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THE DISCHARGE OF FILTER CAKES

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Experiments were made with Brazilian iron ore (CVRD-Ore) and different filter media. The adhesive tensions of the filter cake were measured. The distribution along the filter area was plotted over the saturation of the filter cake with water. It is shown that there are often non uniform tensions along the filter cloth. By numerical integration of the distribution of tensions over the filtering area an average adhesive tension can be calculated which is effected by the construction of the filtering cloth.

INTRODUCTION

In many different branches of industry, the mining industry, the chemical industry and the food industry for instance, filters are used for separating solid-liquid suspensions. The filterpress, the disk-filter and the drum filter are typical examples. Thereby the operator as well as the constructor are often confronted with the problems of discharging an adhesive filter cake.

While operating a frame filter press it is often necessary with some products to remove the filter cake with a scraper from both sides of the frame, in spite of using a smooth, calendered polyamid filter medium. On that account it is important to know the magnitude of adhesion forces, when designing the discharge equipment. While operating a disk- or drum filter almost all filter cakes are not discharged to 100%, because each filtration cycle causes a residue of finest solid particles. They cannot be removed from the filter medium even after washing or backflushing as thoroughly as possible. The particles are also moving into the filter medium. The pores are blocked and the adhesion forces may increase. When operating a filter apparatus with poorly discharging filter cake, the economics not only depend on the quality of separation but also on the result, how completely the filter cake is removed. If the filter cake adheres too firmly to the filter medium, it may be impossible to operate a disk filter or a frame filter press. In this case a drum filter is substituted for a disk filter and a filter press with a mechanically aided discharge substituted for a frame filter press. Of course, the specific costs per filter area are considerably higher. The selection of the best filter medium needs experience and so labour-consuming experiments with

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high costs. Up to now, the adhesion forces between the filter cake and the filter medium cannot be predicted. They depend on the characteristics of the filter cake and on the design of the filter medium. In order to predict the adhesion forces and to give some direction to the producer of filter mediums, how to reduce adhesion forces, we developed a measuring method to determine adhesion forces between the filter cake and filter medium. In this paper the method and some results are presented.

SOME REMARKS TO THE THEORETICAL BACKGROUND

Adhesion forces were taken into consideration by Rumpf in his research on agglomeration. In his publications |1,15| he gave a complete summary of bonding mechanisms. Schubert published experimental results and theoretical descriptions of the tensile strength of moist agglomerates |22|. Their treatise deals with the fundamentals of adhesion forces between single particles and plates. Lately Robel |23| described the adhesion power of moist, solid-disperse systems to a plate. Different bonding mechanisms between particles were compared by Rumpf and Schubert |21|. In figure 1 the calculated adhesion force is plotted against sphere diameter for a sphere adjacent to a plane surface. The liquid-bridges forces are about four times as large as the van der Waals forces, which are by an order of magnitude greater than electrostatic adhesion forces between conductors, due to contact-potential, and these are again about 100 to 10 times as great as adhesion forces due to maximum surplus charges of opposite sign. The figure shows that adhesion forces as electrostatic adhesion and van der Waals forces are unimportant to the discharge of moist filter cakes. They are always smaller than the forces caused by liquid bridges. Liquid bridges are exerting a strong influence on the adhesion of particles in the region of capillary condensation up to a degree of saturation of 0.4. The degree of liquid saturation means the relation of the volume of liquid in the filter cake to the void space. For moist agglomerates with less than 30% of the void spaces filled with liquid, a theoretical tensile strength can be calculated from the mean value of the number of contact points. With an equation by Rumpf the tensile strength can be calculated as

$$\sigma = \frac{1-\varepsilon}{\varepsilon} \cdot \frac{F}{x^2}$$

where ε is the porosity of the agglomerate, F mean adhesive force between the particles and x the diameter of the spheres forming the agglomerate. If more than about 80% of the void space between the particles is filled with liquid, a capillary suction is formed in the liquid space and the agglomerate is held together by the outer pressure. The tensile strength σ can be calculated with

$$\sigma = S \cdot p_K$$

where S means the degree of liquid saturation and p_K the capillary pressure.

In figure 2 the capillary pressure is plotted against the degree of liquid saturation. Capillary pressure and tensile strength are associated with each other.

The research on the tensile strength of moist agglomerates give an understanding of the physical aspects of adhesion forces between filter cake and filter medium. But the applicability to the calculation of the discharge of filter cake is not given as long as the influence of the filter medium is not taken into consideration and there is still no research on a preliminary calculation of adhesive strength of moist filter cake on filter medium. The measurements, presented in this paper, provide a contribution to the investigation of this field.

EXPERIMENTAL ARRANGEMENT

To investigate the adhesion forces between filter cake of iron ore and filter medium, a set-up was composed of two separate measuring instruments. First the filter cake is formed in a filter apparatus and the moisture content is reduced to different degrees of liquid saturation, and a centrifuge is used, in which the filter cake is strained by centrifugal force and thrown off the filter element into a collecting cup. The experimental results give the adhesion forces between the filter cake and the filter medium in the moment of discharge of the cake.

Filter-Apparatus

Description of the Pressure Nutch

The filter cake is formed and the moisture content is reduced in a pressure filter. Figure 3 shows the flow-sheet of the filter apparatus. The essential part is a pressure nutch, as it is used in the industry to project or to lay out a vacuum or pressure filter. The nutch is connected to pressure air via a pressure reducing valve and flowmeter. A manometer shows the pressure in the nutch above the filter medium. During the outflow of filtrate the scales take continuously the weight of filtrate over the time and transfer the signal to the recorder. In the upper part of the nutch an attachment is placed, indicating the moment, when the surface of liquid sinks into the filter cake. This attachment consists of a lamp and a photoelement. The signal measured is the reflexion power of the surface of liquid and of filter cake. This signal is transmitted to a measuring amplifier and indicated.

The mount, in which the filter medium is fixed, is removeable. Different samples of filter medium can be put into this mount with little effort. The round filter area has a size of 20 cm^2. The mount consists of two rings of brass, a locking ring to keep the filter medium slightly stretched and plane, and a perforated plate to support the filter medium.

Trial procedure

To form the filter cake repeatedly in an identical manner is an important precondition that reproducible results are obtained. Always an equal quantity of 7 g iron ore and 5 g destilled water was weighted out with a laboratory weighing machine. It was mixed in a hypodermic syringe, the contents completely ejected onto the plane filter medium, the filter mount inserted into the filter nutch, the nutch was closed and filled with compressed air. Changing the dewatering time different degrees of liquid saturation were realized.

The Centrifuge

The discharge of filter cakes was put into effect by tensile force perpendicular to the plane filter medium. The centrifugal force serves this purpose. The amount of centrifugal force can be changed continuously by the speed of rotation.
To calculate the tensile strength is easy and relatively exact.

Description of the Centrifuge Set-up

Figure 4 shows the arrangement of the set-up in a schematical diagram. The essential part is the centrifuge. Two rotating arms are screwed on the rotor. One is the mount of the filter medium and the other one the counter weight. The distance between the filter medium and the rotor centre amounts to 150 mm. The centrifuge is closed with a plate. In this plate is an opening to watch the filter cake with the help of stroboscope, which is synchronized by the speed of rotation. The speed of rotation is taken electronically by an inductive measuring instrument. The indication is stopped by the observer with a push-button key in the moment of discharge.

Trial procedure

After the filter cake has been formed and the moisture content reduced in the filter apparatus, the mount of filter medium with the filter cake is inserted into the centrifuge. The speed of rotation is increased steadily and the filter cake watched with the lamp of the stroboscope. As soon as the first part of the filter cake is detached from the filter medium and thrown into the collecting cup (this is heard), the indication of the speed of rotation is held. When the centrifuge stops, the collecting cup is taken off the centrifuge and the part of filter cake in the collecting cup is weighted. The rotating arms are accelerated again with a new collecting cup until the next part of filter cake detaches. This procedure is repeated until the last part of filter cake is removed. The parts of filter cake are dried in a drying cupboard and the moisture content is calculated afterwards. In the centrifuge the filter cake is enclosed in the collecting cup to protect it from drying. Nevertheless the duration of the experiment should be as short as possible.

EVALUATION OF MEASUREMENTS

The tensile strength is calculated with the equation

$$\sigma_A = \frac{m_{s,w} \cdot r \cdot w^2}{A}$$

where $m_{s,w}$ is the mass of the moist filter cake, r the distance between the filter medium and the center line of the rotor of the centrifuge, w the speed of rotation and A the filter area.
To determine the distribution of the adhesion forces, the ratio of the mass of the removed parts of filter cake to the total mass of filter cake (m/m_o) is plotted (as in figure 5) against the

adhesion force. In each curve the degree of liquid saturation S is constant. For the different curves the saturation ranges between 0 and 0.5. If the saturation increases, the adhesion force increases too. In figure 6 the adhesion force decreases, if the saturation increases. In this figure the saturation ranges between 0.7 and 1. Using the curves in figure 5 and 6 the adhesion force is taken at different degrees of liquid saturation with a constant ratio of mass, and in that manner the figures 5 and 6 are transformed into figure 7. In this diagram the adhesion force is plotted against the degree of liquid saturation. It is similar to the diagram of Schubert in figure 2. The values of the parameters at the curves represent the ratio (m/m_o) of discharged filter cake.

The influence of shear forces on the measurement of adhesion forces

The construction of the filter medium causes inhomogeneities in the layer between the filter medium and the filter cake. A distribution of particle size , degree of liquid saturation, and pore diameter in the filter medium cause a distribution of the adhesion forces between the filter medium and the filter cake, as it is shown in figure 7. In the filter cake are elements, which are more ore less adhesive to the filter medium. When the centrifugal force stresses the filter cake, shear forces result, due to the different adhesion of the elements of the filter cake. The distribution of the adhesion forces can only be measured, if the shear forces are much smaller than the differences of the adhesion force of adjacent elements of the filter cake. A balance of forces is shown in figure 8. The magnitude and therefore the importance of shear force decreases in the balance of forces, if the filter cake gets thinner. To effect this the measurements were carried out with very thin filter cakes.

Calculation of the integral adhesion forces

In thick filter cakes the shear stress balances the different adhesion forces of different parts of the filter cake. The filter cake is discharged from the filter medium as one piece. In this case the average of the adhesion force over the filter area is of interest. The average of the adhesion forces was calculated from the measurements of the adhesion forces of the thin filter cakes. The measured distribution of the adhesion forces was integrated numerically over the total filter area with the equations

$$\bar{\sigma}_A = \frac{1}{A} \int_0^A \sigma_A \cdot dA$$

$$\bar{\sigma}_A = \frac{1}{m} \int_0^m \sigma_A \cdot dm = \frac{1}{m}\left[\sigma_{A,1} \cdot \Delta m_1 + \sum_{i=2}^{i=n} \sigma_{A,i} \cdot \Delta m_i \right]$$

$\bar{\sigma}_A$ is the integral average of the tensile strength, A the filter area, σ_A the tensile strength of the single elements of the filter cake and m the mass of filter cake per filter area. Figure 9 shows the integrated curves of figure 7. The magnitude of the adhesion forces is much lower than in figure 7.

INFLUENCE OF TIME ON THE ADHESION FORCES

To study the dependence of adhesion force on the different parameters of the filter medium, all other influences have to be eliminated as completely as possible. On of these is the change of filter medium over the times of use. Therefore at the beginning of each measurement of a new filter medium 30 running-in tests were made under identical conditions. It turned out, that filter media which are known to block in practice, show steadily or statistically increased adhesion forces. In the following 4 figures, 4 typical examples are presented. The figures show the integral adhesion stress plotted against the times of use.

Figure 10 shows a filter medium with an insignificant increasing of the adhesion stress over the times of discharging. The weight of the filter medium was nearly constant over the number of experiments. This curve is characteristic for a filter medium with a very homogeneous surface.

In figure 11 two things are of interest. At one hand the adhesion force of the new filter medium is relatively low, and at the other hand the adhesion force shows an oscillation. The amplitude is larger in the beginning, and becomes constant in the following part. Oscillations are typical for nearly all filter mediums.

In figure 12 the adhesion force of the new filter medium is relatively high, but it does not increase very much during the following experiments. This curve is for a filter medium with a profiled surface, in which the filter cake was interlocked. During the experiments the adhesion force increases, because of the adsorption of finest particles.

In the fourth example in figure 13 a very smooth filter medium is used. The filter cake cannot interlock so that a small adhesion force results in the beginning. With time finest particles are adsorped, as was the case with the filter medium in figure 12, and the adhesion force increases. But time and again part of the filter cake is taken off the filter medium so completely that nearly no particles are remaining on the filter medium where this part of the filter cake has been. After the filter cake is taken off totally on the filter medium remain some parts, which are completely free of particles, and some parts,where particles are still attached to the filter medium.

CONCLUSION

After the running-in time of the filter medium the adhesion force was measured on dependence of the degree of liquid saturation of the filter cake. The results were curves with a marked maximum between 0.6 and 0.9 of the void space filled with water. The magnitude of the maxima ranges for the differential adhesion forces between 3000 N/m^2 and 30.000 N/m^2.

At small degrees of saturation (S<0.1) the filter cake was taken off in the form of many small, single parts at one time. At high degress of saturation (S>0.9) the filter cake was taken off in the form of one piece.

In the range of saturation between 0.1 and 0.9 a wide distribution of the adhesion force appeared. The filter cake was always taken off in very small parts. The fraction of filter cake with the highest adhesion force was by an order of magnitude greater than the fraction with the lowest adhesion force. The adhesion force of the last 10% of filter cake is considerably higher than the remainder for many filter mediums.

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List of Figures

Formulae

A surface (m^2)
F force (N)
$m_{s,w}$ area specific mass of the filter cake(kg)
P_K capilary pressure (N/m^2)
r radius (m)
S degree of liquid saturation (%)
x diameter of the particle (m)

Δ difference
ε porosity
σ tensile strength

Indices

A Adhesion

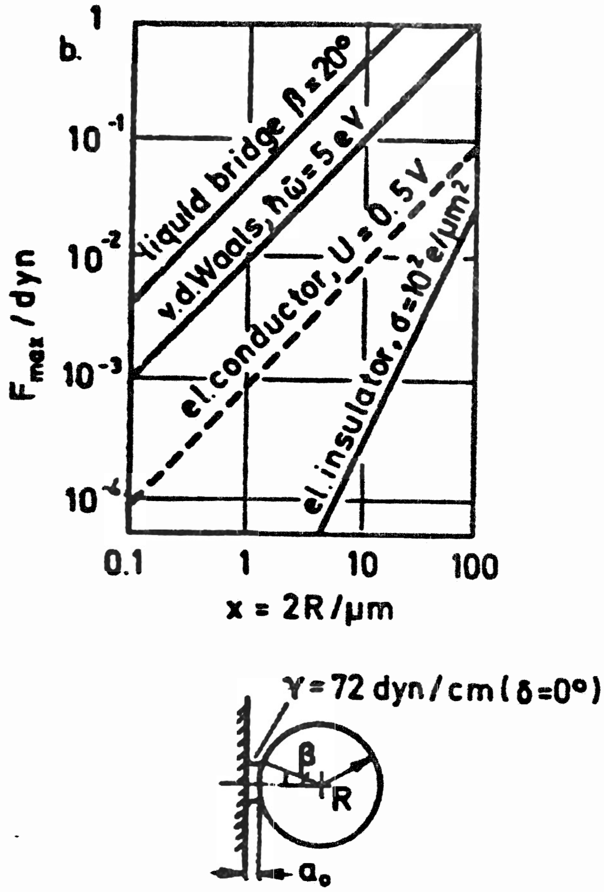


Figure 1: Adhesion force F_{max} of liquid bridge, van der Waals, and electrostatic interaction between a smooth sphere and a half space as a function of the sphere diameter x. The surfaces of the two interacting bodies are in contact, $a_o = 4 \times 10^{-8}$ cm

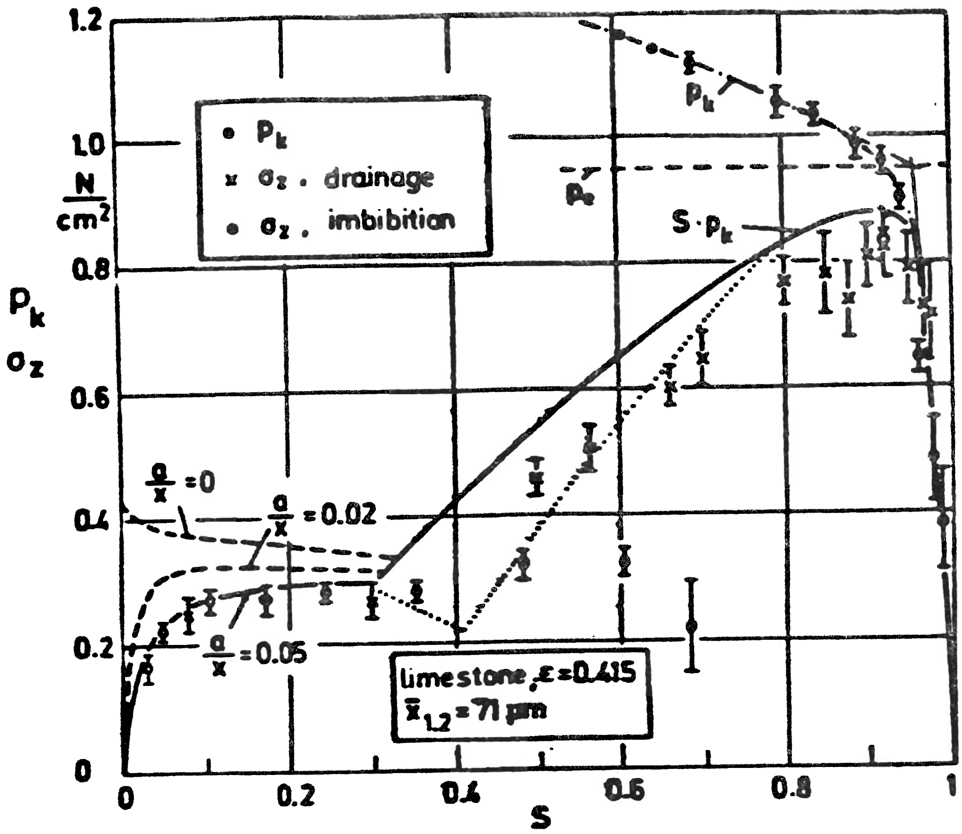
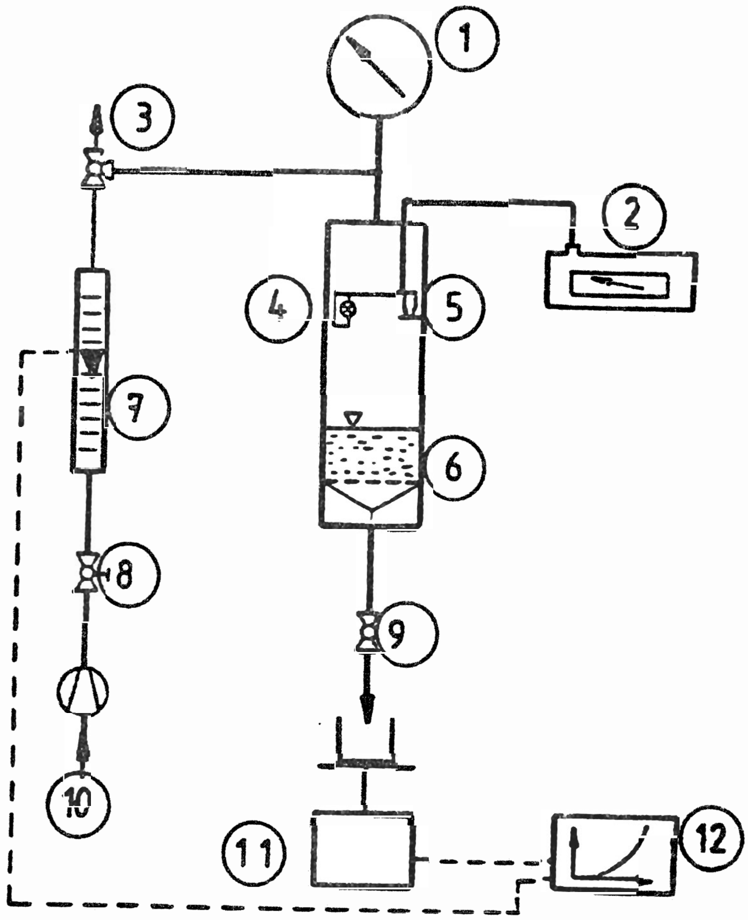
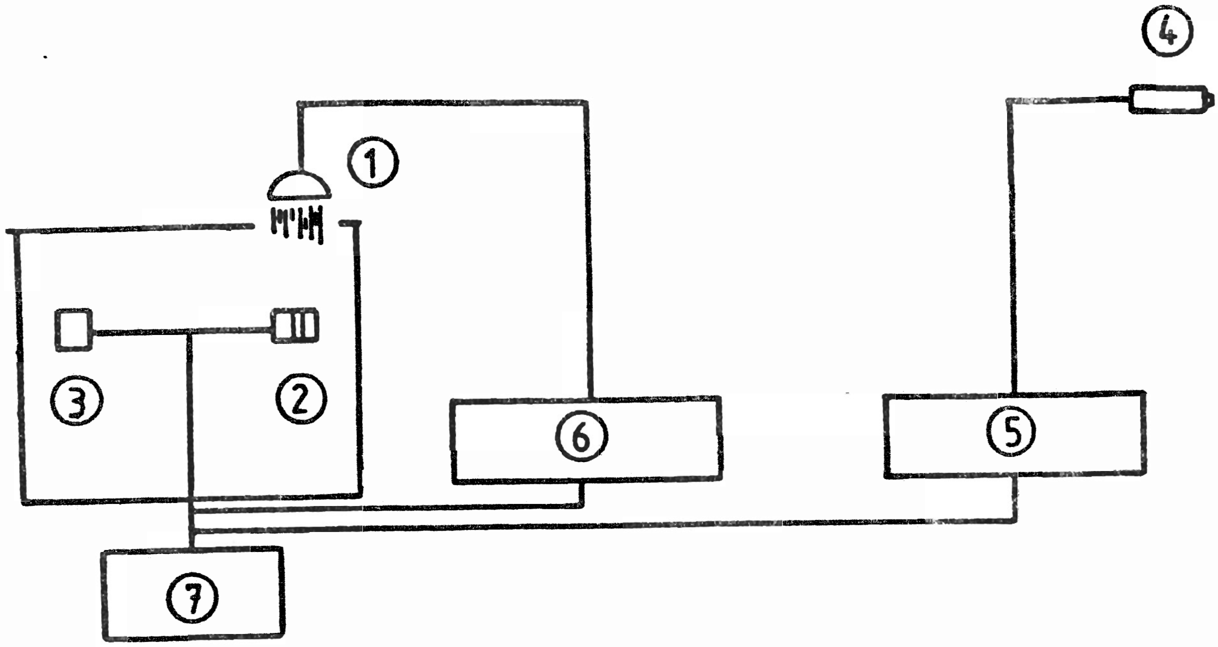


Figure 2: Capillary pressure, p_k and tensile strength σ_z as a function of the liquid saturation



<u>Figure 3</u>: Schematic diagram of the filter apparatus

1 Manometer	7 Flowmeter
2 Amperemeter	8 Reducing valve
3 Valve	9 Tap
4 Lamp	10 Pressure air
5 Photodiode	11 Weighing maschine
6 Pressure filter cell	12 x-t-Recorder



<u>Figure 4</u>: Schematic diagram of the centrifuge apparatus

1 Stroboscope lamp
2 Mount with the filter cake
3 Conter weight
4 Push-button
5 tachometer
6 Stroboscope
7 Motor

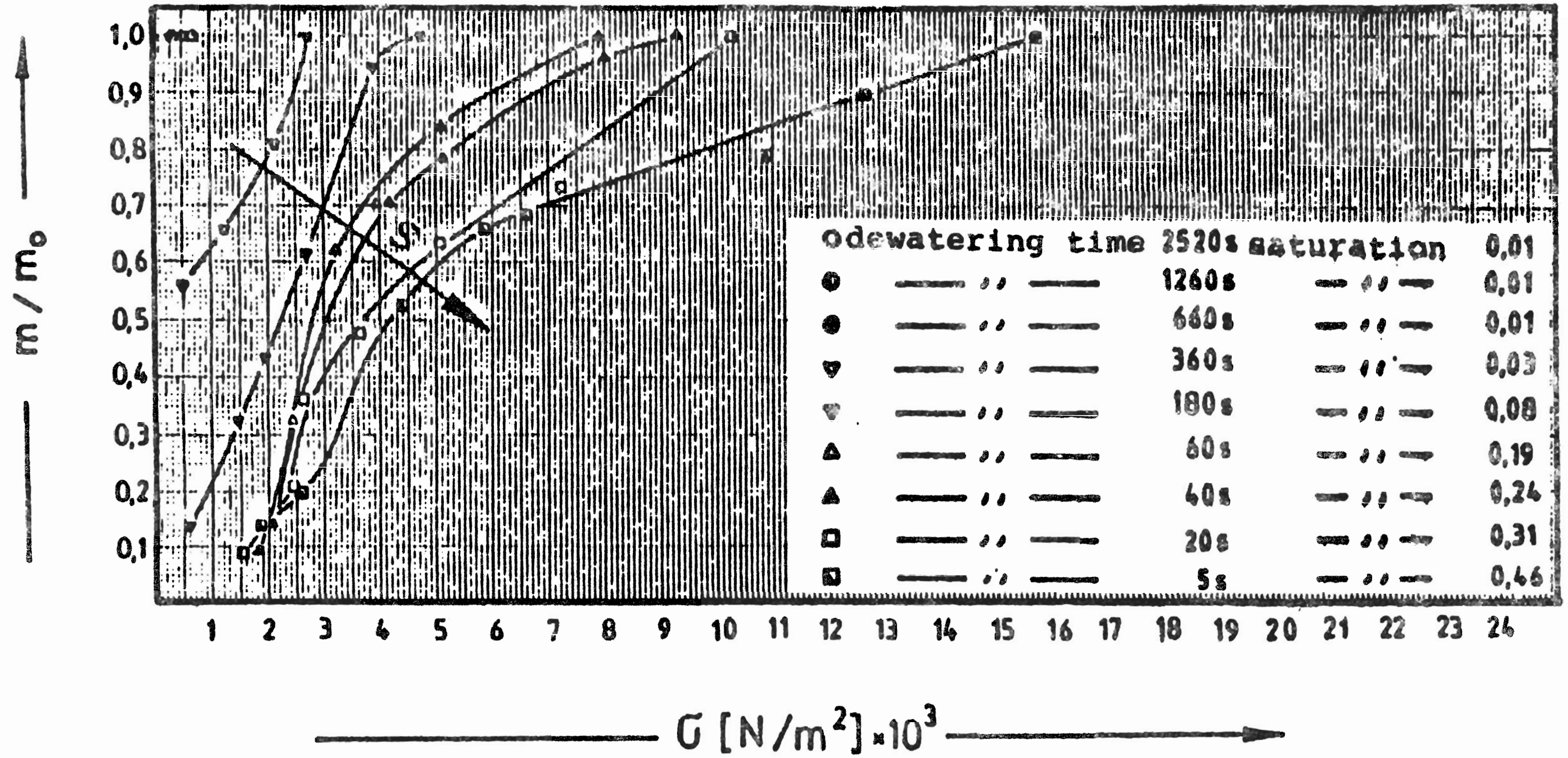
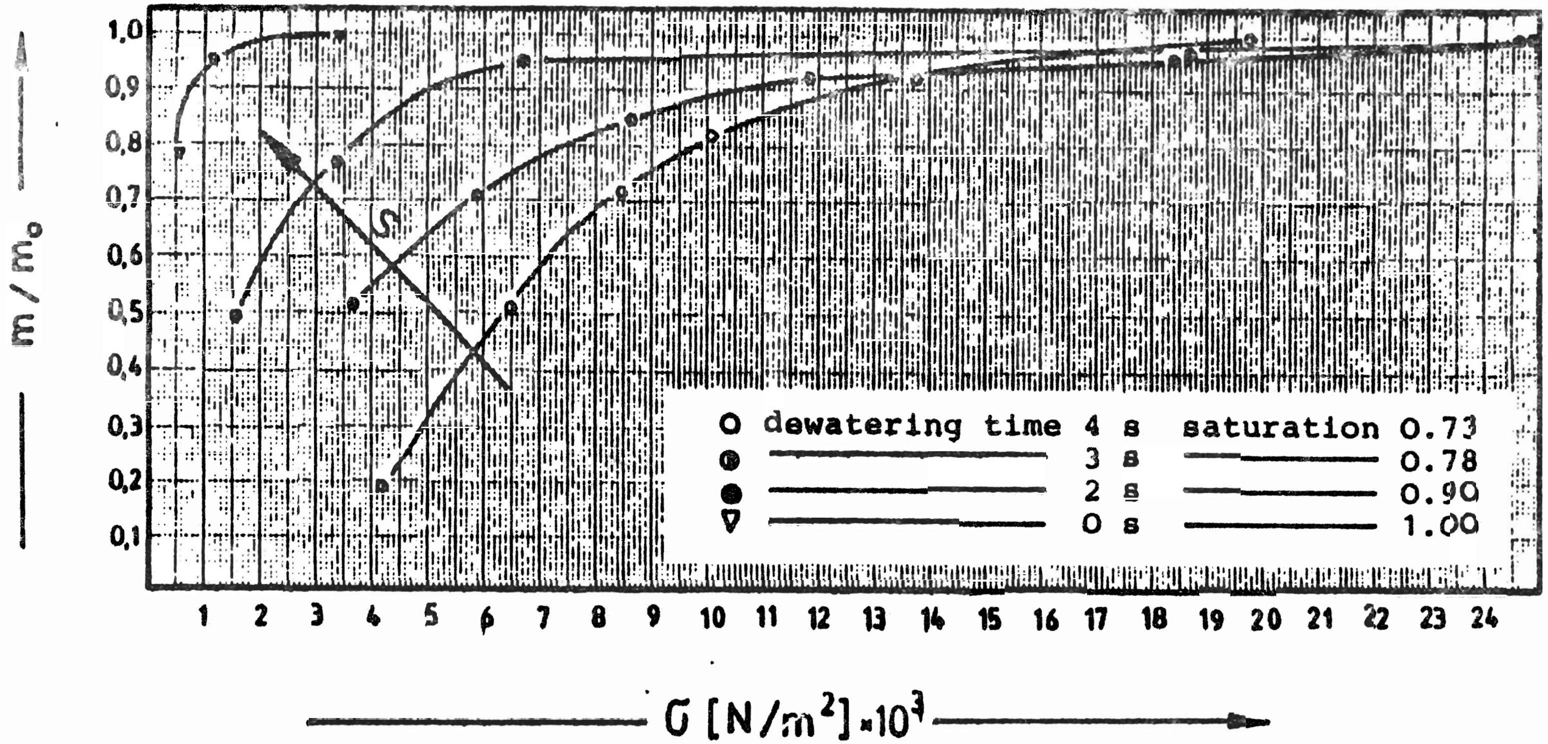


Figure 5: Ratio of masses versus tensile strength.
Parameter is the degree of liquid saturation



<u>Figure 6</u>: Ratio of masses versus tensile strength.
Parameter is the degree of liquid saturation

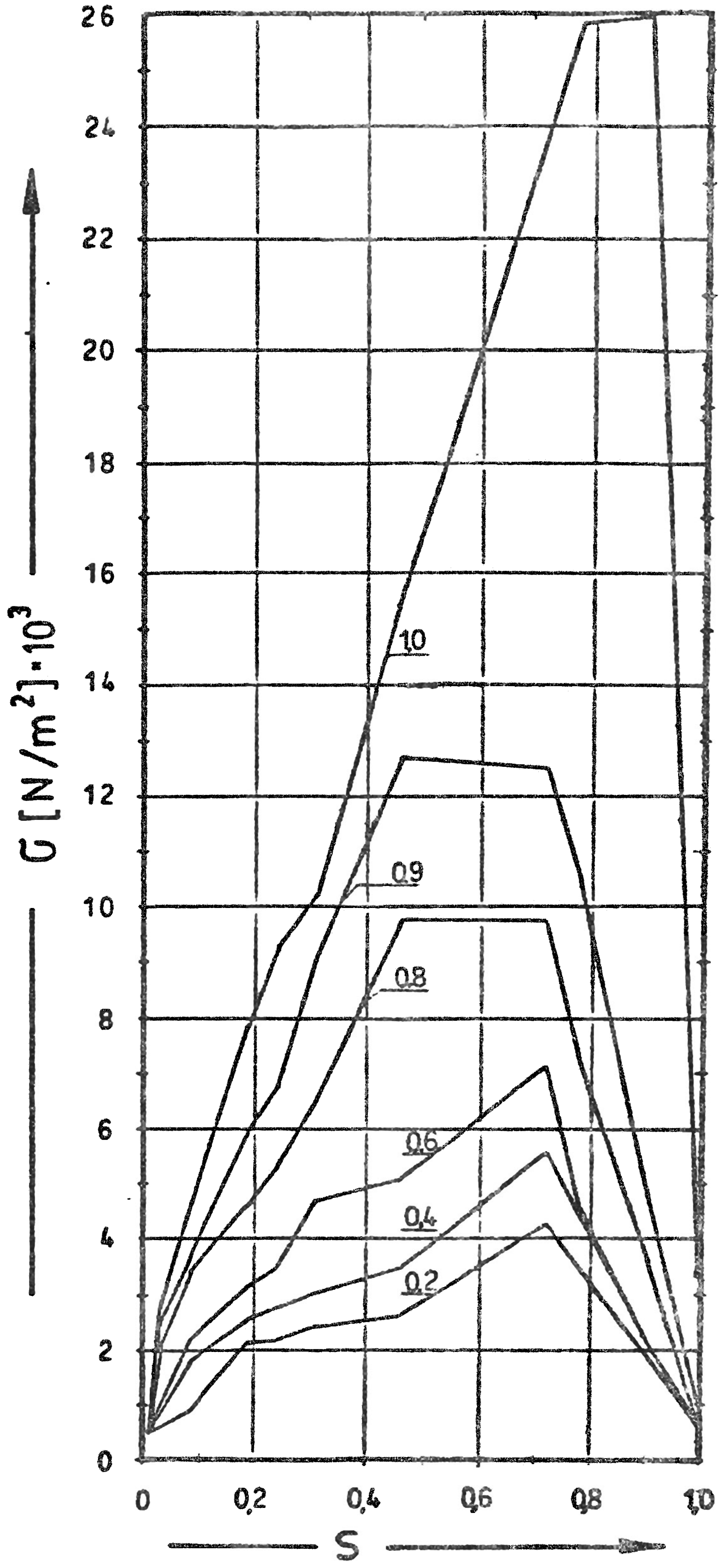


Figure 7: Tensile strength σ as a function of the liquid saturation S. Parameter is the ratio of the discharged filter cake to the total filter cake

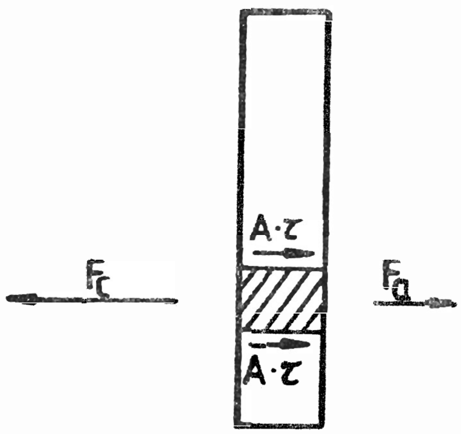


Figure 8: Balance of forces in the filter cake
F_c: Centrifugal force
F_a: Adhesion force
A : Fractured area
τ : shear stress

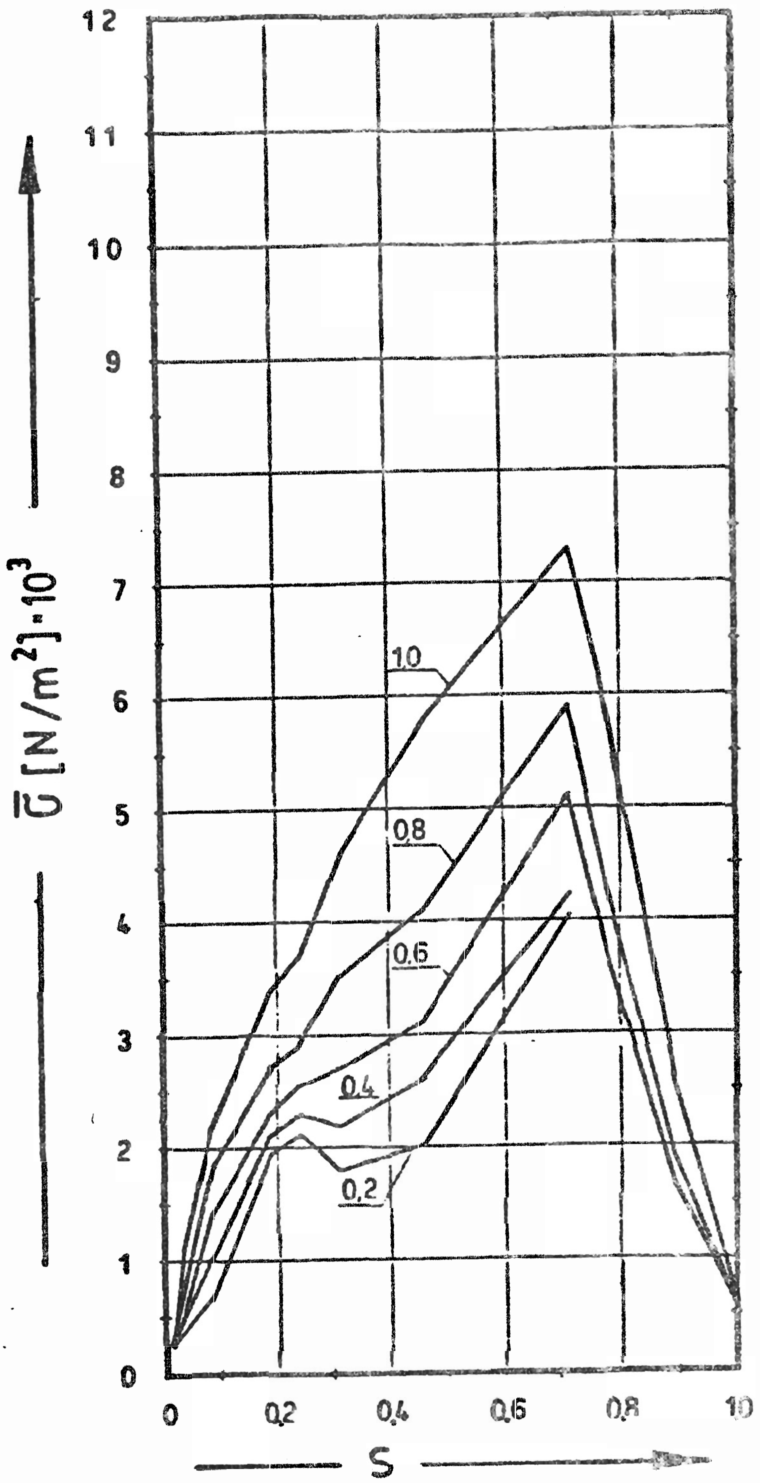


Figure 9: Average of the maximum transferable tensile stress σ as a function of the liquid satursacion S. Parameter is the ratio of the discharged filter cake to the total filter cake

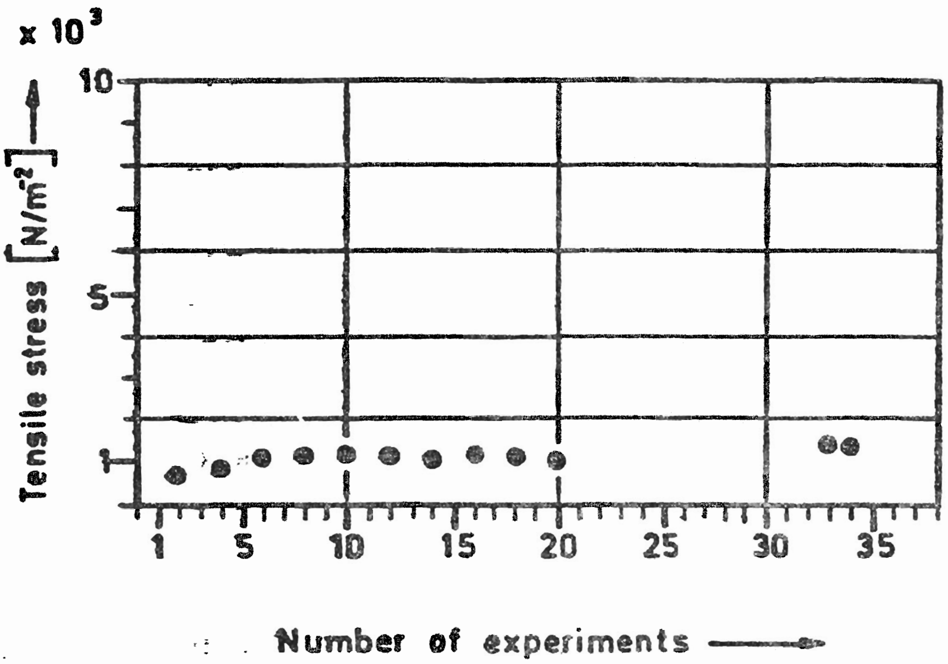


Figure 10: The diagram shows the average of the maximum transferable tensile stress as a function of the number of experiments for a filter medium with a nearly constant adhesion force

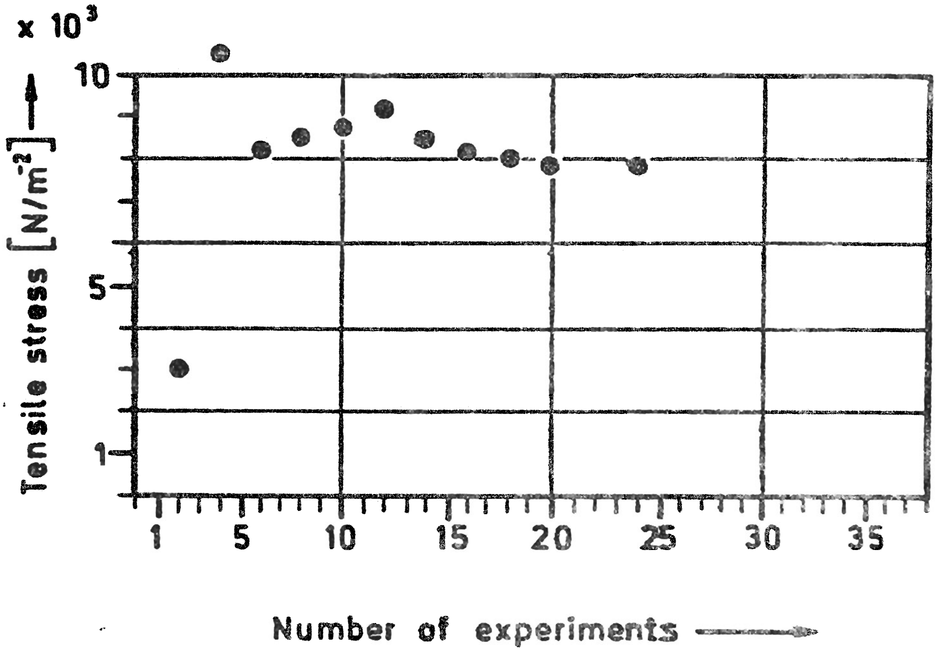


Figure 11: The diagram shows the average of the maximum transferable tensile stress as a function of the number of experiments for a filer medium with a radidly increasing adhesion force

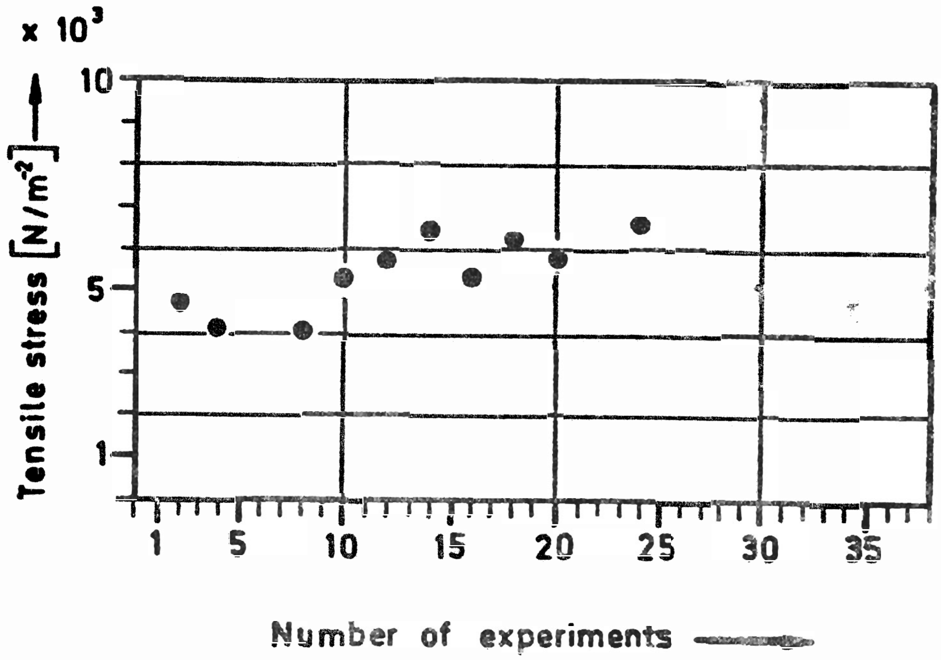


Figure 12: The diagram shows the average of the maximum transferable tensile stress as a function of the number of experiments for a filter medium with a slowly increasing adhesion force

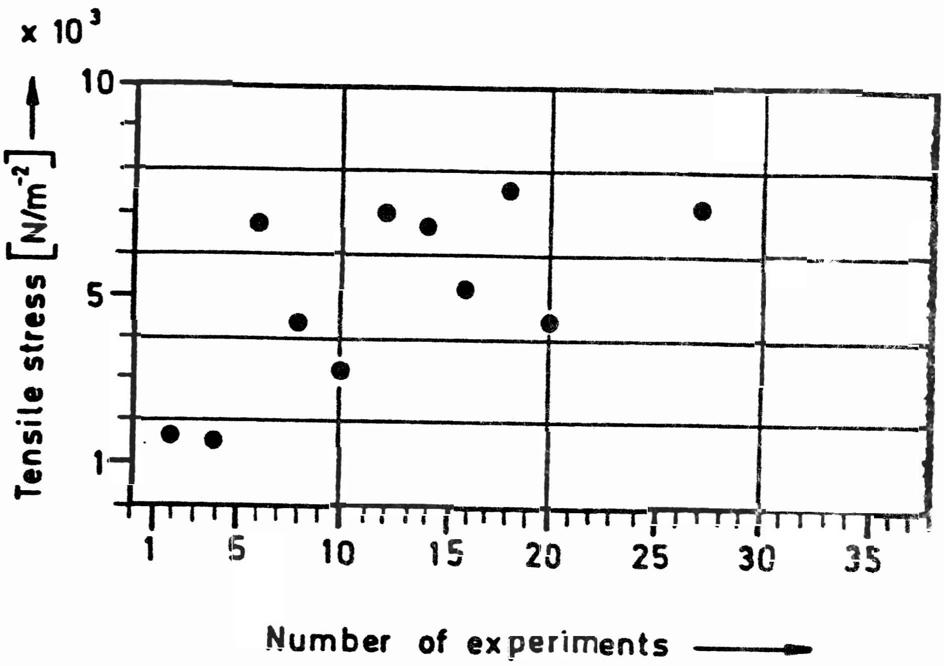


Figure 13: The diagram shows the average of the maximum transferable tensile stress as a function of the number of experiments for a filter medium with a statistically increasing adhesion force