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Physical and engineering properties of urea briquettes relevant to design of mechanical applicator

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Abstract
Fertilizer deep placement has been proven effective in increasing fertilizer use efficiency in wetland rice production, but because of problems associated with fertilizer granules properties, machines developed to place them gave inconsistent results. Despite the wide range of metering mechanisms used, metering variation is still inherent in the machines developed because of the varying physical and engineering properties of the fertilizer material. Keeping this in view current study was carried out to determine the physical and engineering properties of urea briquettes relevant to design of the mechanical applicator. Physical and engineering properties viz. size, shape, urea briquette weight, bulk density, angle of repose and coefficient of friction of urea briquettes of UB_1 (3g) and UB_2 (2g) were evaluated in laboratory. Size and shape of metering cup were designed on the basis of maximum size of briquettes. Both roundness and sphericity of briquettes affected singulation. Free flow of urea briquettes in the briquette hopper was influenced by angle of repose and coefficient of static friction of urea briquette. Length, breadth and thickness of the urea briquettes UB_1 and UB_2 were 18.84±0.2.8 mm, 18.39±0.33mm, 13.76±0.28 mm and 16.49±0.18 mm, 16.22±0.19 mm and 11.18±0.17 mm, respectively. Mean diameter was greater for UB_1 (16.83±0.22 mm) in comparison to that of UB_2 (14.41±0.15 mm). Roundness of UB_1 (3g) and UB_2 (2g) were 0.82±0.01% and 0.78±0.11%, respectively, while sphericity of these briquettes in the natural rest position were 0.89±0.01 and 0.85±0.01%, respectively. Mean briquette weight was greater for UB_1 (2.81±0.11 g) than that of UB_2 (1.78±0.07 g). Angle of repose for mild steel surface was 31.64±0.13° and 31.67±0.28° for urea briquettes UB_1 and UB_2 respectively. The design values of the metering cup viz. cup diameter and depth were selected based on the dimensions of urea briquettes.

Keywords: Angle of repose, coefficient of static friction, metering device, urea briquette

1. Introduction

Fertilizer, particularly nitrogen fertilizer, is the main driving force to produce large rice yields under irrigated and favourable rain-fed conditions. Nitrogen fertilizer is usually broadcast as prills in paddy fields prior to transplanting, followed by one or more topdressing in the floodwater within the period from transplanting to flowering. Such practices are inefficient because only about one-third of the fertilizer nitrogen is used by the plants. The remainder is lost through gaseous losses, runoff, and leaching or is immobilized in the soil. One means to reduce nitrogen losses and improve fertilizer efficiency is to deep place fertilizer nitrogen as urea briquettes (UB) of compacted prilled urea. UB can be produced by a village-level briquetting machine by granulation and compaction processes.

Granulation and compaction processes can be used to produce urea briquettes that are larger than common fertilizer grade prilled urea (1-2 mm in diameter). Because of the simplicity of the process and cost effectiveness, briquetting appears to be the most viable method to produce UB. UB fertilizer is a simple physical modification of ordinary urea fertilizer. It consists of large discrete particles of urea containing 46% nitrogen. UB weight may vary considerably, but the general range that has been evaluated is 1-3 grams per particle. The shape of the granules depends on the production process used. UB prepared by any one of the melt-type granulation processes is nearly spherical, but they may vary in size and weight. Those prepared by briquetting are pillow shaped, oblong, or oblate, with broken edges due to webbing, and they are reasonably uniform in size and weight.

The physical and engineering properties of urea briquettes play an important role in designing briquette metering device. Physical properties *viz.* length, breadth, thickness, geometric mean diameter (GMD), angle of repose, coefficient of static friction, bulk density and true density were measured for determining design parameters of an applicator. Depth and diameter of the briquette metering cup would be influenced by the maximum length and thickness of urea briquettes. Both roundness and sphericity influence the singulation of briquettes in the hopper. Angle of repose and coefficient of static friction affect the flow characteristics of urea briquettes in the hopper.

Very less information is available about physical and engineering properties of urea briquettes which are essential for designing suitable applicator. The objectives of this paper is to determine such properties viz. size, shape, briquette weight, bulk density, true density, angle of repose and coefficient of static friction for two types of urea briquette UB_1 (3g) and UB_2 (2g). Based on the information on these properties of two forms of urea briquettes the design values for mechanical applicator were recommended.

2. Review of literature

The physical properties of urea influence the design of various machine components of an applicator. Therefore, information on physical and engineering properties of urea briquettes relevant to design of an applicator has been reviewed and presented.

Rutland and Polo (1951) [6] prepared a fertilizer dealer handbook in IFDC and discussed the physical properties of fertilizer. They found that angle of repose of fertilizers was influenced mostly by particle shape, size, and surface texture. Angle of repose values for fertilizers normally ranged from about 25° to about 40°. Spherical products, such as prilled urea, usually had lower angle of repose values (<30°). Irregularly shaped products, such as granular potassium chloride, usually had higher angle of repose values (>35°).

Rutland (1986) [5] prepared a manual for determining physical properties of fertilizer outlining methods for determination of physical properties of fertilizer, which includes procedures used by IFDC to evaluate the physical quality of commercial and experimental fertilizer products and raw materials. The physical properties of fertilizer were size analysis, angle of repose, bulk density, true density of solids and liquids, granule crushing strength, sphericity, porosity. Results obtained for granular urea are at Table 1.1.

Table 1: Physical and engineering properties of granular urea

Physical properties	IFDC code	Type of fertilizer	Range
Size	S-107	Granular urea	90% (1.7 mm) cumulative percent retained
Angle of repose	S-110	Granular urea	38 degree
Bulk density (loose pour)	S-111	Granular urea	745 $kg.m^{-3}$
Bulk density (tapped)	S-112	Granular urea	820 $kg.m^{-3}$
True density of solid	S-114	Granular urea	1.33 $g.cm^{-3}$
Granule crushing strength	S-115	Granular urea	2.5 kg/granule
Sphericity	S-121	Granular urea Prilled urea	57, 89-93
Porosity	S-125	Granular urea	8%

Allaire and Parent (2004) [1] compared the physical properties of compound organic based (COF) and bulk-blended organic-based fertilizers (BOF) with those of mineral fertilizers (MF). Standard and modified methods were used to measure their static properties. Compared with MF, COF had significantly lower bulk, granule, and particle densities and higher bulk and granule porosities and angles of repose. The variation in these static properties could be predicted in part with the N, P, K and organic matter contents as well as the particle size distribution. The organic matter content significantly influenced most physical properties. Bulk density, granule density, and the angle of repose decreased with increasing organic matter content while porosity and tensile strength increased with organic matter content. Bulk density and tensile strength were also significantly related to granule size distribution. The initial water content influenced density, porosity, tensile strength, and the angle of repose.

Pare *et al*. (2009) [4] determined the relationships among physico-chemical properties of organo-mineral fertilizer so that the number of measurements required by the industry during manufacturing was reduced. Organo-mineral fertilizers were granulated into 50 mixtures of composts, peat, and mineral fertilizers. Fifteen physical properties and 12 chemical properties were measured following standard and modified methods. Bulk density, easy and inexpensive to measure, significantly affected other physical properties (R^2=0.74), such as tapped and granule densities and porosities, and crushing strength. In addition, concentrations of Fe, Mg, organic matter, and Na significantly affected many physical properties of OMF granules, whereas other chemical properties had a limited effect. These findings would directly affect OMF manufacturing by reducing time and costs needed for property measurements related to product development and quality control.

3. Materials and methods

UB fertilizer is a simple physical modification of ordinary urea fertilizer. It consists of large discrete particles of urea containing 46% nitrogen. Weight may vary considerably, but the general range that has been evaluated is 1-3 g per particle. The experiments on the measurements of the physical and engineering properties of UB were carried out in the laboratory of Division of Agricultural Engineering, IARI, New Delhi. Urea briquettes of 3g and 2g, provided by M/S Tata Chemicals Ltd. were used in the experimentation. Experiments were carried out for urea briquette at two levels namely UB_1 (3g) and UB_2 (2g). The relevant properties of UB were measured and listed in Table- 1.2. Physical and engineering properties for UB_1 and UB_2 were measured using appropriate methodology. Thirty urea briquettes were selected randomly for each, from the bulk of respective sample and the mean value determined. Size of the briquettes in terms of briquette length, breadth and thickness were measured using Digital vernier caliper having least count 0.01mm. The shape of the urea briquette was expressed by its roundness and sphericity. The per cent roundness was calculated as follows (Mohsenin, 1986) [3]

$$Rp = \frac{Ap}{Ac} \times 100 \qquad \ldots (1.1)$$

Where,

Rp = Roundness, %,

Ap = Projected area, mm^2, and

Ac = Area of the small circumscribing circle, mm^2.

The sphericity is a measure of shape character compared to a sphere of the same volume. The degree of sphericity was calculated as follows (Mohsenin, 1986) [3]:

DS = Geometric mean diameter/ major diameter

$$D = \frac{\sqrt[3]{(a\times b\times c)}}{a} \quad \ldots (1.2)$$

Where,
DS = Degree of sphericity,
a = Longest intercept, mm,
b = Longest intercept normal to a, mm, and
c = Longest intercept normal to a and b, mm.

Bulk density of briquette was measured using a wooden box of known volume. The wooden box was filled with briquettes and excess was poured out before taking the weight. Thirty times the same procedure was repeated and mean value determined.

The bulk density was calculated as:

$$BD = \frac{SW}{V} \quad \ldots (1.3)$$

Where,
BD= Bulk density, g.cm^{-3},
SW= Weight of the test sample, g, and
V= Volume of wooden box, 1000 cm^3.

The apparatus, used for measuring angle of repose, consisted of a funnel with an adjustable throat opening, mounted on a stand. A circular plate, with four centering arms, was mounted in the funnel above the adjustable throat. The funnel was filled with urea briquette by keeping its adjustable throat closed. The throat was fully opened to allow free flow of briquette over and around the plate mounted in the funnel. At the end, a heap-cone of the briquette was formed on the plate. The base diameter and height of cone was measured. Thirty times the same procedure was repeated and mean value determined.
The angle of repose was calculated with the following relationship:

$$\theta = tan^{-1}\left(\frac{2h}{d}\right) \quad \ldots (1.4)$$

Where,
θ = Angle of repose, degree,
h = Height of the cone, cm, and
d = Base diameter, cm.

The coefficient of static friction for UB on mild steel surface was measured by using inclined plane method. The material was kept on a horizontally placed surface and the slope was increased gradually. The angle (α) at impending slide was recorded. The coefficient of static friction was expressed by tangent of angle α. The true density was measured using hexane displacement method. The experiment was repeated 30 times and the mean value was determined. The experiments were repeated for different treatments.

4. Results and discussion

The size, shape, bulk density, seed weight, angle of repose and coefficient of static friction for urea briquettes were measured and the average values were determined, as given in Table 4.1.

Table 2: Physical and engineering properties of urea briquettes under different briquette treatments

Property	Urea briquette	
	UB_1	**UB_2**
Length (mm)	18.84 ± 0.28	16.49± 0.18
Breadth (mm)	18.39 ± 0.33	16.22 ± 0.19
Thickness (mm)	13.76 ± 0.28	11.18 ± 0.17
GMD (mm)	16.83±0.22	14.41±0.15
Sphericity (%)	0.89 ± 0.01	0.85 ± 0.01
Roundness (%)	0.82 ± 0.01	0.78± 0.01
Bulk density (g.cm^{-3})	0.72 ± 0.01	0.75± 0.00
True density (g.cm^{-3})	1.22 ± 0.05	1.29± 0.06
Briquette weight (g)	2.81 ± 0.11	1.78 ± 0.07
Angle of repose (deg)	31.64 ± 0.13	31.67 ± 0.28
Coefficient of friction	0.52 ± 0.04	0.49 ± 0.01

4.1 Size of urea briquettes

Dimensions of the urea briquettes determine the size and diameter of cups on metering rotor. The size of the urea briquette specified the spatial dimensions, Table 1.2. The mean length of the urea briquette UB_1 and UB_2 were 18.84 mm and 16.49 mm, respectively. Breadth of the urea briquettes UB_1 and UB_2 were 18.39 mm and 16.22 mm, respectively. Thickness of urea briquettes UB_1 and UB_2 were 13.76 mm and 11.18 mm, respectively. Length, breadth and thickness of urea briquettes were higher for UB_1 as compared to the briquette UB_2. There was significant increment in the length, breadth and thickness for two forms of urea briquettes, Table 1.3. The geometric mean diameter for urea briquettes UB_1 and UB_2 were 16.83 and 14.41 mm, respectively. A significant increment was observed in geometric mean diameter (GMD) of UB_1 and UB_2 at 5 % level of significance, Table 1.3.

4.2 Shape of the urea briquettes

The shape of the urea briquette was determined in terms of roundness and sphericity, Table 1.2. The sphericity of two forms of urea briquettes UB_1 and UB_2 were 0.89 and 0.85 % respectively. So UB_1 were more near to the spherical shape in comparison to UB_2. The roundness of urea briquettes were 0.82 and 0.78 for UB_1 and UB_2 briquettes respectively. The roundness of UB_1 was greater than that of UB_2. The cup size determined on the basis of major briquette dimensions thus could be expected to meter the briquettes properly. The shape of the cup was, therefore, considered as semi–spherical with characteristic dimensions greater than or equal to the length, breadth and mean diameter of urea briquettes.

4.3 Urea briquettes weight

The average weights of briquettes were 2.81 g and 1.78 g for UB_1 and UB_2, respectively, Table 1.2. This clearly showed the difference in the weight of the briquettes and it was found that UB_1 had significantly higher weight than that of UB_2, Table 1.3.

4.4 Angle of repose and coefficient of static friction

Mean value of angle of repose on mild steel surface for the two forms of urea briquettes UB_1 and UB_2 were 31.64° and 31.67°, respectively, Table 1.2. The mean values of coefficient of static friction of UB_1 and UB_2 were recorded on mild steel surface and found to be 0.52 and 0.49, respectively.

4.5 Bulk density and true density

The mean bulk and true density of urea briquettes along with vital statistics were determined, Table 1.2. Both bulk density and true density were different for different forms of urea briquettes. Average bulk density of the two forms of urea briquettes UB_1 and UB_2 were 0.72 and 0.75 g.cm^{-3}, respectively, where as true density of urea briquettes UB_1 and UB_2 were 1.22 and 1.29 g.cm^{-3}, respectively. The bulk density and true density were significantly higher at 5% level of significance for urea briquette UB_2 than that of urea briquette $UB_{1,}$ Table 1.4.

Table 3: Independent sample test for size of different urea briquettes

Properties	Treatment comparison	t-test for equality of means			
		t-value	Df	*p*-value Sig (2-tailed)	Std. Error Difference
Length	UB_1-UB_2	38.27	58	0.000*	0.061
Breadth	UB_1-UB_2	31.14	58	0.000*	0.069
Thickness	UB_1-UB_2	43.24	58	0.000*	0.590
GMD	UB_1-UB_2	49.45	58	0.000*	0.048
Sphericity	UB_1-UB_2	18.32	58	0.000*	0.002
Roundness	UB_1-UB_2	14.75	58	0.000*	0.002

Note: GMD- geometric mean diameter,* Significant at 5% level of significance, UB_1- 3g urea briquette, UB_2-2g urea briquette

Table 4: Independent sample test for gravimetric and frictional properties of urea briquettes under different treatments

Properties	Comparison between UBs	t-test for equality of means			
		t-value	df	*p*-value Sig (2-tailed)	Std. Error Difference
Bulk density	UB_1-UB_2	-8.802	18	0.000*	0.00365
True density	UB_1-UB_2	-3.506	18	0.003*	0.025
Angle of repose	UB_1-UB_2	-0.340	18	0.738	0.097
Coefficient of static friction	UB_1-UB_2	4.320	18	0.000*	0.006

* Significant at 5% level of significance, UB_1- 3g urea briquette, UB_2-2g urea briquette

5. Conclusions

Urea briquette with higher dimensions of length, breadth, thickness resulted in higher weight. With the change in briquette from UB_1 to UB_2 there was significant increment in the linear dimensions and weight, Table 1.3. T-test indicated the significant difference between the length, breadth, thickness weight and mean diameter of urea briquettes with 5 per cent level of significance. The length of UB_1 was 14.25% higher than that of UB_2. Urea briquette dimensions played a vital role in deciding cup shape, size and its diameter. The roundness and sphericity observed for different forms of urea briquettes were near to the sphere due to regularity in the dimensions. There was significant difference observed in the sphericity and roundness between UB_1 and UB_2 at 5% level of significance, Table 1.3. Sphericity and roundness was higher for UB_1 in comparison to $UB_{2.}$ The shape of the cup was selected hemi-spherical with characteristics dimensions greater than or equal to mean urea briquettes dimension for determination of size of the cup. The cup shape and size determined on the basis of major urea briquettes dimensions is expected to meter the briquettes properly.

T-test also indicated significant difference in bulk density and true density of urea briquette UB_1 and UB_2 at 5% level of significance, Table 1.4. The bulk density and true density of UB_2 was higher than that of UB_1. This might be due to the smaller size and higher compaction in the UB_2 during compaction process. There was no significant difference between angle of repose of UB_1 and UB_2, but there was significant difference in coefficient of static friction between UB_1 and $UB_{2,}$ this was due to higher weight and dimension of UB_1 in comparison to $UB_{2.}$ Therefore, considering the ease and economy of fabrication the mild steel was selected for the fabrication of parts. Diameter of the cup was selected as 20.63 mm on the basis of maximum length of UB_1, allowance and manufacturing process into consideration. While the depth of cup was selected on the basis of half of thickness of UB_2, three levels were taken to find out the optimum size required to pick up the briquettes and proper delivery. If the depth would have been more it might have affected the briquette delivery process as the spherical briquette could sit deeper in the cup and could have taken longer time to drop. Mean angle of repose calculated for mild steel surface were 31.67-to-31.64° for UB_1 and UB_2, thus design value required to be more than this value with allowance. Taking into consideration the vertical cup feed metering mechanism and picking process angle of repose was selected as 52°, Table 1.5. Based on the results and discussion of this study the design values relevant to mechanical applicator for two levels of urea briquettes were taken as:

Table 5: Design values selected for applicator development

Diameter of the cup	20.63 mm
Depth of cup	6.5, 3.5, 2.5 mm
Angle of repose	52°

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