing the flowability methods of bulk materials have expressed that the first step in designing displacement equipment for mass flow processes to measure the flowability properties of bulky material (Schwedens and Schulze, 1990). It has been stated that powder flowability is a combined result of physical properties and equipment used for the handling, storage and processing of materials. Density measurement and the angle of repose are some of the commonly used techniques in measuring the flowability of materials (Prescott and Barnum, 2000).

$$HR = \frac{TD}{BD} \quad (1)$$

Riley and Hausner (Riley and Hausner, 1970) were the first to express the importance of Hausner ratio.

Another dependent index, which is the ratio of the tab density difference and bulk density to tab density, is the main index which is expressed by equation (2).

$$CI = \frac{(TD - BD)}{TD} \times 100 \quad (2)$$

Adhesive materials have a Hausner ratio greater than 1.4 (Cain, 2002). Based on the work (1965), materials with a Carr index of more than 20 to 25 percent are non-flow materials. Thalberg et al. (2004) used the modified Hausner ratio method to evaluate different flowability formulas. They used a dense mass volume instead of a bulk density that requires less power to achieve compression conditions. Table 2 shows the relationship between flowability and powder compression percentage (Carr, 1965). Hausner ratio is a measure of the flowability of bulk materials; therefore, this reduction in the Hausner ratio with increasing particle size indicates an increase in bulk materials flowability (Hayes, 1987).

Table 2: Definitional relationship between flowability and Hausner ratio (Carr, 1965; Joens, 1977)

Flowability rate	Hausner ratio	Carr index (compressibility percent)
Excellent (smooth granules)	1.11-1.05	15-5
Good (powdered granules)	1.18-1.12	16-12
Medium (crushed granules)	1.25-1.19	21-18
Poor (very soft fluffy powders)	1.33-1.27	28-23
Weak (sticky soft powder)	1.45-1.35	35-28
Very weak (relatively smooth adhesive powders)	1.59-1.47	38-35
Extremely weak (sticky non-fluent powders)	1.82-1.61	More than 40

The purpose of this study is to investigate the effect of particle size and moisture content on vermicompost fertilizer flowability. In this study, the Hausner and Hel-Shaw methods were investigated.

1. MATERIALS AND METHODS

1-2. Method of preparing vermicompost fertilizer

The produced vermicompost in this study was processes and evaluated in Vermicompost production unit located at the Faculty of Agriculture of the city of Safadasht, Tehran province.

2-2. How to measure moisture, fertilizer size and weight

To determine the initial moisture content of the fertilizer, three 100 grams samples of fertilizer according to the ASAE S358.2

standard were installed in the oven manufactured by aqua-ASA Company at $3 \pm 103^\circ \text{C}$ for 48 hours. The moisture content was measured according to equation (3) in wet condition and equation (4) based on dry condition (ASAE Standards S269.4, 1998).

$$M_{w.b.} = \frac{w_w}{w_t} = \frac{w_w}{w_w + w_d} \quad (3)$$

$$M_{d.b.} \% = \frac{w_w}{w_d} \times 100 \quad (4)$$

That in these equations:

- $M_{w.b.}$ = Fertilizer moisture content based on wet condition (%);
- w_w = The weight of water in the fertilizer (gr);
- w_t = Total weight of fertilizer (gr);
- w_d = weight of dry matter in the fertilizer (gr);
- $M_{d.b.}$ = moisture content of fertilizer based on dry matter (%).

2-3. How to prepare a sample of vermicompost with desired moisture content

For the preparation of samples with the required moisture levels for each experiment, the amount of water was added by sprinkler, the added amount of water was calculated from equation (5).

$$m_w = \frac{m_i(M_{wf} - M_{wi})}{1 - M_{wf}} \quad (5)$$

That in this equation:

- M_w = Added water mass (gr);
- M_i = Primary mass of fertilizer (gr);
- M_{wi} = initial moisture content of the fertilizer based on wet condition;(%)
- M_{wf} = final moisture content (%).

After adding distilled water, the samples were stored in plastic bags in a refrigerator at a temperature of 5°C for 48 hours to uniformly distribute moisture in the samples. To determine the actual moisture content of the samples, five samples of 10 grams of each moisture level were placed in the oven.

2-4 Bulk density

Generally, bulk density is determined by measuring the mass of materials based on the volume of occupied dish by masses. To measure the volumetric mass of fertilizer a cylinder with a volume equal to 250 cubic centimeters was used. With a fixed funnel, the fertilizer powder was poured into the dish. From equation (6) and according to Fig. 1, the bulk density was measured in three replications.



Figure 1: How to measure mass density

$$\rho_b = \frac{M}{V} \quad (6)$$

The in this equation:

- M = mass of fertilizer (g),
- V = volume of container (3cm)
- ρ_b = Volume of fertilizer (3g / cm).

2-5. Normal repose angle

The natural repose angle was calculated method defined by Bouman; first, the fertilizer was poured into a cylinder with an approximate diameter of 15 cm and slowly pulled up the cylinder so the fertilizer naturally forms a cone, Figure (2). The desired parameter can be calculated by equation (7).

$$\varphi_d = \tan^{-1}\left(\frac{2H}{D}\right) \quad (7)$$

φ_d , natural repose angle H , cone height and D is the diameter of the cone in cm.

The camera was placed on a level surface aligned with the base of the cone. After photography, the two lines were drawn exactly on the cone edges and the third line was mapped to the base of the cone. Then the angle formed between the base and the edges of the triangle was read. Calculation of the natural deposition angle was done by using a digital camera and determining the angle with AutoCAD software. (Figure 2)

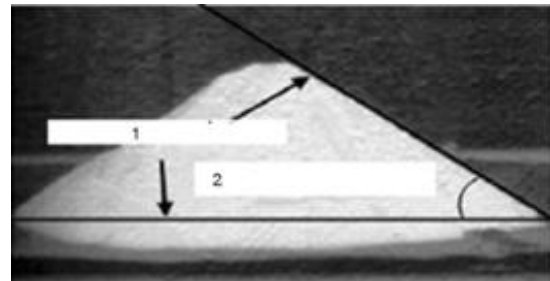


Figure 2: Determining the angle of repose by pouring the material onto the surface by using a funnel.

1. Reference line
2. Repose angle

2-6- Tab density (TD)

The tab density of mass is equal to the mass density after the particles become close together. This closeness is achieved in accordance with ASTM B527 standard. Bulk density is the ratio of bulk materials density to volume of materials in the container where these materials are, because these materials flow in the dish, there is an empty space between the particles. If the material become arranged under vibration or shock the density achieved with this new arrangement is called tab density. In fact, creating shock and vibration causes exiting the air between the particles and they will be arranged in a new fashion. In this method, a of 100 or 250 milliliters cylinder containing vermicompost fertilizer powder with the tab density test apparatus, up to 14 mm high and with the speed of 300 times per minute, it was thrown 500 times and it was hit on the rigid surface. After completing the experiment Beaker volumes which contained the materials was read and recorded. Again this test was done for 750 times and the volume is measured. If the difference between this volume and the first test volume is greater than 2% the experiment is repeated again, otherwise the test is over (ASTM Standard, B527, 2005). By using the tab density and bulk density, according to (8), the Hausner coefficient is calculated which is used for flowability.

$$\text{Hausner Ratio} = V_0/V_f \tag{8}$$

V_0 : initial volume (ml);

V_f : final volume (ml).

Finally, the flowability status of the fertilizer is determined according to table (2).

2-7. The angle of repose in the Hele-Shaw method

The Hele-Shaw method is a method by which the angle of deposition can be determined. In this method, as shown in Fig. 3 a box is made of Plexiglas that it makes easy to see inside. The adjustable door is located at the top of box. The height of this valve is adjustable to allow for the uniform entry and shrinkage of materials and nearly 30-degree angle makes with the horizon. The test procedure is such that by dropping the material out of the valve, bulk materials are leaned against the walls under an angle. After the material was loaded, a Canon A800 digital camera was use to take photographs. Photographs were analyzed by using Solid works engineering software that it was tangent to the edge of straight line material its angle with the horizon was measured which is considered as the angle of repose and according to Table 1, its flowability status is determined.

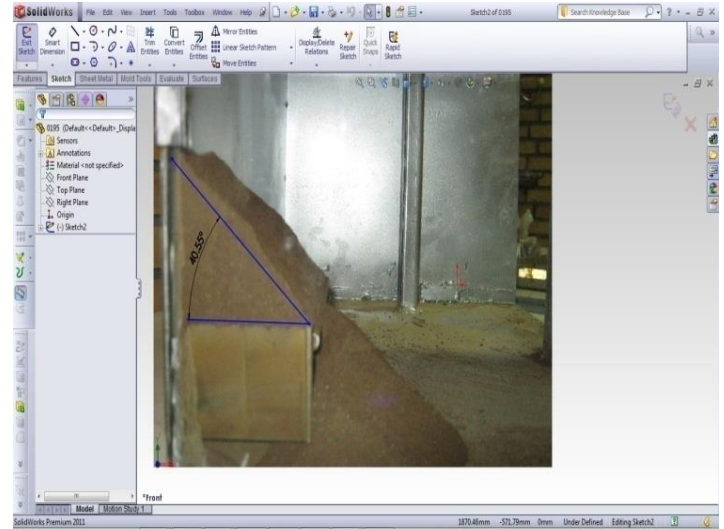
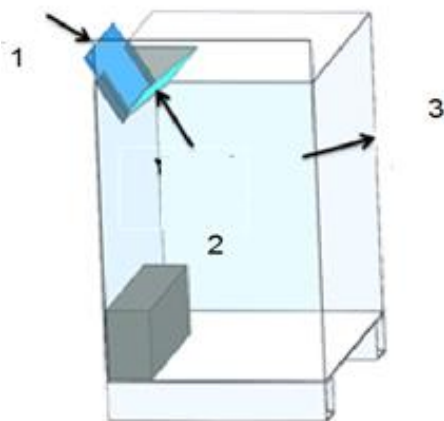


Figure 3: The method of measuring the angle of repose by the Hele-Shaw method

1. Flap Valve
2. 30-degree slope
3. Protective glass

3-1.RESULTS AND DISCUSSION

3-2. Determination of the Size and Dispersion of Compost Fertilizer

The particle size, distribution, and shape of compost particles play an important role in the pelleted phenomenon. The size and shape of the vermicompost particles were determined according to ASTM E-11-70 Part 41 standard in order to choose the best particle size in the final production of pellets in different pelletizing methods; therefore, the measured values were determined by four sieves with 10, 16, 30 and 50 mesh sizes (American standard size), Table (3).

Table 3: Dimensions of the pores of the sieves used according to ASTM E-11-70 Part 41)

Sieve size	50	30	16	10
Pore diameter (mm)	0.3	0.6	1.18	2
Particle size percentage in vermicompost	26.9	34.58	13.15	25.37

3-3. Results of determination of the natural repose angle

The results of the investigation of the angle of repose of Fig. 4 showed that in this diagram, the horizontal axis represents the size of the used sieve and the vertical axis represents the natural repose angle obtained for the vermicompost fertilizer. By examining the graph associated with the natural repose angle in this study, we found that with increasing particle size of vermicompost, the natural repose angle is gradually decreasing.

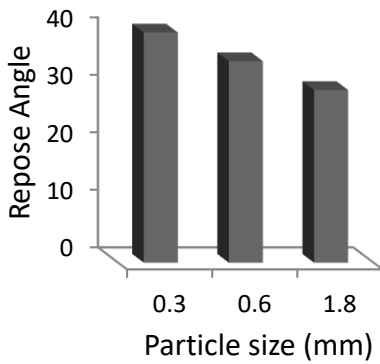


Figure 4: The graph of the results of determining the natural repose angle and particle size

3-4- Bulk density

Measuring the bulk density of vermicompost powder was done with the size of holes (meshes) 0.3, 0.6 and 1.18 mm at humidity level of 10%, 20%, 30%, 40% and 50% and wet condition. Figure (5) shows the effect of particle size on bulk density of vermicompost powder that with increasing particle size from 0/3 to 1/18 mm bulk density ranges vary from 0.85 to 0/60 grams per cubic centimeter. Volume of particles size is increased with increasing particle size; however, due to the fact that in a container with constant volume if larger particles are poured, in some areas due to the formation of solid bridges, a smaller number of particles will be present at volume unit. Therefore, the mass per volume unit decreases, and as a result the bulk density is decreased.

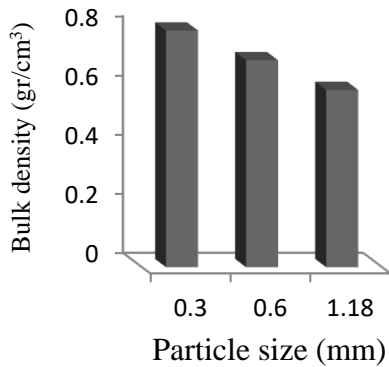


Figure 5: The effects of particle size is the bulk density

Figure (6) shows the effect of moisture on bulk density. It can be seen that with increasing humidity of 10% to 50% (wb) the bulk density of vermicompost has dropped from 0.85 to 0.35 grams per cubic meter. Generally, bulk density decreases with increasing moisture content and this indicates that increasing the volume of vermicompost powder is greater than the amount of water added to the mass. Therefore, in designing equipment necessary for management, warehousing and transportation of vermicompost by increasing the moisture content more space is better to consider. Relationship between moisture content and bulk density of Vermicompost shows with the mathematical expression, the linear fit $y = -0.012x + 1.02$ with $R^2 = 0.91$, Figure (6).

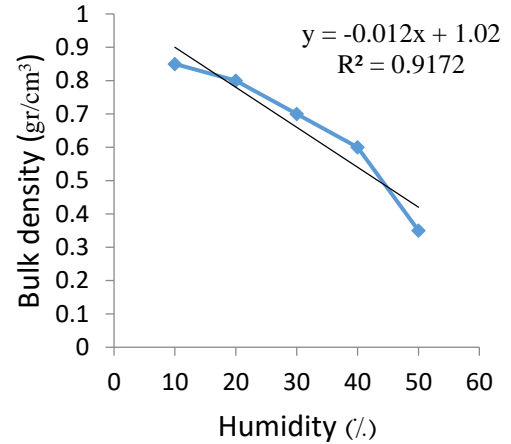


Figure 6: Relationship between moisture content and bulk density (grams per cubic centimeter)

3-5. Tab density

The results of analysis of variance of particle size and moisture content, on tab density in three levels of moisture content for three levels of particle size is shown in Table (4). As can be seen from this table, the simple effects of particle size and moisture content are significant at 1% level on tab density, but the interaction of particle size × moisture content parameters is not meaningful.

Table 4: Results of variance analysis (mean squares). Effect of particle size and moisture content on tab density

Variation resources	df	Mean squares of tab density
Particles size	2	0.019**
Moisture content	2	0.073**
Particles size * Moisture content	4	0.00094ns
Error	18	0.00018
Coefficient of variation (%)	-	1.86

** Significant at a probability level of 1% and ns is not significant

Figure 7 shows the results of the comparison of the mean particle size of the vermicompost on the tab density. As can be seen, with the increase in the particle size, tab density decreased significantly. In a mass with smaller particle sizes, particles will have more contact surface or, in other words, the size of the porosity is less than the size of the particle size; therefore, the ratio of mass to volume will be greater in smaller particle sizes. The results indicate an increase in actual volumetric mass from 0.68 to 0.77 with a decrease in particle size from 1.18 to 0.3 mm. Tab density for different vermicompost meshes with different moisture contents amounts is in the range of 0.67 to 0.8 grams per cubic centimeter. Figure 8 shows the results of the comparison of the mean content of vermicompost moisture content on the tab density. That its effect is significant at 1% probability level and with increasing moisture content, the volume of impact mass is reduced.

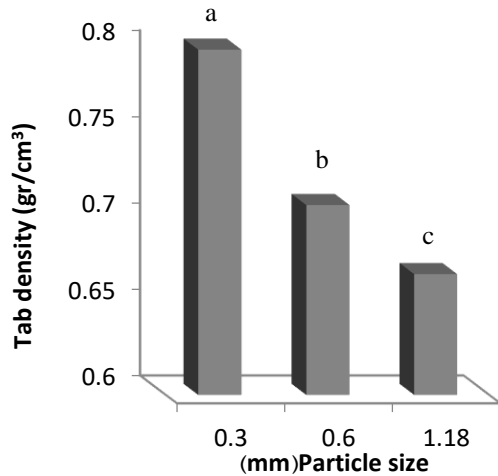


Figure 7: Impact of particle size on tab density

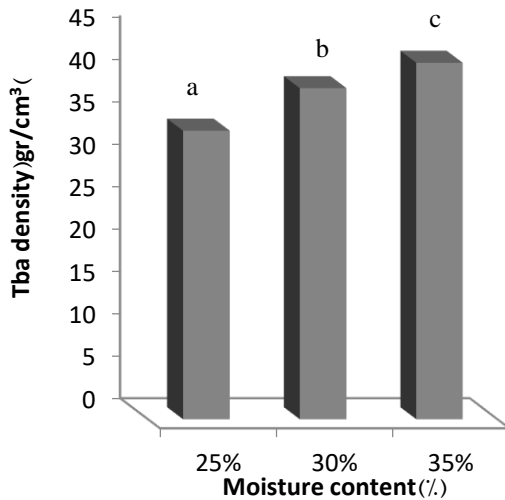


Figure 8: Effect of moisture content on Tab density

In tab density, the particles are displaced by successive strikes and fill the intervals, with the increase in humidity, the volume of particles will increase, and this time, with multiple strikes, even with the displacement of particles, the distances between them are more than that of low humidity. Therefore, we do not have much reduction in volume due to the strike which does not reduce the tab density significantly. The results of the comparison of the mean square of bulk density indicate that the interaction effects of moisture content and particle size were not significant on tab density. It can be said that for the mixture of fine and coarse particles the strike causes the particles to split that the coarse particles are transferred to the top of the container containing particles and fine particles move towards the bottom of the container and fill the empty spaces. But in the middle and top of the container, due to the presence of large particles, there is a large amount of free space between particles and fine particles are not available to fill these spaces so we should strike many times to fill the empty spaces. However, mass particles that are a set of fine

and coarse particles have lower tab density than their Hausner ratio is higher which indicates high compressibility and low flowability (Bodhmag, 2006).

3-6. True Density

The results of analysis of variance of particle size and moisture content, on true density values for 125 Mpa at two levels of moisture content and the three particle size levels are shown in Table (5). As shown, only the effect of particle size on the true density at the 1% level is significant.

Table 5: Results of variance analysis (mean square). Effects of particle size and moisture content on

Variation resources	df	Mean squares of true density
Particles size	2	0.024**
Moisture content	1	0.0009ns
Particles size * Moisture content	4	0.0007ns
Error	12	0.0062
Coefficient of variation (%)	-	1.5

** Significant at a probability level of 1% and ns is not significant

The results of the comparison of means showed that particle size has a significant effect on the true density at the probability level of 1% (Fig. 9), by increasing the particle size from 0.3 to 18.1 mm, the true density will decrease from 1.59 to 1.46. This can be due to the effect of increasing the particle volume with increasing particle size is greater than the increase in particle volume with increasing particle size. Research conducted for biological agricultural products has similar results (Nimkar and Chattopadhyay, 2001).

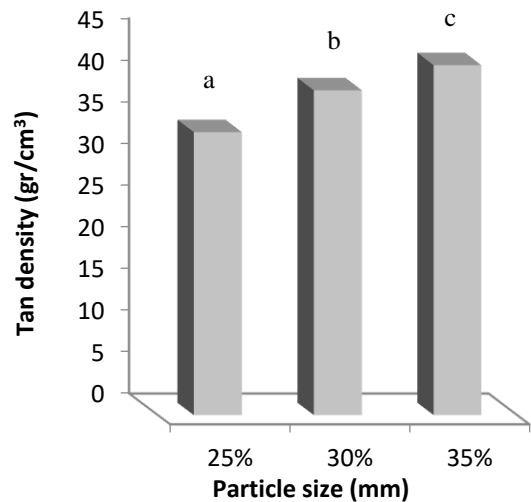


Figure 9: Effect of particle size on real volume mass

3-7. Hausner ratio

Compression can be considered as a criterion for the mass flow of materials, which Hausner ratio shows this characteristic (Carr, 1965). The results of variance analysis of the effect of particle size and moisture content on the Hausner ratio at three levels of moisture content for three levels of particle size are shown in Table (6). The simple effects of particle size and moisture content variables on Hausner ratio are significant at 1% level and the interaction effect of particle size × moisture content on the Hausner ratio is not significant.

Table 6: Result of variance analysis (mean square). The effect of particle size and moisture content on Hausner ratio

Variation resources	df	mean square of Hausner ratio
Particles size	2	0.055**
Moisture content	2	0.0057**
Particles size * Moisture content	4	0.00025ns
Error	18	0.0018
Coefficient of variation (%)	-	0.81

** Significant at a probability level of 1% and ns is not significant

The effect of particle size on the Hausner ratio is shown in Fig. 10. As can be seen, this ratio decreases by increasing the particle size from 1.30 to 1.14 which indicates an increase in the mass flow rate with increasing particle size. Past research results on several powders also showed that by increasing the average particle size, the Hausner ratio decreases, which is associated with increasing flowability. When the average particle size is smaller, it means that the number of fine particles is greater and therefore, no more particles are in contact with each other so there is more space between them. In fact, solid-bridging by particles have given rise to large vacant spaces in the materials mass (Abdullah and Geldart, 1999). Now if these masses of materials are in shock, these bridges will be broken and these particles come together. This results in a greater difference between bulk density and tab density. That is, tab density increases, which results in a lower Hausner ratio (Bodhmag, 2006).

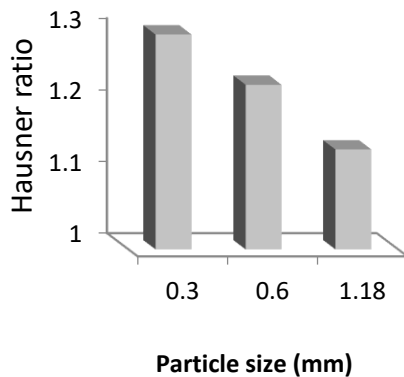


Figure 10: The effect of particle size on the Hausner ratio

The results of the comparison of the averages showed that moisture content had a significant effect on the Hausner ratio at 1% level (Fig. 11).

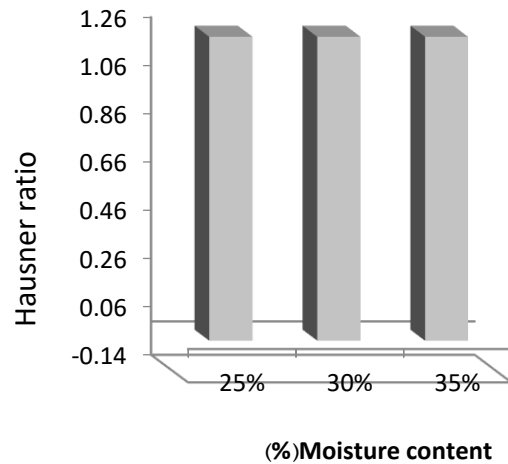


Figure 11: The effect of moisture content on Hausner ratio

As the moisture content is increased, as explained for the densities, if increase in the volume of particles is high and the free space between the particles increases with this volume increase which causes the difference between mass density and tab density to increase and by breaking solid bridges, reduction in volume will be tangible and its difference with tab density will be higher and the Hausner ratio, which is the ratio of tab density to bulk density will increase. The average Hausner ratio for Guano was 1.07 (Bernhart, 2007). Adhesive materials have a Hausner ratio higher than 1.4. At 25% humidity, the particles actually act as non-sticky powder and they flow through pipes and canals easily. The Hausner ratio is a standard for powder material flowability. Table (2) expresses the definitional relationship between the flowability and the Hauser ratio (Hayes, 1987). According to table (2), vermicompost powder is very fluid in the range of powdered granules and very soft powder.

3-8. Results of the angle of the mass in the Hell-Shaw method

The results of variance analysis of the effect of particle size and moisture content on the mass angle at three levels of 25, 30 and 35% moisture content and three levels of particle size of 0.3, 0.6 and 1.8 mm are shown in Table (9). As can be seen, the simple and cross effects of the size of the particles and the moisture content on the mass at the level of 1% is significant. As the particle size increases, the angle of the mass will decrease. Fig. 12 shows the increase in fluidity with increasing particle size.

Table 9 - Results of variance analysis (mean squares). The effect of particle size and moisture content on mass angle values

Variation resources	df	Mean squares mass angle
Particles size	2	81.17**
Moisture content	2	101.69**
Particles size * Moisture content	4	19.21**
Error	18	0.84
Coefficient of variation (%)	-	1.68

** Significant at a probability level of 1% and ns is not significant

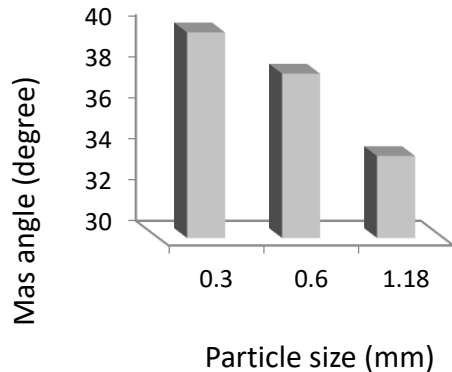


Figure 12: The effect of particle size on the average mass angle in different moisture content

Also, the results of the comparison of the averages showed that Moisture content had a significant effect on the mass angle at 1% level. As shown in Fig. 13 as the moisture content increases, the angle of the mass increases that indicates a decrease in fluidity with increasing moisture content.

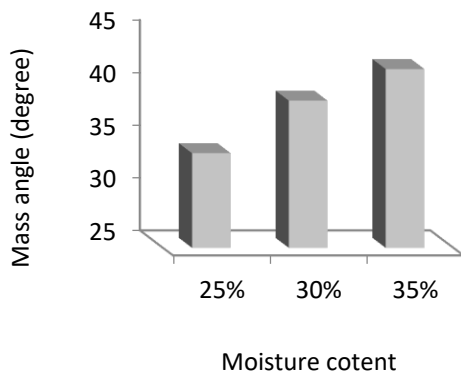


Figure 13: Effect of moisture content on the average mass angle in different particle sizes

Also, the comparison of the means showed that the interactions of moisture content and particle size were

significant at 1% level. Figure (14) shows the interaction effects of particle size and moisture content.

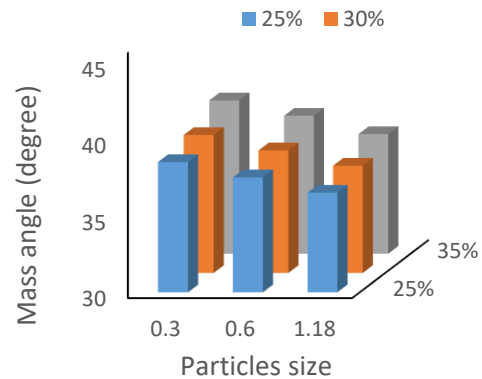


Figure 14 – Interaction effects of Particle Size and Moisture Content on Mass Angle

By increasing the moisture content and decreasing the particle size, the mass angle rises from 27.36 to 41.81, which means that the flow rate decreases in this process. According to table (1), in this range, the moisture content and the size of the vermicompost particles are within the range of very free flow and flowing stream as smooth as possible; therefore, according to the results obtained, a relationship can be established between the angle of internal friction and the angle of mass to study the vermicompost flow rate with the simplest test. Figure (15) shows the relationship between the angle of the mass and the internal friction angle.

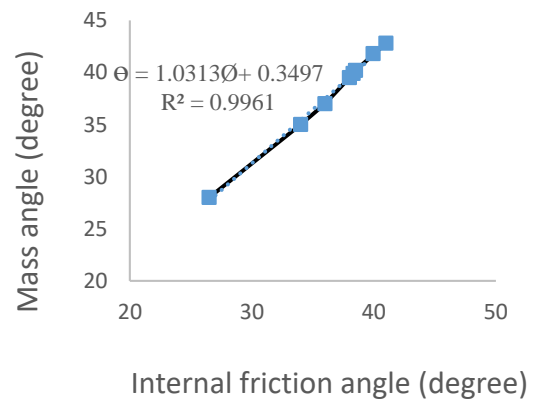


Figure 15: Relationship between the angle of friction and the angle of mass

Figure 15 shows the existence of a completely linear relationship with the correlation coefficient $R^2 = 0/99$. As it turns out, the values of the angle of mass with the values of the internal angle of friction are almost equal. This result is consistent with the vermicompost flow rate of the mesh size and the tested moisture range (Peleg, 1978 and Reimbert, 1991).

CONCLUSION

Bulk density decreases with increasing humidity and this suggests that increasing the volume of vermicompost powder is greater than the amount of water added to the mass. By increasing the particle size from 0.3 to 1.18 mm, the bulk density is reduced from 0.80 to 0.60 grams per cubic centimeter. Also, the results of the repose angle indicate that by reducing the particle size, the coefficient of internal friction increases and the angle of repose increases. Particular effects of particle size and moisture content at 1% level on impact mass volume and Hausner ratio are significant and with increasing moisture content the tap density decreased. Hausner ratio decreases by increasing the particle size from 1.30 to 1.14 which indicates an increase in flowability rate with increasing particle size. Both the Hausner and Hele-Shaw ratio indices were used to determine the properties of each other.

REFERENCE

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