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Physical and Engineering Properties of Fertilzers and their Combination for the Design of Hopper

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The physical and engineering properties of the urea (46-0-0), ammonium phosphate (16-20-0), potash (0-0-60), and their fertilizer combination were studied to design the hopper for the fertilizer application unit. The six important properties discussed were angle of repose, moisture content, particle size distribution, flowability, crushing strength and coefficient of kinetic friction. The largest angle of repose values was 33°, 35°, 41° and 47° for urea, ammonium phosphate, potash and their combination respectively. The bulk density value for fertilizer combination was considered for the design of hopper, as the mixture of three fertilizers were applied in the field and its value was 0.92 g cm^{-3}. The urea has lowest coefficient of friction compared to others, which is 0.3. The flowability of the fertilizer was free and the crushing strength of ammonium phosphate and urea was having medium hardness compared to potash, which is very soft. The observed engineering properties viz., flowability, coefficient of friction, moisture content, angle of repose were satisfactory for designing the mechanical fertilizer applicator and bulk density for the volume required for the storage of fertilizer.

Keywords: Angle of repose; coefficient of friction; bulk density; particle size distribution; moisture content; flowability.

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1. INTRODUCTION

The physical form of the fertilizer is having importance in both agronomically and in regard to satisfactory transport, handling, storage and application to the field [1]. The most common problems encountered in fertilizers were caking, poor flowability, segregation, dustiness and excessive hygroscopicity due to differences in physical properties. The physical and engineering properties of fertilizer plays an important role in the storage, transport and spreading of fertilizer. These properties can affect the way of the fertilizer is spread [2]. The coefficient of friction and particle size distribution has great influence in the spread pattern [3]. The study of physical and engineering properties of fertilizer helps in the usage of low amount of fertilizer, which means the fertilizer was applied in the right way with the optimal amount and at the correct time [4]. The study of moisture content of the fertilizer helps to decrease the cacking tendency of the fertilizer in hopper and clogging of the equipment [5]. So, in order to study these properties in brief some of the measuring methods have been used and reported in the below sections.

2. MATERIALS AND METHODS

2.1 Selection of Fertilizers

The selected fertilizers for the determination of physical and engineering properties were Urea (40:0:0), Ammonium Phosphate sulphate consisting of traces of sulphur (16:20:0), Muriate of potash (0:0:60) and fertilizer combination. The fertilizer combination was prepared by mixing the Urea, Ammonium Phosphate and Muriate of potash in a required proportions and made it into a 5kg sample.

2.2 Angle of Repose

The angle of repose of a granular material is determined by the steepest angle made by the material with the horizontal plane when the material is heaped without any collapsing. The angle of repose was the important parameter that determines the characteristics of fertilizer granular materials with their storage surface and its values were used in the design of the hopper. The angle of repose of fertilizers was mostly influenced by surface texture, particle shape and size [6].

It is measured by the fixed funnel method, where the funnel was fixed to a stand and fertilizer mixture was poured from the funnel at a certain height on to a base consisting of the plate until the heap reaches to a pre-determined height. The diameter of the conical-shaped heap and its height formed on the plate were measured. Then, the Angle of repose of fertilizer mixture was found out by the following equation:

$$\text{Angle of repose } (\theta) = \tan^{-1}\left(\frac{2h}{d}\right) \text{ [7]}$$

where,

θ = angle of repose in degree
h = height of the heap in mm
d = diameter of the heap in mm

Angle of repose values were having a greater influence on the design of hopper for an attachment to a rice transplanter and free flowing of fertilizer mixture from hopper to the field. Higher values of angle of repose were showing free flowability compared to lower values.

2.3 Coefficient of Kinetic Friction

It is the degree of friction developed between a material and the storage surface. A higher degree of friction can result in longer contact with the surface. It is useful in the design of the hopper where the fertilizer slide over the hopper sheet. The coefficient of kinetic friction was calculated by the apparatus consists of horizontal surface, pan at the end of apparatus which is hanged through a pulley and a container. The fertilizer mixture was poured into a container and besides weights were added to the pan till the container begins to slide on the horizontal surface. Thus, it can be calculated by using the below formula:

$$\mu = \frac{F}{N}$$

where,

F = frictional force (force applied on pan)
μ = coefficient of kinetic friction
N = normal force (fertilizer weight)

2.4 Bulk Density

It is defined as the mass per volume of a bulk fertilizer, including void space in a container. It is expressed in kilogram per cubic metre. Bulk density of fertilizers decides the requirements of the volume of the hopper. The bulk density of fertilizer can influence the behaviour of the fertilizer particles as the segregation of particles may occur if the bulk density values vary. It can affect the application rate of fertilizer as it is directly related to the hopper design.

Bulk density can be measured by considering a metal cylinder of volume (v) and weight (w_1). Then, the fertilizer was poured gently into a cylinder and make the surface level by removing excess material by passing a straight edge across the cylinder. Then the cylinder with fertilizer was weighed (w_2), and the weight of the empty cylinder is subtracted from the test sample weight (w_2). The bulk density was calculated as follows:

$$D_L = \frac{W2 - W1}{V}$$

where,

D_L = loose-pour bulk density (kg m^{-3})
w_1 = weight of the empty cylinder (kg)
w_2 = weight of the cylinder and fertilizer (kg)
v = volume of the cylinder (m^3)

2.5 Particle Size Distribution

It measures the amount of material that falls into each of the various size ranges within a given sample. A random sample of 250 g was taken from each fertilizer and the weight of the fertilizer particles which are retained on each sieve was calculated.

Sieve analysis was done to determine the particle size distribution. The mesh diameters of the sieve taken for the study were: 4.75 mm, 2.0 mm, 1.0 mm and 0.5 mm, 0.25 mm, 0.106 mm and 0.053 mm IS sieves respectively and the weight of fertilizer particles retained on each sieve is noted. The particle size distribution for fertilizers were calculated by using the following equation:

$$P_{S\,(n)} = \frac{P_{sw(n)}}{P_{TW}} \times 100 \text{ [8]}$$

Where,

$P_{S(n)}$ = percentage of fertilizer particles on sieve number (n)
$P_{SW\,(n)}$ = mass of fertilizer particles on sieve number (n)
P_{TW} = sample mass of fertilizer particles, g

2.6 Moisture Content

The moisture content of fertilizer was determined by using a hot air oven. A 5 g sample of fertilizer was taken and kept in porcelain dish w_1. Heat in an oven for about 5 hours by keeping temperature 105°c ± 2°c, and then it was cooled in a desiccator. The dried sample weight was noted w_2. Then moisture content can be measured by using the following formula:

$$\text{Moisture content \%} = \frac{w_1 - w_2}{w_2}$$

Where,

w_1 = initial weight of the sample
w_2 = final weight of the sample

In general, this method does not apply to all fertilizers as they yield a volatile substance other than water at drying temperature. The oven drying method can be applied for only urea and potash. Urea was kept under a temperature of 70°c ± 5°c for 5 hours [1].

2.7 Flowability

It is an important parameter where it is directly related to the flow rate, handling, metering, broadcasting and deposition of fertilizer. The flowability of fertilizer is reduced due to its cacking tendency, moisture content, humid conditions and segregation of fertilizer particles.

The fertilizer flow rate was measured by considering 2kg of fertilizer sample placed in a standard funnel with a closed bottom. It has an aperture of 25mm diameter at its base. Then the gap was opened and the time consumed for the flow of 2kg of fertilizer from the funnel was measured [9].

2.8 Crushing Strength

The crushing strength of fertilizer is defined as the measure of the resistance of granules to deform under pressure. It is used in estimating the handling and storage properties of fertilizer granular materials and pressure limiting values can also be determined during bulk storage for granular materials. Crushing strength is expressed in kg per grain. An easy way to find the of the fertilizer particles crushing strength was to apply pressure on individual granules. A simple test that can be used to evaluate the hardness or strength of the particles at the time of spreading is the finger test [3]:

1. Granules crushed between thumb and the forefinger is soft granule

2. Granules crushed between forefinger and hard surface is medium hard granule
3. Granules not crushed between forefinger and hard surface is hard granule

Fig. 1. Angle of repose

Fig. 2. Fertilizer moisture samples for oven drying

Fig. 3. Sieve analysis

Fig. 4. Fertilizer combination

3. RESULTS AND DISCUSSION

3.1 Angle of Repose

The angle of repose is the important parameter which influence the design of hopper for the flowability of fertilizer without any clogging. The angle of repose of urea, Ammonium Phosphate, muriate of potash and its mixture were found out. The determination of angle of repose was explained in above section 2.2. The observed values of angle of repose for prilled urea (46:0:0) were 28° to 33°. The values for Ammonium Phosphate (16:20:0) were 33° to 35° and for potash (0:0:60) it was 35° to 41°. The angle of repose of fertilizer mixture (urea + Ammonium Phosphate + potash) was 45° to 47°. Based on the values of angle of repose of fertilizer combination the hopper angle was decided. So, to flow the fertilizer freely from the hopper, the inclines angle of the hopper should be greater than 47°.

3.2 Coefficient of Kinetic Friction

The coefficient of kinetic friction of fertilizers (viz., urea, Ammonium Phosphate, potash and fertilizer combination) was determined for GI sheet material as it is used for making hopper. The methodology was explained in section 2.3. The results were mentioned in Table 1. The coefficient of friction for urea was observed low compared to other fertilizers [2].

3.3 Bulk Density

The bulk density of fertilizers and its combination were determined as explained in section 2.4. and is found to be ranging between 0.76 to 0.79 g cm^{-3} for urea, 0.93 to 0.96 g cm^{-3} for Ammonium Phosphate, 1.02 to 1.04 g cm^{-3} for potash and 0.9 to 0.92 g cm^{-3} for fertilizer combination. The bulk density values were statistically analysed in below Fig. 5 The bulk density of urea was less compared to Ammonium Phosphate, potash and its combination as it is having lesser weight for a given volume of beaker.

3.4 Particle Size Distribution

The particle size distribution of urea, Ammonium Phosphate and potash were determined by the sieve analysis explained in section 2.5. The sieves used for the analysis were 4.75 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.106 mm and 0.053 mm. The particles size distribution for the prilled Urea of grade (40-0-0) on the sieves 4.75, 2, 1, 0.5, 0.25, 0.106 and 0.053 mm were 0%, 70%, 24.3%, 4.9%, 0.78%, 0% and 0%, where most of the particles were settled under the 2 mm and 1mm IS sieve. The obtained particle size distribution for the Ammonium Phosphate of grade (16-20-0) were 0%, 73%, 22%, 3.5%, 0.09%, 0.05% and 0%, where most of the particles were settled under the 2mm and 1mm IS sieve. Similarly, the observed particle size distribution for potash of grade (0-0-60) were 0%, 0%, 0%, 64.2 %, 32.4 %, 2.7% and 0%, where most of the particles were settled at below 0.5 mm IS sieve.

The percentages of particle size distribution for urea, Ammonium Phosphate and potash were shown in Fig. 6. and the obtained data of particle size distribution for three fertilizers were represented in the Table 2.

Table 1. Coefficient of friction values of urea, Ammonium Phosphate, potash and fertilizer combination

Sl. No.	Material surface	Urea	Ammonium Phosphate	Potash	Fertilizer combination
		Mean ± SD			
1.	GI sheet	0.30 ± 0.01	0.41 ± 0.02	0.43 ± 0.01	0.38 ± 0.01

Table 2. Particle size distribution percentages of fertilizers

S.no	IS Sieve size, mm	Particle size distribution, % Urea	Particle size distribution, % Ammonium Phosphate	Particle size distribution, % Potash
1	4.75	0	0	0
2	2.0	70	73	0
3	1.0	24.3	22	0
4	0.5	4.9	3.5	64.2
5	0.25	0.78	0.09	32.4
6	0.106	0	0.05	2.7
7	0.053	0	0	0

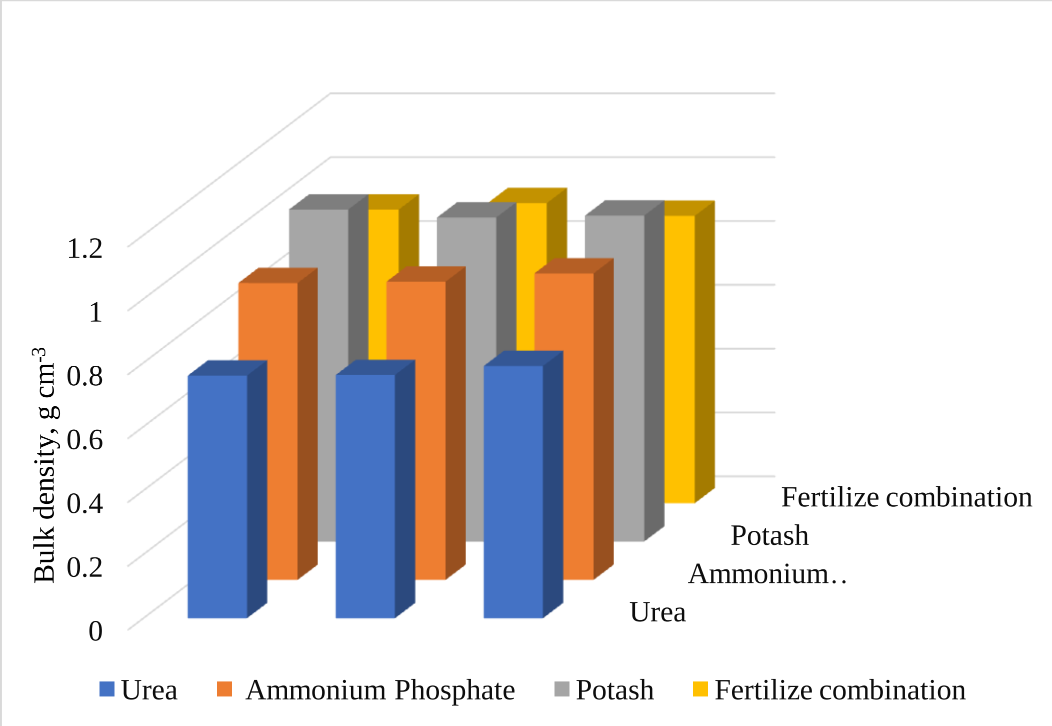

Fig. 5. Bulk density of fertilizers *viz*., urea, Ammonium Phosphate, potash and fertilizer combination

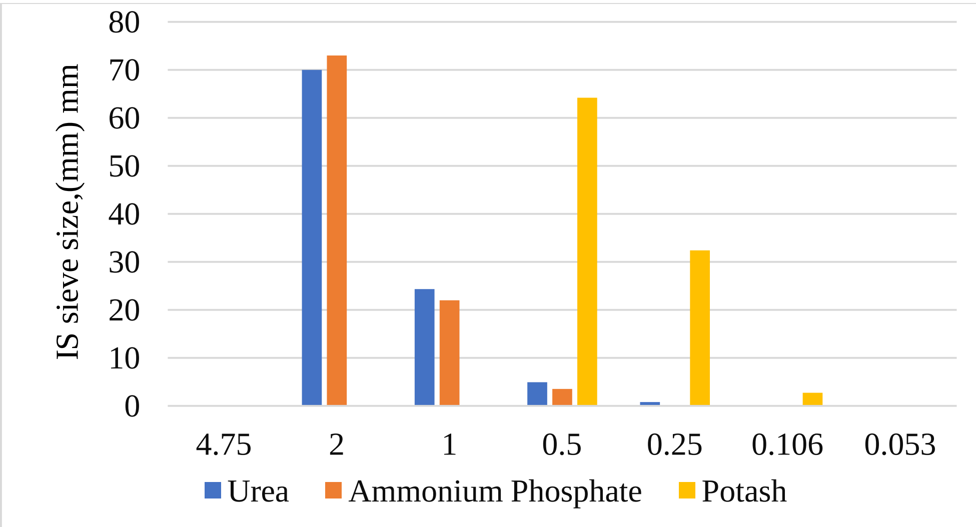

Fig. 6. Particle size distribution percentage for Urea, Ammonium Phosphate and potash

3.5 Moisture Content

The moisture content of fertilizers *viz*., urea and potash were determined under oven dry method as explained in section 2.6. The moisture percent by weight present in these fertilizers ranges between 0.5 to 2%. As the moisture content of fertilizer increases above 2% the fertilizer mixture tends to the formation of lumps, which affects the flowability of the fertilizer.

The average moisture content present in urea and potash were 1.8%, and 0.9% respectively. The moisture content of Ammonium Phosphate and fertilizer combination were not able to find in oven drying method due to the release of volatile substances other than water at drying temperatures.

3.6 Flowability

The flowability of fertilizer combination was determined by following the section 2.7. The average time taken to flow 2 kg of fertilizer combination from the funnel bottom was 4 seconds. It was observed that the fertilizer was flowing freely without any segregation in the funnel.

3.7 Crushing Strength

The crushing strength of fertilizers were determined by following section 2.8. The muriate of potash as it is in powder form it is very soft, besides urea and Ammonium Phosphate were having medium hardness as they were crushed between forefinger and hard surface.

4. CONCLUSION

The angle of repose value for Urea, Ammonium Phosphate, potash and fertilizer combination were 28° to 33°, 33° to 35°, 35° to 41° and 45° to 47° respectively. So, the obtained results made the hopper to keep the inclined angle value greater than 47°. The flowability of the prepared fertilizer combination has free flow. The observed moisture contents of urea and potash were 1.8% and 0.9%, where the increase in moisture content of above 2% showed the chances of lump formation in between particles. The scope of lump formation for prilled urea was high when exposed to atmosphere due to its high hygroscopicity. The average bulk density of Urea, Ammonium Phosphate, potash and fertilizer combination were 0.77 g cm^{-3}, 0.94 g cm^{-3}, 1.02 g cm^{-3} and 0.92 g cm^{-3}. The coefficient of kinetic friction for urea was lower compared to other fertilizers. Most of the fertilizer particles of urea and ammonium phosphate particles were in the 2 mm sieve and for potash in 0.5 mm sieve.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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