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THE ADHESION OF POWDER COATINGS TO FERTILIZER GRANULES

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General

Nowadays fertilizer granules are frequently coated with finely ground mineral powders such as chalk, kieselguhr or aluminium silicates. In this way the tendency of finely dispersed materials to adhere and cake, which would normally be undesirable, is used to create a layer of powder on the granules. The powder coating will bind the moisture taken up from the atmosphere by adsorption or capillary forces and prevent or at least delay caking of the granules during storage.

The success of these measures, known generally as "dusting", depends very much upon whether the layer of powder adhering to the granules is of adequate thickness and uniformity. The apparatus used for coating the granules (1) must therefore be constructed and operated in such a way that the powder medium

(1) reaches each granule in about the same quantity and

(2) is induced to adhere as much as possible.

Complete adhesion is the exceptional case which in practice cannot be achieved.

Factors controlling adhesion are, apart from analysis of particle size and other physical properties of the powder:

operating conditions during granulation,
the nature of the surface of the fertilizer,
the thickness of the layer of powder and
the atmospheric humidity.

The chemical composition of the powder medium is not important, as most powders of the same particle size have roughly the same power of adhesion to the same type of material. (Kieselguhr is an exception because of its great variety of particle shapes and its great adsorptive capacity). The general law formulated by R. Meldau (2) applies to the adhesion of powders: that with diminishing particle size the properties of the substance are of decreasing importance compared with the structural properties. Electrostatic forces of attraction are insignificant with moisture contents of the level of those occurring with fertilizers (dissipation of the charge).

Measurement of Adhesive Capacity

The adhesion of powders to granulated materials can be determined by the method of "screening adhesion measurement" (3)

The granular material is coated with the powdered substance under exactly determined experimental conditions and then screened in a flow screen connected to a cyclone. The screener, which can be readily constructed from a glass or perspex tube, must be of a size such that the non-adherent particles of powder can be practically all removed after one screening. The adhesive capacity can then be obtained by differential weighing of the dusted sample of granules before and after screening. The ratio of powder which has adhered to the total amount of powder used, expressed as either a fraction or a percentage, is what we call the "relative adhesive capacity" (H_{rel}) of the powder.

Most Important Factors of Influence

In the investigations which led to the results described below the material to be coated was mostly granules (2-3mm size) of normal commercial calcium ammonium nitrate (KAS) and ammonium sulphate nitrate (ASS). There is, however, no doubt that conditions are similar for adhesion to granules of complete and compound fertilizers. Consequently we shall confine ourselves mainly to the description of conditions as they occurred with KAS.

1. Influence of Atmospheric Humidity and Moisture Content of the Fertilizer

The relative humidity of the atmosphere has considerable influence especially with strongly hygroscopic, e.g., nitrate-containing, fertilizer types. It is known that above a definite atmospheric humidity which is specific for each material, these substances take up water vapour from the atmosphere and, so long as the water vapour partial pressure of their saturated solution is lower than that of the surrounding atmosphere, they are covered by a surface film of their saturated solution.

On fertilizers of this type there can be observed with increasing water content of the granules, a quite outstanding adhesive capacity of the powder medium. Fig. 1 gives an example; it shows the relative adhesive capacity of ground quartz powder on KAS as a function of the fertilizer moisture for various grades of fineness of powder. (Parameter: powder surface according to Blaine). The measurements were carried out at about 70% relative atmospheric humidity (f). (The limit of stability of KAS in relation to atmospheric humidity is approx. f = 65% at room temperature).

As can be seen, adhesive capacity at first increases slowly with moisture in a slightly bent curve. At a particular moisture content, which at a first approximation is found not to depend upon fineness of grind and which must therefore be determined by the surface characteristics of the fertilizer, there occurs a steep rise in the forces of adhesion. This is due to the fact that above the moisture content in question, diffusion into the inside of the granule can no longer keep pace with the uptake of moisture from the atmosphere. This is when the liquid film mentioned above forms on the surface of the granule, which can be recognized visually by the darker colour of the granules.

At atmospheric humidities which are below the stability limit of fertilizer as against water vapour, i.e., when the KAS is below 64% f, the adhesive capacity curve cannot, of course, be expected to behave in this manner. Under these conditions a slow steady rise in adhesive capacity is observed as the fertilizer moisture increases.

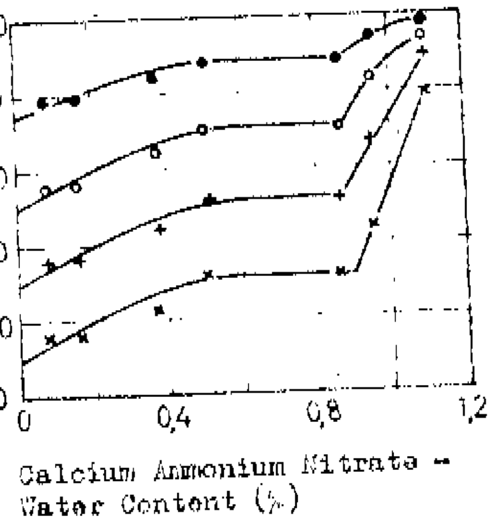

Fig. 1. Adhesive capacity of quartz powder as a function of the moisture content of KAS. Dusted with 5g per 100g KAS; f = 67 - 75%; 22 ± 2°C.

Symbols	O_{Bl} cm^2/g
x	4,000
+	6,000
o	8,000
●	11,000

2. Influence of fineness of grind and of the specific surface of the powder.

Among the factors which determine adhesive capacity, fineness of grind, and hence the surface area of the powder, takes pride of position. While the determination of the particle size distribution curve at the required fineness of powdered materials usually demands a considerable amount of work, if indeed it can be determined at all with the desired precision, the surface area may be found relatively easily. It may, for example be determined rapidly and fairly accurately by Blaine's method (4,5) or any other of the known permeability methods. It must however be borne in mind that the surface area (O_{Bl}) which can be calculated directly from the Blaine value is not identical with the specific surface area (O_{sp}). Like most experimentally determined surface values, it requires a correction factor. The conversion factor, however, is related to the fineness of the powder (6). But for purely comparative figures where the powder media used are the same substance, prepared by similar methods, it is often quite unnecessary to apply a correction to the Blaine values, a fact that makes the Blaine test with its simple measuring procedure a very useful method for investigating powders. It is recommended that the low-temperature adsorption procedure of Brunauer, Emmett and Teller (BET Method) should be used as the calibration test.

Figure 2 shows the adhesive capacity of some (non-fractionated) powders on KAS and ASS as influenced by the Blaine surface values. It can be seen that H_{rel} obviously rises exponentially with the powder surface area from zero to a limit value (= 100%). If a fractionated, e.g. classified, powder is used, the adhesive capacity curve obtained does not begin at zero but at a particular lower limit value of the specific surface area (O_{gr}) (see Fig. 3). This is understandable because in coarse particle fractions the finer particles are missing and consequently above a particular median particle size, the particles will no longer adhere.

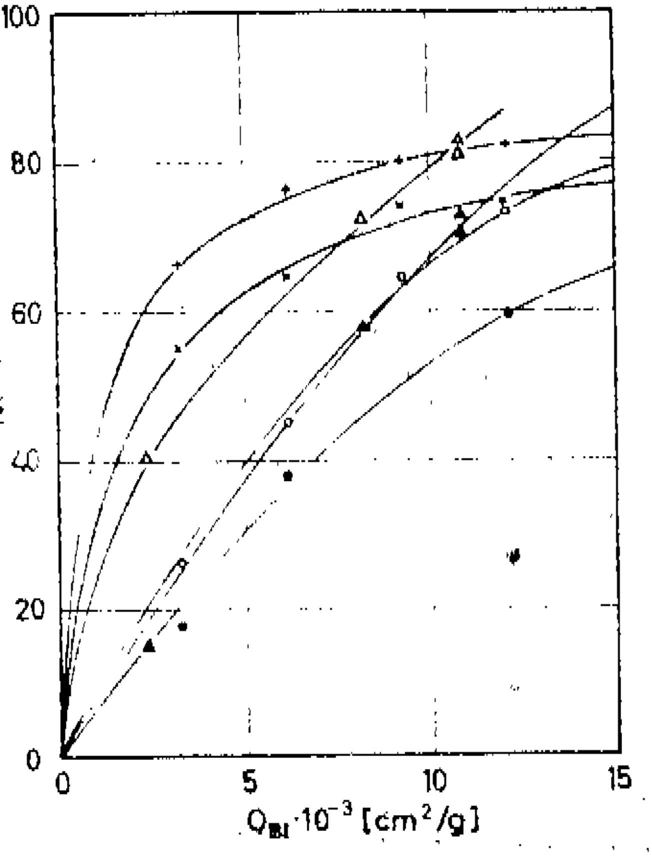

Fig. 2. Relative adhesive capacity of unscreened finely ground materials.

Dusted with:

● 5% Pandermite ⎫
o 10% Pandermite ⎬ on ASS
▲ 5% dolomite ⎪
△ 10% dolomite ⎭

\+ 5% Pandermite ⎫ on
x 10% Pandermite ⎭ KAS

A curve such as that seen in fig. 2 can be expressed by the general equation :

$$y = b - e_s^{-ax}$$

Referred to the present problem, this gives an empirical adhesive capacity equation as follows :

$$H = H_{max} - e^{-C.O_{sp}} = 1 - e^{-C.O_{sp}}$$

where $O_{sp} = O_{Bl} . \alpha$ (α = correction factor obtained by BET method)

and C is a constant. If we replace e by the base 10 in the above equation, we get the simple relationship :

$$H = 1 - 10^{-k.O_{sp}} \quad \text{(thickness of layer = constant)} \quad (1)$$

In the same way, the following is valid for classified powders :

$$H = 1 - 10^{-k(O_{sp}-O_{gr})} \qquad (1a)$$

3. Influence of particle size distribution of the powder

The attempt to present the results of adhesive capacity measurements functionally in this way showed that the "adhesive capacity coefficient" k which occurs in the exponential is often not a constant, even when the layer thickness is the same, but depends upon the particle size distribution in the powder. For reasons we shall discuss presently, we postulated:

$$k = k_1 \cdot \frac{1}{n} \qquad (k_1 = \text{constant})$$

where n is the value characterizing the uniformity of particle size according to the particle size distribution function of Rammler and Bennett :

$$R = 100 \cdot e^{-(d/d')^n}$$

where R = the residue on the screen above mesh-size d [%] ; d = particle size (mm), and d' = particle size characteristic (mm). It is understandable that the value characterizing uniformity can constitute a parameter for the adhesive capacity figure. It is merely necessary to remember what properties of the particles making up a powder are represented by n. High values of n indicate : exceptional distribution maximum, relatively large unfilled space, a small number of points of contact. Coincident n-values have the same significance, particle structure is analogous and there are similar points of contact within the powder dispersoid if we assume the same number of particles and similar particle shape. Hence it would be expected that powders with the same specific surface area would have coincident adhesive capacities only if their particle size distribution, and therefore their n-values, were identical or at least very similar. Even this presupposes that all other conditions (material to be coated, type of substance, medium) would be the same. Taking all this into account, we get a general equation for adhesive capacity:

$$H = 1 - 10^{-k_1 \frac{1}{n} O_{sp}} \qquad (2)$$

Fig. 4 A gives an example (powdered Pandermite on KAS) where failure to observe the particle size parameter n resulted in a large discrepancy between the measured curve and the calculated adhesive capacity curve (broken line).

Only when n was introduced into the adhesive capacity equation was a satisfactory agreement achieved between the calculated and measured values (extended curve). This also applies, as appears from fig.4 B, to larger applications of powder.

In all experiments with calcium ammonium sulphate the adhesive capacity of the powder was influenced by the value for uniformity of particle size, but with other types of fertilizer there was often no dependence upon n. There is a plausible explanation for this initially surprising circumstance : if the layer of powder on the surface of the granule is governed by mechanical or other loading, as, for example, in the case of measurement of adhesive capacity, then without doubt the points of weakest adhesion determine the adhesive stability of the particles of powder. If conditions are particularly favourable for adhesion to the powder/material interface to be coated, the degree of adhesion also depends mainly upon the particle size distribution of the dispersoid. In this case, the n-value is a co-determinant. (example: KAS)

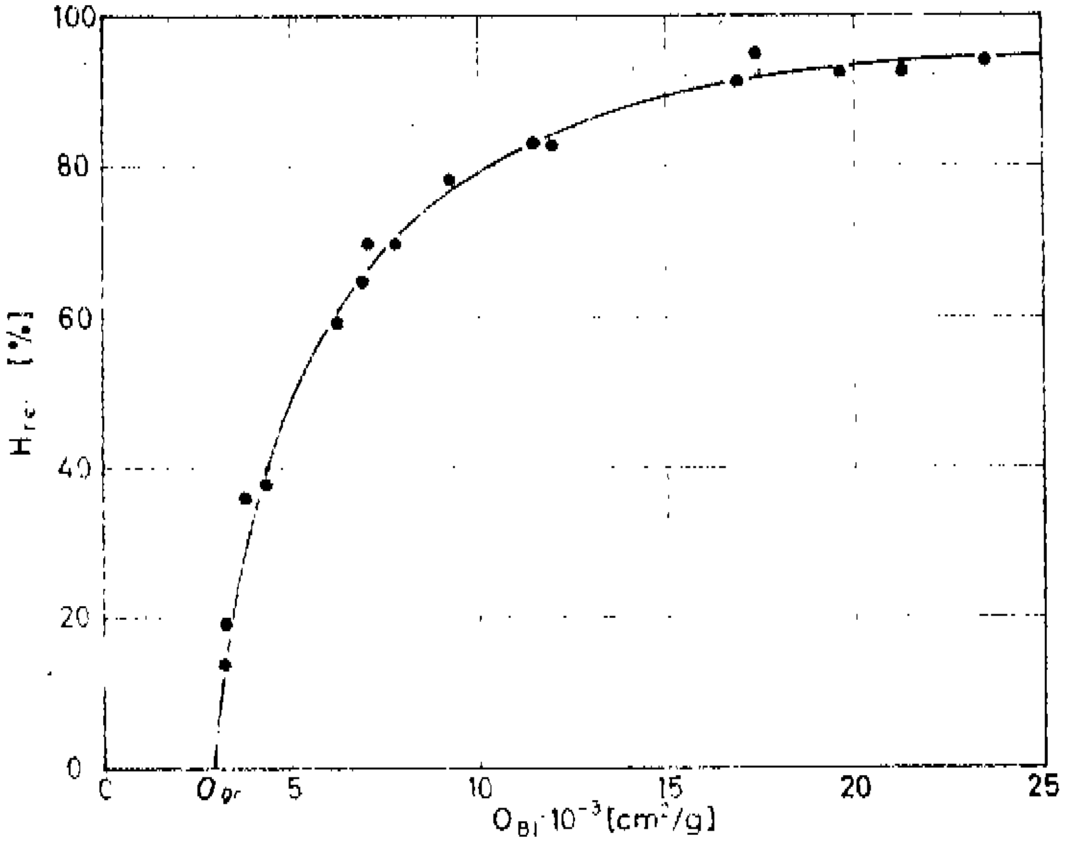

Fig. A. Powdered with 5 g. on 100 g. Ammonium Sulphate Nitrate

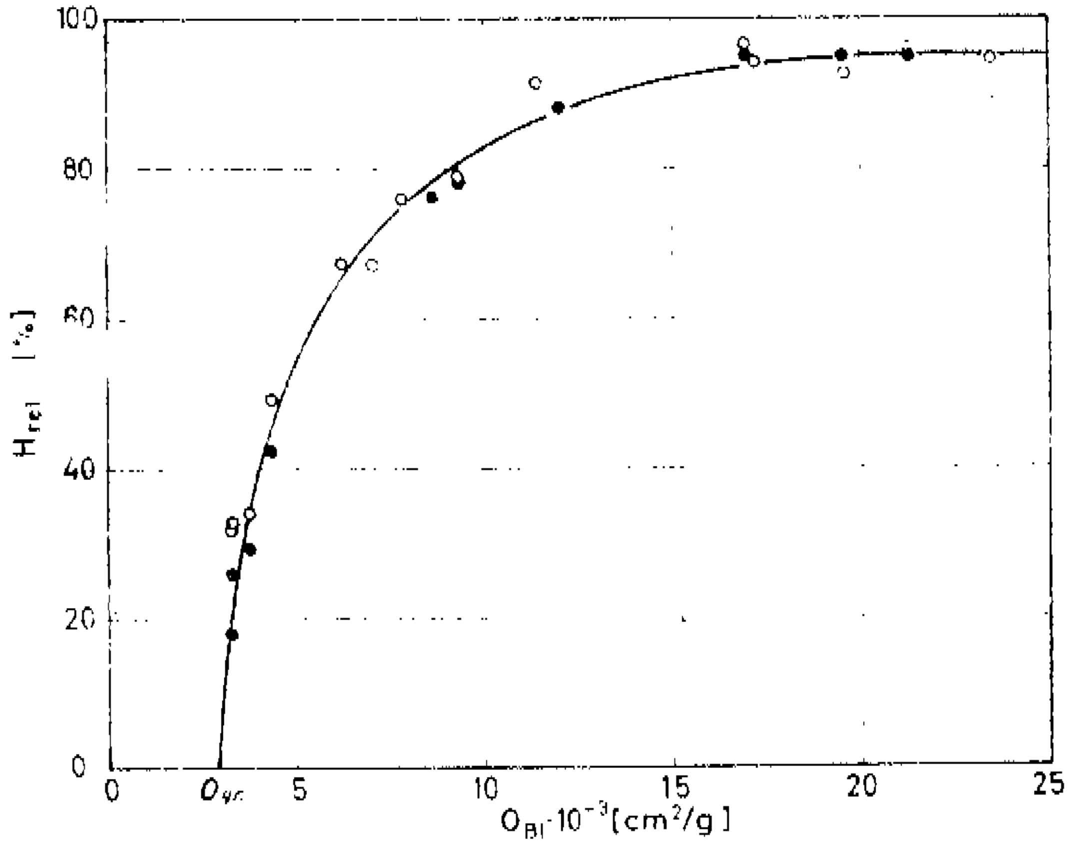

Fig. B. Powdered with 7.5 (●) and 10 g. (○) on 100 g.
Ammonium Sulphate Nitrate

Diagram 3 : ADHESIVE CAPACITY OF SCREENED PANDERMIT SAMPLES ON AMMONIUM SULPHATE NITRATE

If the material to be coated offers weaker adhesive forces, as might be expected from the irregular but glass-smooth surface of the less hygroscopic Montan potassium nitrate crystals, then the particle distribution will affect the adhesive capacity only under certain conditions. It will then depend upon the contact surface within the powder collective whether the dominant factor is the material to be coated or the distribution function. In many cases the number of contact points in the powder layer, measured from the adhesive forces between granule surface and powder particle, may be so small that the relationships involved are the same as with calcium ammonium nitrate. With unclassified powders with a wider particle size distribution, however, there is a greater probability that the adhesive forces operating within the particle layer amount to several times those on the (smooth) base surface.

Thus it becomes comprehensible that the adhesive capacity of unclassified powder media on ASS should be found to be independent of the particle size distribution function.

The observation graphically expressed in fig. 2, that with KAS adhesive capacity deteriorates as the thickness of the powder layer increases, while with ASS it improves, is due to the same causes. A quantitative standard for this divergent behaviour is provided by the adhesive capacity coefficient (k or k_1) which may be worked out according to equation (1) or (2), as the case may be. Some examples of this are quoted in Table 1.

Table 1

Adhesive capacity coefficients of some systems

1	2	3	4	5	6	7
	Calcium ammonium nitrate 1)			Ammonium sulphate nitrate 2)		
Powder	depending on n?	$k_1 \cdot 10^4$ (g/cm^2) powder rate of 5%	10%	depending on n?	$k_1 \cdot 10^4$ (g/cm^2) powder rate of 5%	10%
Pandermite unclassified	yes	1,07	0,833	no	0,331	0,450
screened	yes	-	-	no	0,394	-
Dolomite unclassified	-	-	-	no	0,456	0,837
Chalk, screened	yes	1,57	-	-	-	-
Adhesive capacity equation	$H = 1 - 10^{-k_1 O_{sp}/n}$			For unclassified powders $H = 1 - 10^{-k' O_{sp}}$		

1) ~ 0.8% H_2O

2) ~ 0.4% H_2O

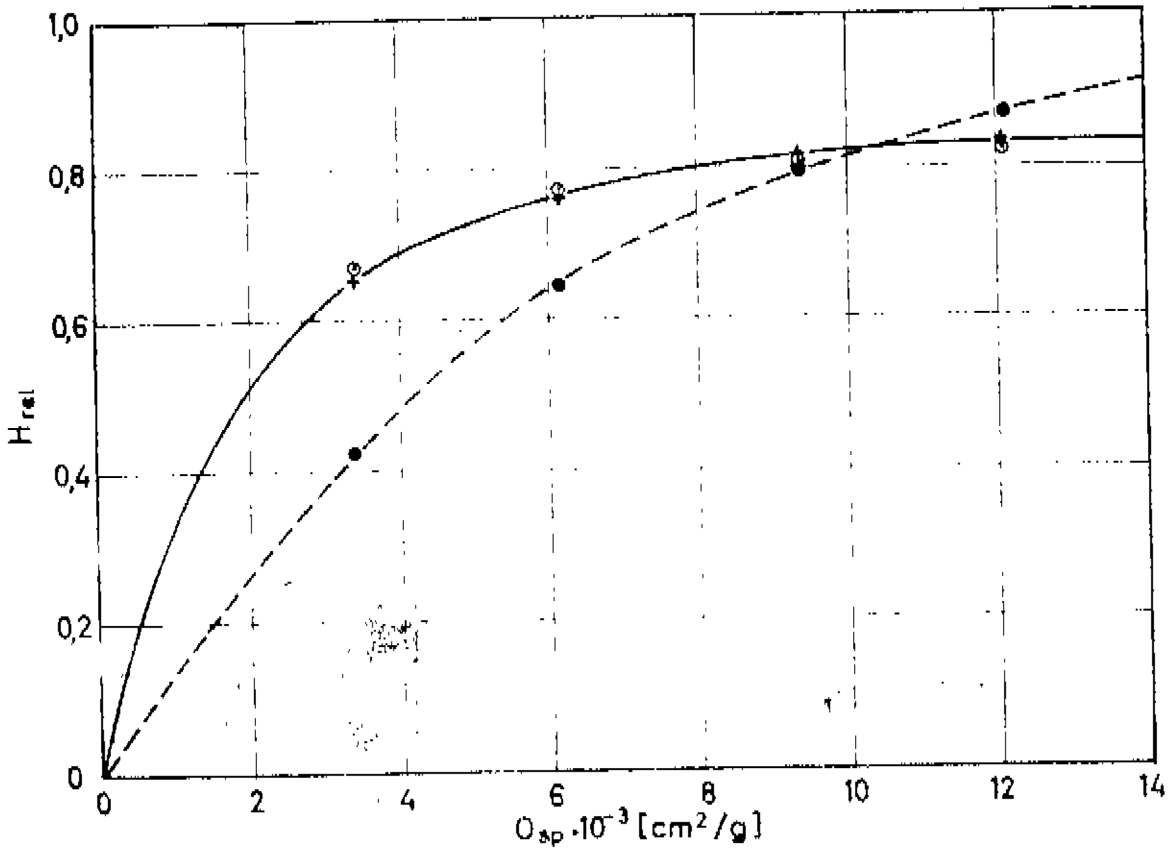

Fig. A. 5% Powder added • $k = 0{,}725 \cdot 10^{-4}$, + $k_1 = 1{,}07 \cdot 10^{-4}$

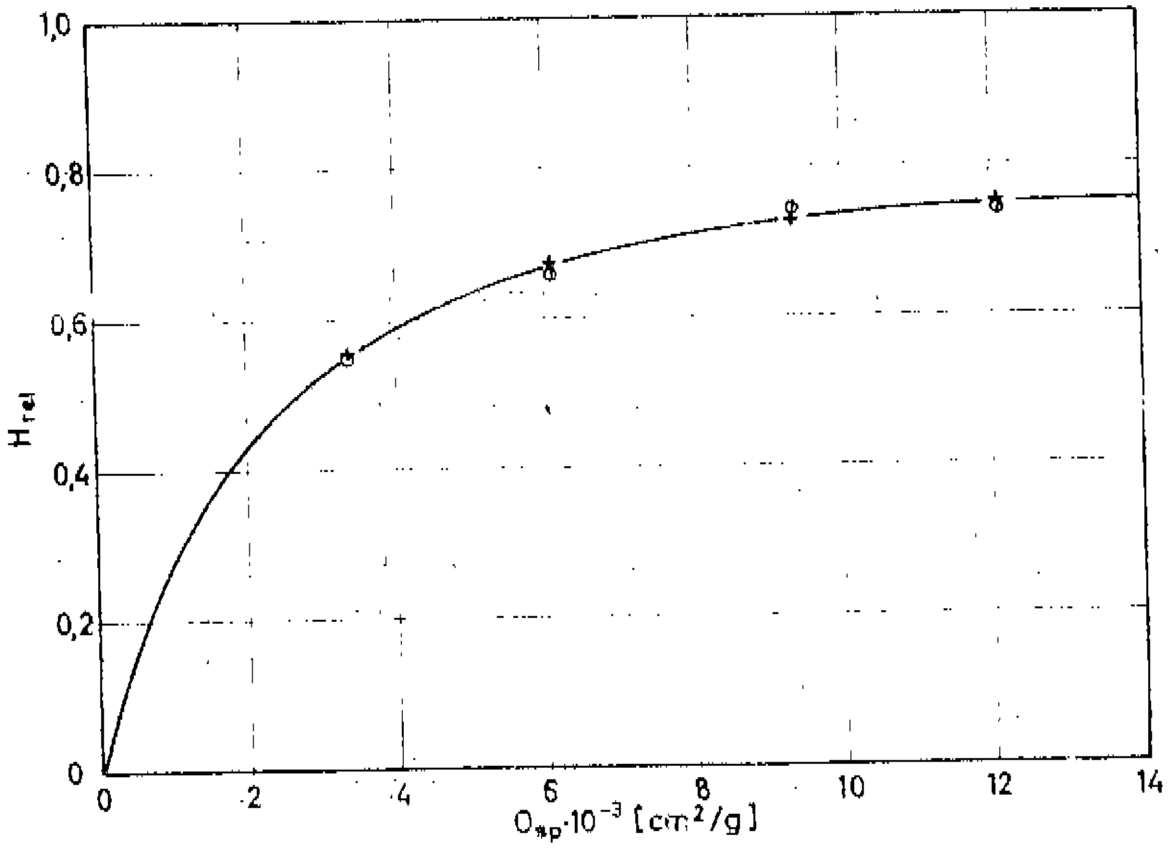

Fig. B. 10% Powder added + $k_1 = 0{,}833 \cdot 10^{-4}$

Diagram 4 : CALCULATION OF ADHESIVE CAPACITY OF PANDERMIT

◉ Points of measurement • calculated according to $H = 1 - 10^{-k \cdot O_{sp}}$

+ according to $H = 1 - 10^{-(k_1 \cdot O_{sp}/n)}$

The present paper is an attempt to throw some light on the circumstances, which in some respects cannot readily be examined experimentally, which determine the adhesion of powder layers to fertilizer granules. It should be stressed that the relations described as existing between adhesive capacity, fineness of powder and particle distribution are demonstrably valid for "normal" relationships. Under extreme conditions, with very damp fertilizers for instance, quite different factors might predominate. To discuss this, however, would be outside the scope of this paper.

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