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# Determination of some rheological properties of cow manure using a shear vane

**Heman Amiri[1], Akbar Arabhosseini, Mohamad Hosein Kianmehr**
Department of Agrotechnology, College of Abouraihan, University of Tehran, Iran

## ABSTRACT

Knowledge about rheological properties of biomass is necessary for optimization of pelleting process as well as the design of devices with optimum energy and pressure to determine the effect of different variables on the density and durability of produced pellets. Therefore, in this study a shear vane was used to determine the rheological properties of biomass materials and some rheological properties of cow manure. The experiments were done at moisture content levels of 35, 40 and 45% (w.b.), and rotational speed of the shear vane test chamber in three levels of 0.1, 0.2 and 0.3 rpm. The analysis of variance of moisture content and rotational speed of the chamber on the measured traits using SAS software showed that the rotational speed has no significant effect on none of the traits at 1% level. The independent effect of moisture content was significant on all the traits. The interaction between moisture content and rotational speed of the chamber was not significant on any of the traits. The highest maximum torque, maximum shear stress and maximum yield stress were achieved at 35% moisture content and rotational speed of 0.1 rpm. The lowest maximum torque, minimum shear stress and minimum yield stress was found at 40% moisture content and rotational speed of 0.1 rpm.

**Key words**: Cow manure, Shear stress, Shear vane, Yield stress

## INTRODUCTION

Biomass refers to any organic materials that are derived from plants or animals (Loppinet-Serani *et al*., 2008). It is difficult to find a general accepted definition for biomass, however, the one used by the United Nations Framework Convention on Climate Change is relevant here:

"A non-fossilized and biodegradable organic material originating from plants, animals and microorganisms. This shall also include products, by-products, residues and waste from agriculture, forestry and related industries as well as the non-fossilized and biodegradable organic fractions of industrial and municipal wastes" (Crocker, 2010).

Moisture content, high volume and non-uniform materials, are the factors which limit the usage of biomass materials, especially manures and farmyard compost from urban waste. Normally due to low density, the transport of these manures is difficult and expensive. Compression and pelleting are the methods to reduce transportation costs, increase economic efficiency and management for distribution of these materials in farms (Adapa *et al*., 2003).

There are two ways to convert organic manures to platform. The instrument platform which are used for this goal are extruders and die rollers. Extruders have a cylinder and the raw material drives into the cylinder by a screw. The materials will

[1] hemanamiri@ut.ac.ir; ahosseini@ut.ac.ir; kianmehr@ut.ac.ir; Dept. of Agrotechnology, College of Abouraihan, University of Tehran, Pakdasht, 3391653755, Tehran, Iran. Tel: +98 (21) 360 40 614; Fax:+98 (21) 360 40 730

be compacted by pressure of the screw and friction between the wall and screw and then the compacted materials will be exited out of the die by the screw pressure in the shape of narrow cylindrical shapes. These materials will be cut by a knife, at different lengths and even to various forms of rod, bullet, tape or a continuous spiral (Keshvari Sarani, 2011).

Variables such as machine geometry format, duration and amount of storage material in the form of pressure, the inlet roller and process variables such as temperature, moisture content and steam conditions (volume and vapor pressure are used) and the amount of material fed into the machine on the quality pellets affect (McMahon, 1984).

Knowledge about physical and rheological properties of the material and press equipment conditions are necessary to calculate the compression process and to determine the required power. Viscoelastic and rheological properties of manures and compost pellets can be used for models by springs and dashpot (Sitkey, 1986).

Rotational viscometers are important for characterization of non-Newtonian fluid behavior. Viscometers are available in two types, namely; the controlled shear rate instruments and controlled stress instruments. Various devices have been designed for measurement of rheological properties, especially viscosity measurements of liquid, semi liquid and pasty materials that may have different working principles. The methods based on fundamental viscometers are divided into two major categories of tube and spin (Ghanbarzadeh, 2009).

The blade of the shear vane by the motor rotates with constant velocity and the fluid space between the tank and it enters the blade torque, which is measured by a torque converter. Torque is proportional to the viscosity ratio (Landry *et al*., 2002).

Visco-plastic fluid behavior is characterized by the existence of a critical shear stress. Many non-Newtonian materials have a critical yield stress which they do not flow below this level and they are sometimes called visco-plastic materials (Bird *et al*., 1983). They behave like solids when the applied shear stress is less than the yield stress; once it exceeds the yield stress, it will flow just like a fluid. For shear stress greater than yield stress, the internal structure collapses completely, allowing shearing movement to occur (Zisis and Mitsoulis, 2002).

Landry used a shear vane to measure the rheological properties of animal manures. The rheological properties of sheep, poultry, pigs and cows manures were examined at different levels of concentration of solids in two phases of solid and semi-solid (Landry *et al*., 2002).

In another study in 2005, Karmakar in Agricultural Engineering and Biological Research, University of Saskatchewan used a shear vane to evaluate the dynamic soil parameters. He had built himself a device that could be used to study the viscosity and yield stress of the soil. In the device built by Karmakar, the blades move by gears and chains driven by an electromotor. The blades were immersed into the soil inside the container. Then during the rotation of the blade inside the soil, the exerted force by soil was registered and sent to data logger for analysis (Karmakar, 2005).

From practical point of view, there nonetheless is that the yield stress ($\sigma_0$) engineering nature that may affect the process and give technical computing. Thus, various methods have developed to calculate the yield stress. The shear vane method is the most common methods for determining the shear strength and yield stress in the laboratory for plastic materials and powders because of its ease and simplicity. This assumption is that the mass of material within the container, is measurable at all levels within a torsion strength and resistance against the rotation of the blades on a specified length and diameter (Amiri, 2012).

The aim of this study was to determine the maximum torque, shear stress and yield stress materials in order to determine the pelleting factors for biomass and cow manure.

## MATERIALS AND METHODS

Required dairy cattle manure for tests was collected from rural dairy cattle and prepared in different particle size. The manure was considered enough and crushed and storage by electric grinder in the Department of Agrotechnology, College of Abouraihan, University of Tehran. According to ASTM standards for testing manure bed the samples were prepared with the desired mesh. The initial moisture content of the manure was determined in three replications by drying of the samples in the oven at temperature103 ±3˚C for 48 hours. The moisture content was determined according to Eq.1 in terms of wet basis (Anonymous. 1998).

$$MC(w.b.)\% = \frac{m_w}{m_w + m_d} \times 100\ \% \qquad (1)$$

In this equation:

MC (w.b.) % = Moisture content of fresh manure (%)

$m$mass of water in the manure (g)

$n$ mass of dry matter in the manure (g)

To achieve the desired moisture content for preparing the samples, an amount of distilled water was added to the manure based on Eq.2.

$$m_w = \frac{m_t(M_{wf} - M_{wt})}{1 - M_{wf}} \qquad (2)$$

In this equation:

$M$ initial moisture content of fresh manure (%, w.b.)

$M_{,}$ final moisture content of manure (%, w.b.)

$\imath$ initial mass of manure (g)

$n$ the mass of distilled water added to manure (g)

Certain amount of distilled water was added to the samples based on the calculation using Eq. 2 and then the samples were kept at 5°C in the refrigerator in plastic packages for 72 hours in order to have uniformly distributed moisture in the samples. In this study, the samples were prepared at three moisture content levels of 35, 40 and 45% (w.b.).

Viscoplastic will be identified by the behavior of the critical (maximum) yield stress. Non-Newtonian materials which don't flow at lower level than the maximum yield stress are sometimes called Viscoplastic. The yield stress can be determined by various devices like shear vane which in this device the stress required to initiate flow (yield stress) determined by a vane that is immersed in the test material.

A shear vane was used to determine the yield stress, maximum torque and shear force of the biomass materials. The shear vane apparatus consists of shearing vane, vane spindle, test container, vertical displacement vane mechanism, motion transmission mechanism, driveline, data acquisition system and main-frame (Fig. 1).

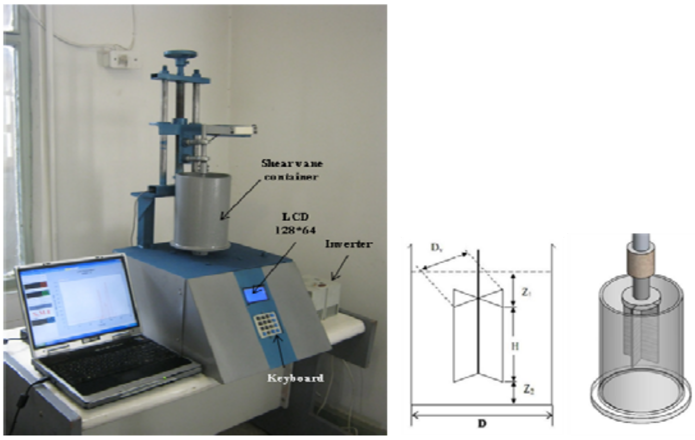


Fig. 1: The shear vane and the main components (Amiri, 2012)

The prepared manures were transferred into the test container in three layers. Each layer was compacted by pounding a wooden block to the predetermined compaction level at controlled conditions in order to have the same density for all experiments (Karmakar and Kushwaha, 2007).

When the manure was prepared in the test container the vane was inserted into the material by moving down the vertical displacement mechanism. The container was rotated at predetermined speeds of 0.1, 0.2 and 0.3 rpm. The speed was controlled by an inverter which was run at a range of frequency (1 to 10 Hz). The response of cow manure to the shearing vane was observed for predetermined manure conditions to find out the maximum torque. Software of the shear vane records the torque required to shear the material with respect to time.

**Rheological analysis of the Shear vane**

It is assumed that the shear stress is distributed uniformly on all vertical edges of the vane but perhaps on the top and bottom of the vane is much non-uniform. Therefore according to Eq. 3, the interpretation of shear vane test results, which consider the shear stress, is very popular:

$$\tau = \frac{0.86\ M}{\pi D_v^3} \tag{3}$$

The total torque ($M_0$) required to surmount the yield stress of the material can be divided into two parts (Tanjore, 2005):

i) The torque ($M_c$) required for the vane's cylindrical surface (Eq. 4),

$$M_c = \left[(\pi D_v H)(\sigma_0)\right]\left[\frac{D_v}{2}\right] = \frac{\pi h D_v^2}{2}\sigma_0 \tag{4}$$

Which in Eq. 4, ($\pi D_v H$) represents the area of stress application (cylindrical surface area), and $D_v/2$ is the distance between the point of applied force and the vane's cylindrical surface (radius of the vane, $R_v$)

ii) The torque ($M_h$) required for the upper and lower horizontal surfaces of the vane (Eq. 5) (Tanjore, 2005),

$$M_h = \frac{\pi \sigma_0 D_v^3}{2\left(3+m\right)} \tag{5}$$

Thus the total torque is equal to the sum of these two parts and eventually (Eq.6);

$$M_0 = M_c + M_h = \frac{\pi \sigma_0 D_v^3}{2}\left(\frac{H}{D_v} + \frac{1}{6}\right) \tag{6}$$

The $D_v$ and H are the vane dimensions which are shown in Fig. 1 and $\sigma_0$ is the yield stress resulted by Eq. 7 (Tanjore, 2005);

$$\sigma_0 = \frac{2M_0}{\pi D_v^3}\left(\frac{H}{D_v} + \frac{1}{6}\right)^{-1} \tag{7}$$

Factorial experiment based on completely randomized design with three replications was applied to investigate the effects of different levels of moisture content and rotational speed on rheological properties of cow manure. Rotational speed of the container of shear vane was tested in three levels as factor A (0.1, 0.2 and 0.3 rpm) and three moisture content levels (35%, 40% and 45%) as factor B. The torque exerted on the blades was measured for a duration of 600 seconds for all treatments in order to calculate the shear stress and yield stress. Data analysis on torque, shear stress and yield stress was performed using SAS software.

The effects of moisture content and the rotational speed of container and also their interaction was performed with Duncan's multiple range test at 5% level.

## RESULTS AND DISCUSSION

Fig. 2 shows the torque value during the shear test. The shear force applied to the manure in the surrounding area of the vane increases by rotation of the container. The shear resistance of the manure against the vane, first increases until a rupture occur in the materials and then decreases. The level of the torque which causes rupture of the materials was chosen as the maximum torque. The results of this section were similar to Karmakar’s results that used a shear vane to calculate the rheological properties of soil (Karmakar and Kushwaha, 2007).

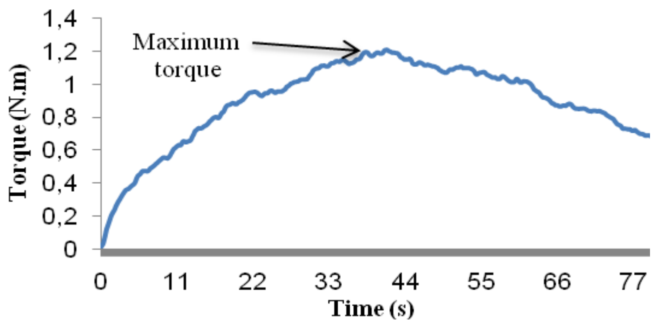


Fig. 2: The changes of resulted torque by shear vane for cow manure at moisture content of 40% and rotational speed of 0.1 rpm.

The maximum torques were obtained at different rotational speeds and different levels of moisture content of the manure (Fig. 3). The maximum torque or shear strength increased by increasing of rotational speed. The results of this section were completely consistent with Karmakar’s results who compared the maximum shearing torques of soil at the 17% moisture content and different rotational speeds. The maximum torque increased with increasing of shear rate (Karmakar and Kushwaha, 2007).

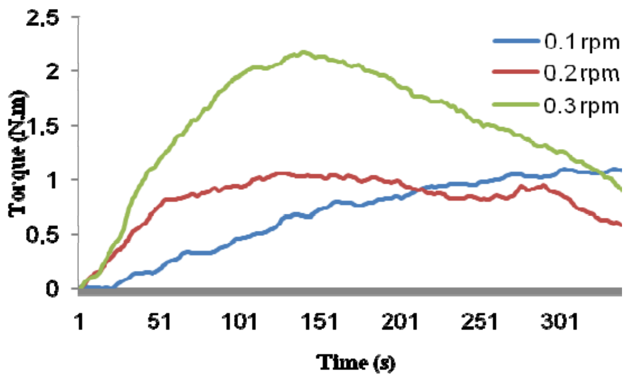


Fig. 3: The resulted torque by shear vane for cow manure with 35% moisture content and at three levels of rotational speed

## The effect of moisture content within shear vane on torque, yield stress and shear stress dough cow manure

The results of analysis of variance and the effect of moisture content on the measured traits showed a significant effect on the rotation within shear vane had none of the traits measured. Independent effect of moisture content on the traits was significant at 1% level. The results showed that the interaction of moisture content and on none of the traits were not significant (Table 1).

Table 1 Analysis of variance the effect of cow manure moisture content and rotational speed of shear vane container on the torque, yield stress and shear stress

| M.S | | | | |
|---|---|---|---|---|
| **Shear Stress** | **Yield Stress** | **Torque** | **df** | **SOV** |
| **334292.44$^{ns}$** | **390113.02$^{ns}$** | **0.093$^{ns}$** | **2** | **Rotation (rpm)** |
| **6250953.01**** | **7253055.53**** | **1.56**** | **2** | **Moisture content** |
| **623582.69$^{ns}$** | **727658.27$^{ns}$** | **0.17$^{ns}$** | **4** | **Rotation × Moisture content** |
| **554910.37** | **640280.34** | **0.128** | **18** | **Error** |
| **21.31** | **21.30** | **21.27** | **–** | **C.V.** |

* & ** - significant at the 5% and 1% level and ns, non significant.

The results showed that the mean independent effect of moisture content on the torque of the torque was achieved in 35% moisture content, with 40% and 45% treatments were significantly different at 5% level indicated. The results showed an increase of 35% to 40% moisture content, torque of 2.164 N.m to 1.390 N.m was decreased. Torque changes in moisture content of 40% and 45% were not significantly different (Fig. 4).

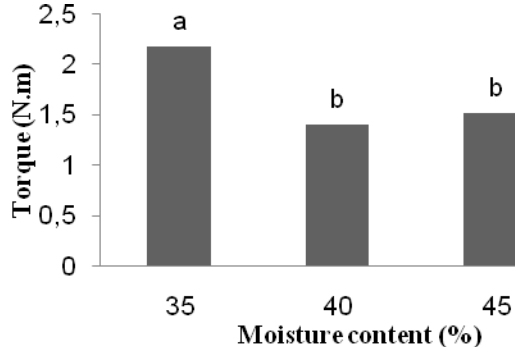


Fig. 4: Effect of different levels of cow manure moisture content on maximum torque

The influence of moisture content on the yield stress of cow manure showed that the yield stress is reduced with increasing moisture content (Fig. 5). This phenomenon could be come out of existence of water between manure particles and the friction between solid particles attributed to manure. With increasing of moisture content, the water molecules move more freely and this phenomenon may lead to reduce solid-solid friction of manure particles. However, the yield stress increased at 45% moisture content. This phenomenon may be due to increasing adhesion in the manure particle by increasing of moisture content. The results of this section were almost consistent with Karmakar results (Karmakar and Kushwaha, 2007).

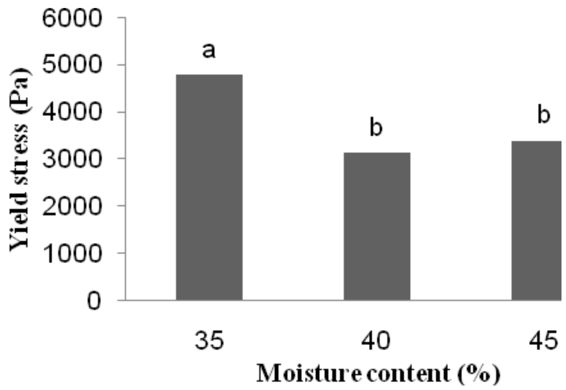


Fig. 5: Effect of different levels of cow manure moisture content on the yield stress in the vane test

The results showed that the maximum shear stress was obtained at 35% moisture content. The shear stress at 35% moisture content was significantly different at 5% level, with the results of 40% and 45% moisture content. The shear stress decreased from 4.44 kPa to 2.89 kPa with increasing of moisture content from 35% to 40%. The changes of shear stress were not significantly different at 40% and 45% moisture contents (Fig. 6).

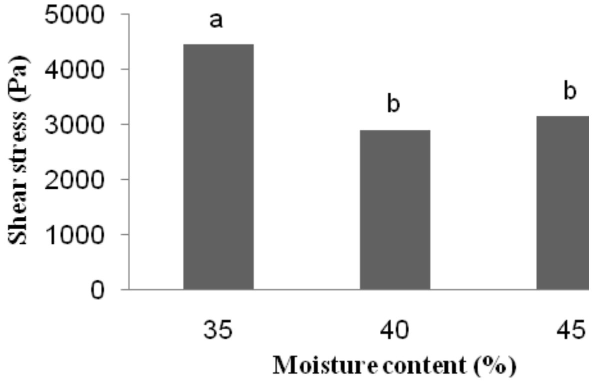


Fig. 6: Effect of different levels of moisture content of cow manure on maximum shear stress in the vane test

The highest maximum torque (2.46 N.m) was obtained at 35% moisture content and a rotational speed of 0.1 rpm, while the lowest maximum torque (1.24 N.m) was at 40% moisture content and rotational speed 0.1 rpm (Fig. 7).

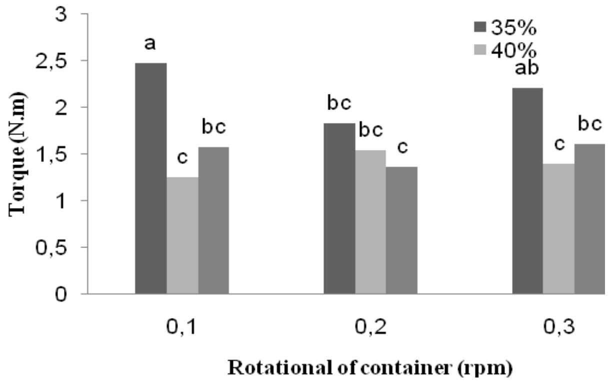


Fig. 7: Effect of different levels of moisture content and rotational speed of shear vane container on maximum torque

The interaction between rotational speed and moisture content showed that maximum shear stress (4.96 kPa) at 35% moisture content and a rotation speed of 0.1 rpm was obtained and the lowest shear stress (2.58 kPa) at moisture content of 40% and the rotation speed of 0.1 rpm was obtained (Fig. 8).

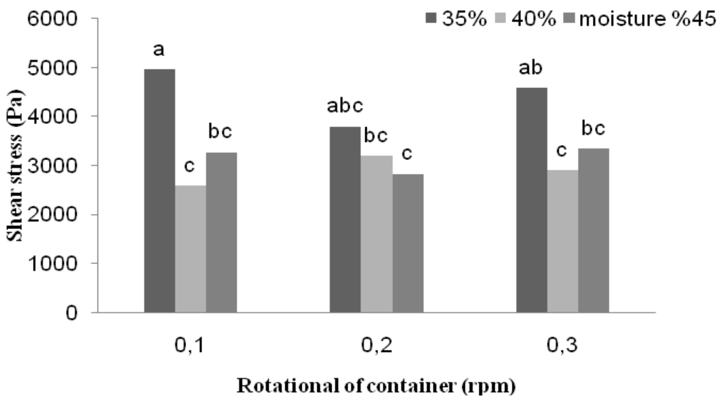


Fig. 8: Effect of different levels of cow manure moisture content and rotational speed of shear vane container on shear stress

Results comparing the effect of treatments showed that the highest yield stress (5.34 kPa) at 35% moisture content and a rotation speed of 0.1 rpm was obtained and the lowest yield stress (2.77 kPa) at moisture content of 40 % and the rotation speed of 0.1 rpm was obtained (Fig. 9).

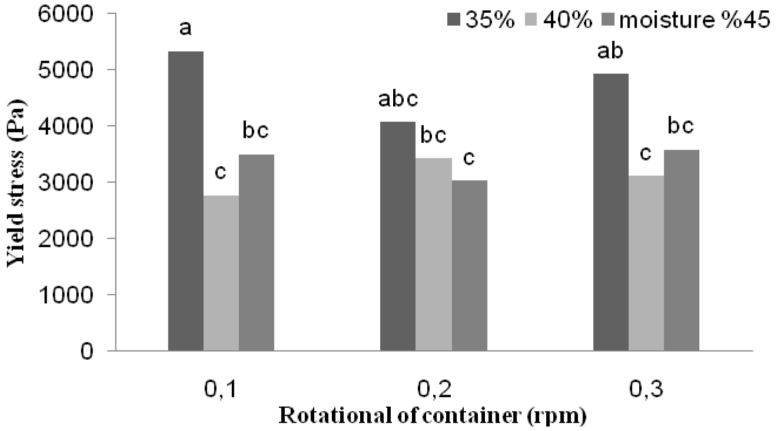


Fig. 9: Effect of different levels of cow manure moisture content and rotational speed of shear vane container on the yield stress

## CONCLUSION

Some rheological properties of cow manure were studied by using a shear vane. The results showed that the maximum torque or shear strength increased with increasing the rotational speed of the vane. Independent effect of moisture content on the traits was significant at 1% level. The maximum torque (2.46 N.m) was obtained at 35% moisture content and rotational speed of 0.1 rpm while the minimum torque (1.24 Nm) was at 40% moisture content and rotational speed of 0.1 rpm. The maximum shear stress (4.96 kPa) at 35% moisture content and a rotation speed of 0.1 rpm and the lowest shear stress (2.58 kPa) at 40% moisture content and a rotation speed of 0.1 rpm was obtained.

The maximum yield stress (5.34 kPa) at 35% moisture content and rotation speed 0.1 rpm and the lowest shear stress (2.77 kPa) at 40% moisture content and rotation speed of 0.1 rpm was obtained.

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