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FRICTION PROPERTIES OF FERTILIZERS AND METHODS OF ANALYSIS

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A b s t r a c t. In many cases the angle of internal friction of fertilizers is substituted by the angle of repose. Theoretically, this is considered correct but there is a risk that other factors such as particle size, shape and surface texture might interfere with the friction properties. For this reason, another method to measure the dynamic angle of internal friction has been developed. The origin is an apparatus made by Brübach (1973) that has been modified for granular fertilizers. The equipment is a shearing apparatus that brings a layer of the test material to slide against another layer. For different normal forces (N) on the layers, different shearing forces (F) is required. The linear relationship between shearing and normal forces gives the angle of friction (Φ) from a well known formula: tan Φ = F/N.

For comparisons a box for measuring the dynamic angle of repose also has been developed. The shearing method gives an angle of internal dynamic friction that for each fertilizer is 7°-9° lower than the angle of repose, and 0°-5° lower than the angle of internal static friction. The apparatus developed can also be used to determine the angle of external friction between fertilizer and other materials such as steel, plastic or wood.

K e y w o r d s: fertilizers, friction properties

INTRODUCTION

Friction properties are of great importance for the storing, transportation and distribution of granular materials. Firstly, friction phenomena can be divided into two parts, internal and external friction; secondly each part itself can be divided into static or dynamic friction. Together, this indicates why friction properties have to be taken into consideration in almost every phase of handling.

Internationally, a lot of research has been carried out in the development of methods of analysis and also in determining in which ways the friction influences different steps of handling. In the case of fertilizer, both economic as well as environ- mental aspects have contributed to the large amount of research done.

This work is part of a survey of fertilizers commonly used by Swedish farmers. The aim is to discover the differences between fertilizers with regard to physical properties of importance for distributor performance in the field.

THEORY

From the 'laws' of friction we know that static friction (μ_s) is higher than (or equal to) dynamic friction (μ_d) [4]. In terms of forces this means that the force (*F*) required to get a body or a layer of material (with a certain weight, *N*) at rest on a horizontal surface moving, is higher than or equal to the force required to keep it moving with constant speed. The coefficient of friction is expressed as the ratio of force (*F*) and normal load (*N*):

$$\mu = \frac{F}{N} . \qquad (1)$$

Calculations of friction are often based on a stress and strain diagram, where loads and forces are expressed as pressures, symbolised by the Greek letters tao (τ) and sigma (σ). Coefficient of friction is then expressed as the ratio:

$$\mu = \frac{\tau}{\sigma} \qquad (2)$$

where $\tau = F/A$, $\sigma = N/A$, A is area on which each force is exerted.

If the body is lying on a sloping surface it can start to move by its own weight since the weight is divided into perpendicular components (Fig. 1).

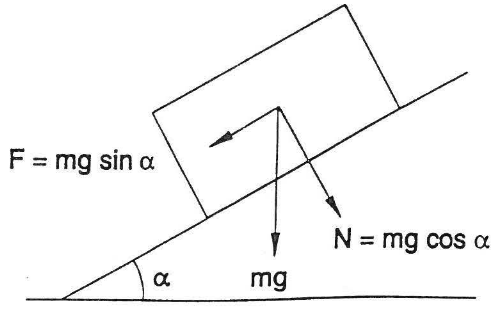

Fig. 1. A body on a sloping surface. The weight is divided into perpendicular components.

The angle of slope gives the relationship between angle of friction (α) and coefficient of friction (μ).

$$\mu = \tan \alpha . \qquad (3)$$

METHODS OF ANALYSIS

Friction properties can be analysed three-dimensionally in a triaxial test [4]. This test may be rather complicated and for routine controls or when a large number of samples are to be analysed simplified routines are more applicable.

By letting fertilizer flow down onto a horizontal surface a heap is made and the angle to the horizontal that is formed is named dynamic or kinetic angle of repose [2]. In accordance with earlier discussion, this angle should be comparable to the angle of internal dynamic friction. When emptying a flat bottomed container or hopper, material will remain in the area around the outlet. The angle to the horisontal that is formed by this material is called the static angle of repose. In these cases, the designations dynamic and static are sometimes a matter of discussion.

Internal dynamic friction can be analysed two-dimensionally with a shearing apparatus. A layer of the material is brought in motion and the required pulling force is continuously registered as the layer moves [4].

Internal static friction can be measured in another type of shearing apparatus (Fig. 2) which may consist of a sample chamber of a thin rubber membrane surrounded with steel rings. The bottom ring is fastened in the frame and the top ring is connected to a horizontal pulling rod. A vertical load is applied and the pulling force is slowly increased until the sample collapses.

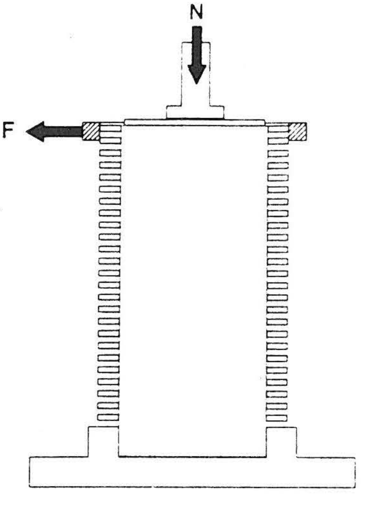

Fig. 2. Schematic view of apparatus for determining internal static friction.

When using these types of shearing apparatus the coefficient of friction is calculated from the relationship between the change in required pulling force for each change in normal load:

$$\mu = \frac{\Delta F}{\Delta N} . \qquad (4)$$

EXPERIMENTAL

At the Swedish Institute of Agricultural Engineering (JTI) 30 types of fertilizers common on the Swedish market were analysed for their frictional and other physical properties. Friction properties investigated were internal and external dynamic friction and angle of repose. For comparisons, five fertilizers were sent to The Royal Institute of Technology (KTH) in Stockholm for analysis of internal static friction.

Angle of repose was analysed with a box 200 x 200 x 500 mm, made of transparent plastic (Fig. 3). Fertilizer was poured into the container at the top and the inclined hatch was opened. As the fertilizer piled up in the lower container, an angle of repose was formed towards the back wall. When the fertilizer reached the overflow the hatch was closed and the angle could be measured with the gauge attached to the box. Measurements were made within $\pm 0.5^{o}$.

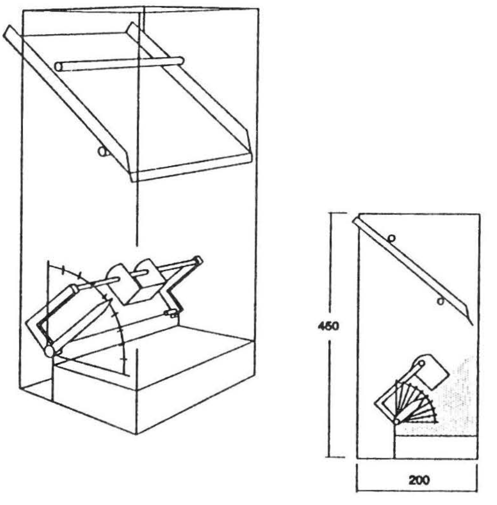

Fig. 3. Equipment used for determining dynamic angle of repose. Scales are in millimeters.

The shearing apparatus developed at JTI (Fig. 4) consists of a box, 340 x 250 x 45 mm, with a diagonal grid pattern (8 mm high) in the bottom, and a plate, 215 x 185 mm, with several 8 mm high angle bars. The apparatus also consists of an electrical motor for constant speed of the shearing plate and the required pulling force was registered with a load cell connected to a computer and a printer.

Fertilizer was poured into the box and levelled to a certain height. The plate was pressed down into the fertilizer surface, a weight was added, and then pulled with constant speed. With four different loads the relationship between load and pulling force gave the coefficient of dynamic internal friction by linear regression. Measurements were made within $\pm 0.5^{o}$.

The equation of the friction line can be expressed as:

$$y = kx + m \qquad (5)$$

where y - estimated pulling force, x - normal load, k - coefficient of friction, m - intercept.

The factor m in Eq. 5 would be, in cases like these, a value of the cohesion in the material. In this case, the intercept was caused

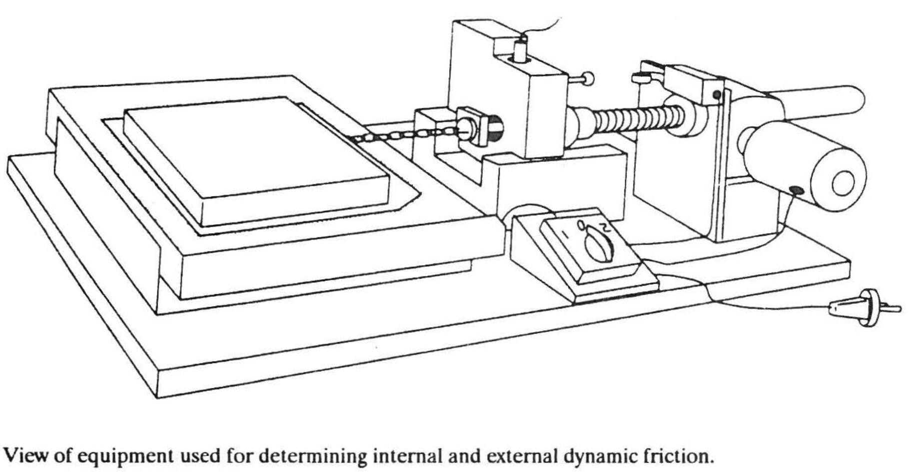

Fig. 4. View of equipment used for determining internal and external dynamic friction.

by the equipment since the weight of the plate and the weight of the layer of fertilizer will transfer the line in parallel. This is supported by the theory that granular fertilizers often are to be considered cohesionless or with very low cohesion [1].

The external dynamic friction, i.e., the friction between two different materials such as fertilizer versus steel, was measured with the shearing apparatus equipped with suitable smooth surfaced plates. The fertilizer was poured in the box and levelled. Measurements with different loads were then carried out and the linear regression between load and pulling force was calculated.

RESULTS

The angle of repose was 3^{o}-11^{o} higher and the angle of internal static friction was 0^{o}-5^{o} higher than internal dynamic friction. The range of angle of internal dynamic friction was 18^{o} to 32^{o}, with the lowest friction for prilled ammonium nitrate and the highest friction for granulated products without coating. The external dynamic friction was measured with a well polished steel plate and a plate of stainless steel. The results showed in most cases very small differences between fertilizers as well as plates. Those fertilizers which were divergent and had the highest external friction were mainly without coating. Particle size had little or no effect on friction characteristics. The mass flow characteristics of the fertilizers were also investigated. The same funnel as was used to determine the bulk density (ISO 3944 1980 E) was used for this purpose. A strong relationship was found between mass flow and the properties: bulk density, mean particle size and angle of internal dynamic friction.

DISCUSSION

Internal dynamic friction is not interchangeable by dynamic angle of repose. However, there seems to be a relationship between the two measurements in the sense that angle

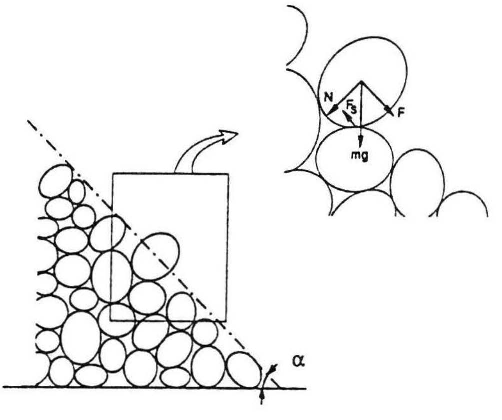

Fig. 5. A particle sliding down on the surface of a heap of granular material. The relatively rough surface results in supportive forces (Fs) that interfere with gravitational force.

of repose is always larger than internal angle of friction. This might be explained by a particle lying on the slope of other particles, as in Fig. 5, is not only affected by gravitational and frictional forces, but also supportive forces (F_s) from other particles that counteract gravitation and act together with friction. These supportive forces vary with factors such as particle size distribution, particle texture and form. However, when performing an angle of repose test it often happens that the fertilizer piles up and flows down in a cyclic pattern, giving a fluctuating angle of repose, which gives an uncertainty in the achieved value.

CONCLUSION

The most important factor influencing friction properties is usually the manufacturing process. Prilled fertilizers have lower internal friction and lower angle of repose than granulated. Coating of granules results in decreased internal friction and in most cases also decreased external friction. This applies to the types of coating (mostly vegetable oil and talcum powder) used on the fertilizers tested.

REFERENCES

1. **Brübach M.**: Der Einfluss der Korngrösse, der Granulfestigkeit und der Reibung auf der Verteilung

von Dünge- und Pflantzenschütz- Granulaten. Techn. Univ., Berlin, 1973.

2. **Hoffmeister G.**: Physical Properties of Fertilizers and Methods for Measuring them. Bull. Y-147, National Fertilizer Development Center. Tennessee Valley Authority, Alabama, 1979.

3. **Sears F.W., Zemansky M.W., Young H.D.**: University Physics: Sixth Edition. Addison-Wesley Publ. Co., 1982.

4. **Smith D.L.O.**: The Triaxial Load Response of Grain. Univ. Microfilms Intern., Ann Arbor. Michigan, 1982.