*Physicochem. Probl. Miner. Process. 52(2), 2016, 575−587*

www.minproc.pwr.wroc.pl/journal/

Physicochemical Problems
of Mineral Processing

ISSN 1643-1049 (print)
ISSN 2084-4735 (online)

*Received August 22, 2014; reviewed; accepted January 2, 2015*

# THE EFFECT OF FILLING OF THE DRUM ON PHYSICAL PROPERTIES OF GRANULATED MULTICOMPONENT FERTILIZER

**Yousef GHASEMI, Mohammad H. KIANMEHR**

Department of Agrotechnology, University of Tehran, College of Abouraihan, Teheran, Iran
ghasemy_jam@yahoo.com

**Abstract:** One of the operations in particulate processing which has an ancient history and a widespread use is granulation. Granulated compost fertilizer was granulated using the drum granulation method under different level of drum filling. Filling of the drum ranged from 5 to 10% (v/v). The effect of filling of the drum on some physical properties granulated compost fertilizer including: useful granules, granules size, crush strength, mass of the granules, bulk density, angle of friction and angle of repose are investigated in the present study. Result indicated that with the increasing of drum filling the percentage of useful granules, crush strength, bulk density, angle of friction and angle of repose increase from 64.97% to 78.82%, 34.32 N to 36.69 N, 745.585 kg/m$^3$ to 762.729 kg/m$^3$, 25.56° to 27.93° and 11.38° to 12.52°, respectively. Also the average size of granules decreases from 10.28 mm to 9.45 mm.

***Keywords:*** *drum granulation, granulation time, filling of the drum, granulation of fertilizer*

## Introduction

Municipal solid waste (MSW) is produced in great quantity in Iran, that is about 16 teragrams (Tg) per year, and its management has become a challenge, both economically and environmentally. More than 50% of the MSW generated by the Iran population is organic waste that can be converted into compost (Mavaddati et al., 2010). Composting MSW is considered as a method of transferring organic waste materials from landfills to a product, which is suitable for agricultural purposes at relatively lowcost (Eriksen et al., 1999). Composting of MSW has the potential to become a beneficial recycling tool for waste management in Iran. A variety of densification systems are considered for producing a uniform format feedstock including (*i*) pellet mill, (*ii*) cuber, (*iii*) screw extruder, (*iv*) briquette press, (*v*) roller press, (*vi*) tablet press, and (*vii*) agglomerator (Wolkowski, 2003).

http://dx.doi.org/10.5277/ppmp160205

Granulation is the generic term used for particle agglomeration processes, in which fine powdery solids are agglomerated together with a liquid/melt binder to form larger aggregates (Ramachandran et al., 2008). The granulation of fertilizers was one of the most significant advances in fertilizer technology, affording considerable advantages to both manufacturer and user. Biomass is very difficult to handle, transport, store and utilize in its original form (Sokhansanj et al., 2005). The agglomeration of fertilizer granules in storage, known as caking or bag set, is a significant quality assurance problem for the fertilizer industry. The agglomeration of fertilizer granules can take place over weeks or months in storage (Ghasemi et al., 2013).

Compression in granule form is one method to get easy storage, transportation, dispose of agricultural wastes and to decrease the costs is to reduce the volume of the manure. The compressed manure can be used as the fertilizer in agricultural farms. This also eliminates the need for manure plants and reduces the cost of manure (Adapa et al., 2003). While substantial research on granulation processes and physical and mechanical properties of granules in chemistry and pharmacy sciences has been made, a limited number of published literatures are available about physical and mechanical properties of fertilizer granule. The mechanisms for granule growth (granulation) including nucleation, growth, random coalescence, pseudo-layering and crushing and layering were studied by Sastry and Fuerstenau (1973).

The analysis of static and dynamic equilibrium of the granulated bed, and also results obtained by Heim et al. (2004a, b) prove that inertia and friction forces in the tumbling feed depend significantly on such equipment and process parameters as bed moisture content, drum diameter, its filling degree and rotational velocity of the granulator. Coalescence is the most probable mechanism for low temperature fertilizer granulation using a feed with a broad particle size distribution (Litster and Liu, 1989). The efficiency of wet granulation process using drum granulator depends on many factors including binder content, rotational speed, surface roughness, size of drum, raw material (feed particle size distribution) and drum filling degree (Chansataporn and Nopharatana, 2009).

Filling degree is also one of the most important factors which influence the production capacity of the granulation process using a drum granulator. Santomaso et al. (2003) studied the effect of drum filling degree on wet granulation process of glass bead. The drum was filled at three levels of 10%, 15% and 25% (v/v). The result revealed that the curvature of bed surface and the transition of granular flow depended on filling level. It has been suggested that different drum loads of calcite caused the different flow patterns. Even though much of this research work showed that binder content and filling degree affected the granulation process and granule qualities, the effects of binder content and filling degree have not been investigated in cassava pearl granulation. This research aimed to study the effect of binder content and drum filling degree on cassava pearl granulation (Ramachandran et al., 2008).

The effect of filling factor on changes in the bulk density as a function of moisture content of the granulated bed was negligible. The change of the drum filling factor k had no effect on the differentiation of bulk density of the granulated product of the same moisture content (Heim et al., 2005).

The effect of the granulation parameters on physical properties of the granules is one of the most important factors in optimal granulation conditions. Therefore the objective of the present work is investigating the effect of drum filling on some physical properties granulated compost fertilizer including: useful granules, granules size, crush strength, mass of the granules, bulk density, angle of friction and angle of repose.

## Experimental

### Production of granules

The compost used in the production of the granules was multicomponent fertilizer powder supplied by Moshaver Haseb Company, Tehran. The compost was produced from organic matter or biodegradable waste, such as urban waste, animal manure and crop residues using turned windrow composting method. Turned windrow composting is the production of compost in windrows using mechanical aeration that represents a low technology and medium labor approach and produces uniform compost. A chemical analysis of the compost was conducted by chemical analytical laboratory (University of Tehran). The amount of N, P and K in compost was 2.21%, 0.1% and 1.02%, respectively. Also the pH of compost was 8.59. Initial MC of compost was determined using the oven method at 103 °C for 24 h (ASAE, 2002). The initial MC of compost was 12±1% ($w_b$). There is an optimal range of particle size to obtain granules with acceptable quality. The results of pre-test indicate that sample with particle size larger than 1.5 mm have not ability to produce granule with acceptable quality because compost samples were ground using a hammer mill with 0.9 mm hammer mill screen sizes. The mean flour particle size $d_z$ = 0.38 mm was determined on the basis its size distribution.

The granules were produced in a no internal flights drum granulation. Production of the granules for each batch was repeated three times. A schematic diagram of the experimental set up is shown in Fig. 1. Drum (3) was driven by electromotor (5) by means of a belt transmission and a clutch (6). The granular bed placed in the drum was wetted drop-wise by means of sprinkler (4), which was introduced axially to the device that ensured a uniform liquid supply. The sprayer was mounted on stand (8), which was independent of the granulator. The wetting liquid (sugar beet molasses) was supplied from reservoir (1), placed at the height of 300 cm from the drum axis and its constant flow rate ($Q = 10^{-6}$ $m^3$/sec) was fixed by means of rotameter (2). During the trial, a constant liquid level was kept in the tank, which guaranteed a constant pressure of supplied liquid. The granular bed was wetted until the material got over-moist which caused that the bed stuck to the inner wall of the granulator (Obraniak and Gluba, 2012).

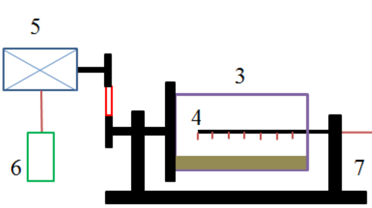

Fig. 1. A schematic diagram of experimental set up (Ghasemi, 2013)

In the present work the following parameters were used: drum diameter $D$ = 200 mm; drum length $L$ = 380 mm, rotational speed 50 rev/min. The solution to solid phase ratio, defined as the ratio of volume of liquid phase to that of solid phase in the granule and is given by the equation 1, cited by Walker et al., (2000):

$$y = \frac{M(1-S)\rho_S}{(1-MS)\rho_L}, \tag{1}$$

where $y$ is solution to solid phase ratio, $M$ is the moisture content, $S$ is the fertilizer solubility, $\rho_s$ is the solid fertilizer density and $\rho_L$ is the liquid fertilizer density.

For each granulation system, the fertilizer liquid and solid densities must remain constant. The range change of drum angular velocity is selected in such a way to provide cascading – the typical feed movement for drum tumbling granulators (Obraniak and Gluba, 2012). Filling of the drum ($k$) with granular material (5%, 6%, 7.5%, 9% and 10% v/v).

After granulation processes, wet granules were left in the atmosphere to dry. After being dried in the atmosphere, the granules were collected for measuring of physical properties

## Physical properties of granules

Physical properties of produced granules and effect of the granulation parameters on physical properties of the granule is one of the most important factors in optimal granulation conditions. Effect of the drum filling on some physical properties of produced granules including: useful granules, granules size, granules fracture resistance, granules mass, bulk density, coefficient of friction and angle of repose of granules were studied in the present work.

## Useful granules

For the purpose of the present work granules in the size range 5 to 10 mm were required. It was therefore necessary to optimize the process to ensure that the larger fraction of the granules from each batch would be within this size range. Any granules that are larger than 10 mm are regarded as oversize and these would need to be crushed in a continuous granulation circuit. Any granules passing through 5 mm were classified as fines and these could be recycled by reintroducing them into the granulation process. The efficiency of the process $\eta$ (Equation 2), is defined as the percentage of the product which meets the size requirement (Mangwandi et al., 2012):

$$\eta = \left(\frac{M_{Target}}{M_{Total}}\right) \cdot 100, \tag{2}$$

where $M_{Target}$ is mass of useful granules and $M_{Total}$ is mass of the batch granules. The mass of the useful granules batch using sieving was measured. Determination of the percentage of the useful granules was repeated three times.

## Granules size

The size distribution of the produced granules for each batch was determined using sieving. The stack of sieves with the granules was placed on an orbital sample shaker. Retsch sieves were used in the size analysis and the aperture sizes are as follows; 850, 1000, 1180, 1700, 2360, 3350, 4750, 12700 and 19050 μm. The duration of sieving was adjusted according to size of the sample. The sieving times for the 500 g batches were 22 min respectively at a speed of 180 rpm. The masses of granules retained on the sieves to determine the size distribution of the granules were used. Determination of the average of the granule size was repeated three times.

## Crush strength of granules

Crush strength ($CS$) of granules is determined by diametrical compression test. A pneumatic press used to measuring the $CS$ of granules (Ghasemi et al., 2013). A granule was placed between two horizontal plates and was compressed radially. A data logger was used for registering of force ($F$). Force was registered with a data logger at a sampling rate of 1000 readings/min. An increasing load is applied at a constant rate, until the test specimen fails by cracking or braking.

To investigate crush strength, for each filling of the drum, 20 granules in the shape close to spherical were taken from the bulk sample, and next each granule was placed separately between parallel compressing plates (mobile and immobile). The test lasted until the moment when the granule was destroyed between the compressing plates (Walker et al., 1997).

## Bulk density

One of significant parameters that describe the properties of granular materials is bulk density. For the determination of bulk density, the bulk material (granules) was put into topless cylindrical container with known weight, height (0.15 m) and volume (0.5 dm$^3$) from a height of 0.15 m at a constant rate (Dash et al., 2008). Bulk density ($\rho_b$) was calculated from the mass of bulk granules divided by volume containing the mass. Measurement of the bulk density was repeated ten times.

## Mass of the granules

In order to determine the effect of the drum speed on mass of the single granule, 100 granules were selected from the bulk samples, quite randomly. Then mass of the granules was measured. From bulk sample 300 granules were selected quite randomly; then granules were divided into three bins so that in each bin 100 seeds were placed. Bin weight was measured and multiplied by 10 to give mass of 1000 granules. The mass of the single granule and 1000 granules mass were measured using a digital balance with an accuracy of 0.01 g.

Mass of granules distribution was modeled using log-normal probability density functions. The probability density functions (*f(x)*) and cumulative frequency functions (*F(x)*) for log-normal distribution are showed in Equation 3 and 4:

$$f(x) = \left(\frac{1}{(x-\gamma)\sigma\sqrt{2\pi}}\right)\exp\left(-\frac{1}{2}\left(\frac{\ln(x-\gamma)-\mu}{\sigma}\right)^2\right), \tag{3}$$

$$F(x) = \varphi\left(\frac{\ln(x-\gamma)-\mu}{\sigma}\right)\ ,\ \varphi(x) = \left(\frac{1}{\sqrt{2\pi}}\right)\int_0^x e^{-t^2/2}\,\mathrm{d}t. \tag{4}$$

According to Equations 3 and 4, for the log-normal distribution, $\mu$ is scale parameter, $\sigma$ is shape parameter and $\gamma$ is location parameter. Whenever $\gamma$ is equal to zero log-normal distribution is called two parameters distribution, otherwise it is called three parameters distribution. Whenever $\gamma$ is equal to zero and $\mu$ equals one the log-normal distribution is called standard log-normal distribution (Mirzabe et al., 2012). In this study, log-normal distribution with two parameters was used.

## Angle of friction

The coefficient of external static friction, using iron sheet, was determined. A topless and bottomless metallic box with known dimensions (length 100 mm, width 100 mm and height 50 mm) put on the surface. The box was filled with granules. The surface was gradually raised by the screw. Both horizontal and vertical height values were measured using a rule and digital caliper when the seeds started sliding over the surface and, the coefficient of static frication was calculated using the following equation (Burubai et al., 2007):

$$\mu_s = \tan(A_F), \tag{5}$$

where $\mu_s$ is coefficient of static friction and $A_F$ is angle of static friction. Measurement of the angle of friction was repeated ten times.

## Angle of repose

Static angle of repose of granules was measured by the use of pouring method (Fraczek et al., 2007). The angle of repose was determined using a topless and bottomless metallic cylinder of 250 mm height and 150 mm diameter. The cylinder was placed at the iron surface and was filled with bulk material. The cylinder was raised very slowly. The height and diameter of the cone was measured using digital caliper and the static angle of repose was calculated using the following equation cited by Ghasemi et al. (2013):

$$A_R = \arctan\left(\frac{h}{r}\right), \tag{6}$$

where $A_R$ is angle of repose, $h$ is height of the cone, $r$ is radius of the cone. Measurement of the angle of repose was repeated ten times.

## Results and discussion

The effect of filling of the drum ($k$) on some physical properties granulated compost fertilizer including: useful granules, granules size, crush strength, mass of the granules, bulk density, angle of friction and angle of repose was investigated in present study.

### Useful granules

The effect of filling of the drum on percentage of the produced useful granules ($\eta$) is illustrated in Figure 2. According to Figure 2 with increasing drum filling from 5% to 10%, percentage of the produced useful granules was increased from 64.97% to 78.82%. For the purpose of present work granules in the size range 5 to 10 mm were required. Therefore maximum percentage of the useful granules was produced when the drum filling was equal to 10%.

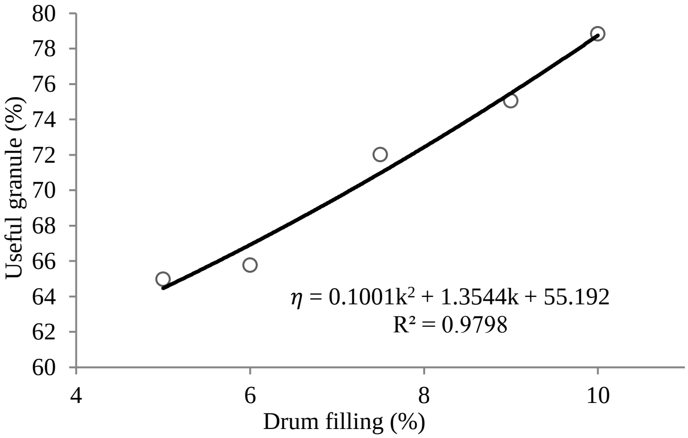

Fig. 2. Effect of drum filling on useful granule

## Granules size

The effect of filling of the drum on average of produced granule size ($D_{50}$) is illustrated in Figure 3. According to Figure 3 with increasing drum filling from 5% to 10%, the average size of the produced granules decreased from 10.28 mm to 9.45 mm.

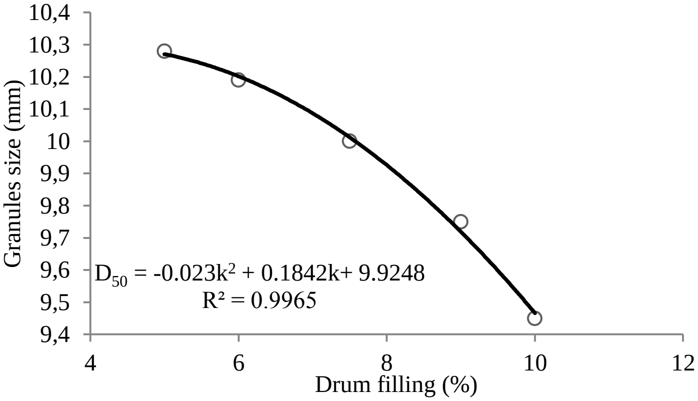

Fig. 3. Effect of drum filling on granules size

## Crush strength

The effect of filling of the drum on crush strength of the produced granules ($N$) is illustrated in Figure 4. According to Figure 4 with increasing drum filling from 5% to 10%, the crush strength of produced granules increased from 34.32 kg to 36.69 kg.

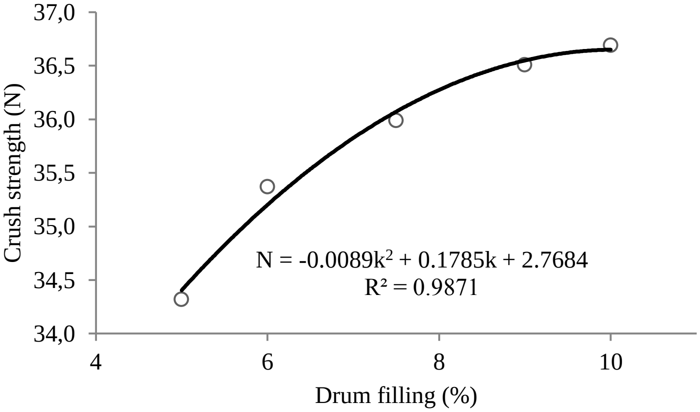

Fig. 4. Effect of drum filling on crush strength

## Bulk density

The effect of filling of the drum on bulk density of produced granules ($\rho_b$) is illustrated in Figure 5. According to Figure 5 with increasing drum filling speed from 5% to 10% the bulk density of the produced granules increased from 745.585 kg/m$^3$ to 762.729 kg/m$^3$.

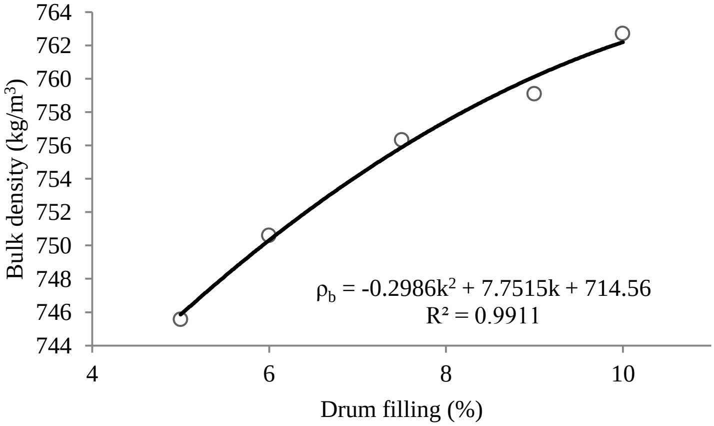

Fig. 5. Effect of drum filling on bulk density

## Mass of the granules

The effect of filling of the drum on mass of the produced granules ($M_1$) is illustrated in Figure 6. According to the Figure 6 with the increasing of drum filling from 5% to 10%, mass of the produced granules decreased from 0.69 g to 0.49 g.

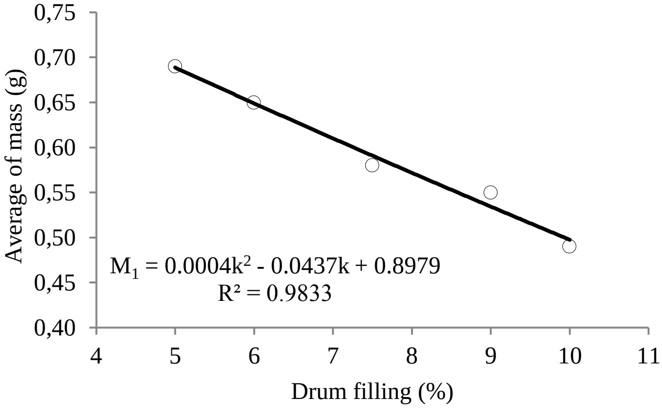

Fig. 6. Effect of drum filling on mass of granule

Mass of granules distribution was modelled using the log-normal probability density functions. The value of the log location parameter, log scale parameter, mean of log-normal distribution, variance of log-normal distribution and log-likelihood for each drum filling were calculated (Table 1). The probability density functions of log normal distributions for all rotational speed are showed in Figure 7.

Table 1. Parameters of log normal distributions for mass of granules

| Drum filling, % | Log location parameter | Log scale parameter | Mean of distribution | Variance of distribution | Log likelihood |
|---|---|---|---|---|---|
| 5 | -0.495 | 0.547 | 0.707 | 0.175 | -15.8267 |
| 6 | -0.565 | 0.531 | 0.654 | 0.141 | -10.5858 |
| 7.5 | -0.742 | 0.687 | 0.603 | 0.219 | -14.8902 |
| 9 | -0.846 | 0.914 | 0.651 | 0.551 | -23.6289 |
| 10 | -0.997 | 0.889 | 0.547 | 0.362 | -14.7129 |

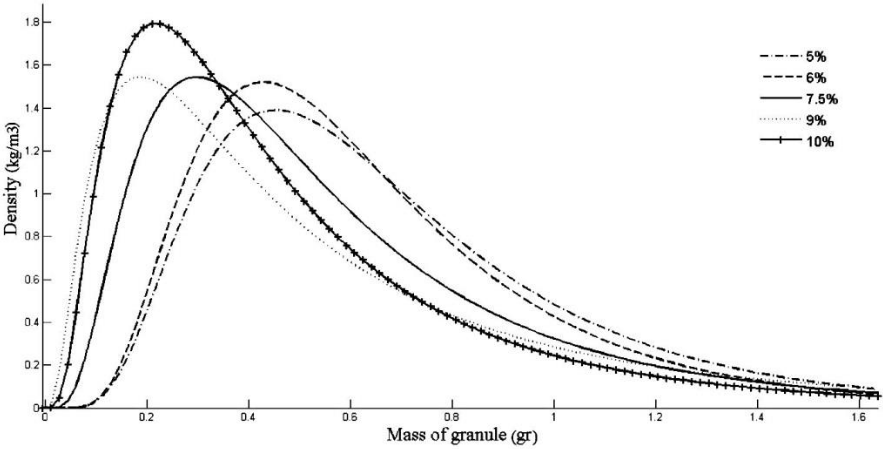

Fig. 7. Probability density function of log normal distributions for all drum filling

## Angle of friction

The effect of filling of the drum on angle of friction of produced granules ($A_F$) is illustrated in Figure 8. According to the Figure 8 with increasing drum filling from 5% to 10%, angle of friction of the produced granules was increased from 25.56$^o$ to 27.93$^o$.

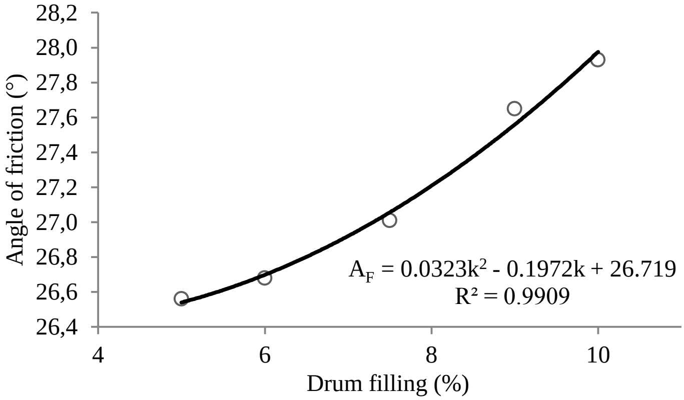

Fig. 8. Effect of drum filling on angle of friction

## Angle of repose

The effect of filling of the drum on angle of repose of produced granules ($A_R$) is illustrated in Fig. 9. It shows that with increasing drum filling from 5% to 10% the angle of repose of the produced granules increased from 11.38º to 12.52º.

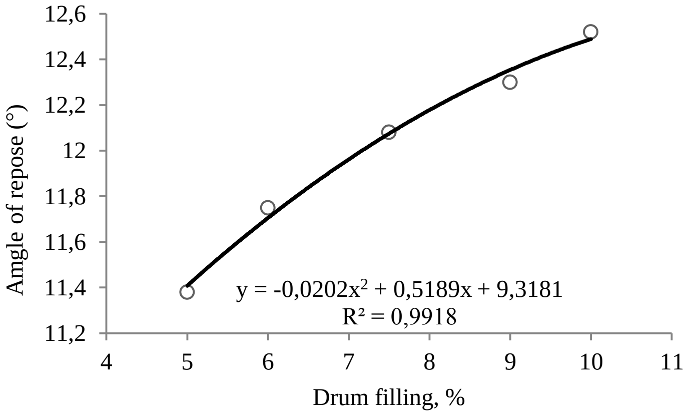

Fig. 9. Effect of drum filling on angle of repose

## Conclusion

In the present study the effect of filling of the drum (*k*) on useful granules, granules size, crush strength, mass of the granules, bulk density, angle of friction and angle of repose of granulated compost fertilizer were investigated. The result indicated that, when the filling of the drum with granular material increased from 5% to 10%. With increasing drum filling: percentage of the produced useful granules increased, average size of the produced granules decreased, crush strength of produced granules increased, bulk density of the produced granules increased, mass of the produced granules decreased, angle of friction of the produced granules increased and angle of repose of the produced granules increased.

## Acknowledgement

The authors would like to thank Dr. Jafar Massah, Dr. Akbar Arab Mohammad Hoseini, and Ms. Zohre Torki for technical supervision and help while writing the paper.

## References

ADAPA P., BUCKO J., TABIL JR L., SCHOENAU G., SOKHANSANJ S, 2003, *Pelleting characteristics of fractionated suncure and dehydrated Alfalfa grinds*, The society for in agricultural, food, and biological systems, 192−207.

ASAE Standards, S385.2. Moisture measurement – Forages. St. Joseph (MI): ASAE; 2002.

BURUBAI, W., AKOR, A. J., IGONI, A. H., PUYATE, Y. T., 2007, *Some physical properties of African nutmeg (Monodora myristica),* Int. Agrophysics, 21, 123-126.

CHANSATAPORN, W., NOPHARATANA, M., 2009, *Effects of binder content and drum filling degree on cassava pearl granulation using drum granulator*, As. J. Food Ag-Ind., 2,739-748.

DASH, A. K., PRADHAN, R. C., DAS, L. M., NAIK, S. N., 2008, *Some physical properties of simarouba fruit and kernel*, Int. Agrophysics, 22, 111-116.

ERIKSEN, G., COALE, F., BOLLERO, G., 1999, *Soil nitrogen dynamics and maize production in municipal solid waste amended soil*, Agron. J., 91, 1009-1016.

FRACZEK, J., ZLOBECKI, A., ZEMANEK, J., 2007, *Assessment of angle of repose of granular plant material using computer image analysis,* J. Food Eng., 83, 17-22.

GHASEMI, Y., KIANMEHR, M. H., MIRZABE, A. H., ABOOALI, B., 2013, *The effect of rotational speed of the drum on physical properties of granulated compost fertilizer*, Physicochem. Probl. Miner. Process., 49, 743-755.

HEIM, A., OBRANIAK, A., GLUBA, T., 2005, *Changes of feed bulk density during drum granulation of bentonite,* Physicochem. Prob. Miner. Process., 39, 219-228.

HEIM, A., KAZMIERCZAK, R., OBRANIAK, A., 2004, *Model dynamiki złoża ziarnistego granulatorze talerzowym*, Inż. Chem. Porc. 25, 993-998.

HEIM, A., GLUBA, T., OBRANIAK, A., 2004, *The effect of the wetting droplets size on power consumption during drum granulation*, Granul. Matter, 6, 137-143.

LISTER, J.D., LIU, L.X., Proc. 5th International Symp. Agglomeration Institution of Chemical Engineers, 1989, P611–P617.

MANGWANDI, C., ALBADARIN, A. B., AL-MUHTASEB, A. H., ALLEN, S. J., WALKER, G. M., 2012, *Optimisation of high shear granulation of multicomponent fertiliser using response surface methodology*, Powder Technol., 238, 142-150.

MAVADDATI, S., KIANMEHR, M. H., ALLAHDADI, I., CHEGINI, G. R., 2010, *Preparation of pellets by urban waste compost,* Int. J. Environ. Res., 4, 665-672.

MIRZABE, A. H., KHAZAEI, J., CHEGINI, G.R., 2012, *Physical properties and modeling for sunflower seeds,* Agric. Eng. Int: CIGR Journal, 14, 190-202.

OBRANIAK, A., GLUBA, T., 2012, *A model of agglomerate formation during bed wetting in the process of disc granulation*, Chemical Engineering and Processing., 33, 153-165.

SOKHANSANJ, S., MANI, S., BI, X., ZAINI, P., TABIL, L. G., 2005, *Binderless pelletization of biomass*, ASAE Annual International Meet ing, Tampa Convention Centre, Tampa, Florida, July 17-20, Paper Number 056061. St. Joseph, MI: ASABE.

RAMACHANDRAN, R., POON, M. S., SANDER, F. W., GLACER, T., IMMANUEL, D. C., DOYLE, J. F., LISTER, J. D., STEPANEK, F., WANG, F., CAMERON, I. T., 2008, *Experimental studies on distribution of granule size, binder content and porosity in batch drum granulation: Inferences on process modeling requirements and process sensitivity*, Powder Technol., 188, 109-101.

SANTOMASO, A. C., DING, Y. L., LICKISS, J. R., YORK, D. W., 2003, *Investigation of the granular behavior in a rotating drum operated over a wide range of rotational speed*, IChemE, 81, 936-945.

SASTRY, K.V.S., FUERSTENAU D.W., 1973, Mechanisms of Agglomerate Growth in Green Pelletization, Powder Technol, 7, P97-P105.

WALKER, G. M., HOLLAND, C. R., AHMAD, M. N., FOX, J. N., KELLS, A. G., 2000, *Drum granulation of NPK fertilizers*, Powder Technol., 107, 282-288.

WALKER, G. M., MAGEE, T. R. A., HOLLAND, C. R., AHMAD, M. N., FOX, N., MOFFATT, N. A., 1997, *Compression testing of granular NPK fertilizers*, Nutr. Cyc. Agroeco., 48, 231-234.

WOLKOWSKI, R., 2003, *Nitrogen management considerations for land spreading municipal solid waste compost*, J. Environ. Qual., 32, 1844-1850.