Technologisch Instituut-K.VIV
Mechanical Separation and
Particle Technology

Volume 8

PROCEEDINGS Part II

WORLD
4th
FILTRATION
CONGRESS

22 - 25 April 1986
Ostend. Belgium

Editors : R. Vanbrabant
J. Hermia
R.A. Weiler

The Royal Flemish Society of Engineers (K.VIV) Antwerp (Belgium)
329th event of the European Federation of Chemical Engineers

ADHESIVE FORCES BETWEEN FILTER CLOTH AND CAKE: AN EXPERIMENTAL INVESTIGATION

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ABSTRACT

The adhesive force distribution of filter cakes versus their water content was tested on several filter cloths for a new Brazilian iron ore. The adhesive force distribution on the filter surface was plotted against the saturation of the filter cake. An average adhesive force is calculated by numeric integration over the filter surface. It is influenced by the design of the filter cloth. The time characteristic of the adhesive force is illustrated for several filter cloths. A statistical method was tested to establish the influence of the various filter cloth parameters.

INTRODUCTION

Filters are used in various industries, for example in mining, as well as in the chemical and food industries, to separate suspensions. Some typical examples: the filter press, the disk-type filter, the drum filter, and the belt filter.

Users and producers of filter devices alike are often faced with the same problem: How to remove an adhering filter cake. If the filter device is operated in such a way that the filter cake is only partially detached, the efficiency of the filter also depends on how much of the filter cake can actually be taken off the filter device.

Filter cake residues which remain attached to the filter, will impede filtering in the following filtering cycle. New filter cakes will build up on old filter cake layers in such a way that the thickness of the filter cake is uneven. In the thicker areas, the filter cake can only be partially dried. The remaining filter cake layers detach themselves from the filter cloth when resubmerged and form clumps at different places on the filter when the filtration is restarted. These parts of filter cake are still highly saturated when the filter cake is taken off.

If the filter cake is not completely removed, the average residual moisture value is poor and the adhering cake parts lead to a loss of solid throughput. Further, the adhesive forces influence the filtering effectiveness of the filter cloth. Minute particles settle in the pores of the filter cloth and press themselves between individual threads of multifilament cloths (see fig. 1). Thus, the flow resistance of the filter cloth and the adhesion of the filter cake grow considerably or the filter cloth can clog. These particles can not always be removed from the filter cloth with simple washing or backwashing.

To this day, it is difficult to forecast the adhesive forces between the filter cake and the filter cloth. They depend just as much on the filter cake parameters as on the textile used to manufacture the filter cloth. A measuring method has been developed to better evaluate filter cake adhesion and to find ways to reduce adhesive forces. The methods and several test results are listed in this publication.

TESTING EQUIPMENT

The measuring facilities comprise two separate measuring devices. First, a filter cake made of water and iron ore is placed in a pressure filter and dried at various saturation degrees. The filter and the filter cake are placed in a centrifuge. In the centrifuge, the filter cake is thrown off the filter cloth by centrifugal force. The filter cake is caught in a receiver. The result of the measurement is the adhesive stress which is overcome between the filter cake and filter cloth when the cake is thrown off.

Figure 2 illustrates the flow diagram of the pressure filter bay stand. The most important element is the pressure filter itself in which the filter cake is formed and dehydrated.

The pressure filter is connected to the compressed air network with a pressure reducing valve and a flow meter to measure the volume of the air flow. A manometer gauge indicates the pressure in the filter. During the test, a balance measures the filtrate flow. The flow curve is plotted over a time axis. A device is installed in the top part of the pressure filter to determine the time when the liquid level submerges the filter cake. This device consists of a lamp and a photodiode. The measurement is based on the reflectance of the liquid and filter cake surfaces.

The filter cloth is installed into the pressure filter with an insert and is easliy exchangeable. The filter surface is round and has an area of approximately 20 cm^2. The holder consists of two cylindrical rings to stretch the filter cloth, and a perforated panel to support the cloth. After the filter cake has been formed and dried, the filter cloth holder and the filter cake can be removed from the pressure filter and placed in a centrifuge.

<u>Description of the Centrifuge</u>

Figure 3 is a schematic diagram of the centrifuge stand. Its most important characteristics are the centrifuge and the two arms which are screwed on the rotor. The insert with the filter cake is mounted on the first arm. A counterweight is mounted on the second arm to maintain balance. The centrifuge is closed with a panel. It has a small opening through which the filter cake can be observed by a stroboscope. The stroboscope is synchronized according to the centrifuge's inductively measured rotary speed.

During the testing period, the number of revolutions is steadily increased until the first part of the filter cake is released from the filter medium and thrown into a receiver. The speed at the time when the cake is thrown off is recorded. The centrifuge is stopped and the released cake layer is weighed. The centrifuge is then equipped with a new receiver and accelerated until the next piece of filter cake falls off. This procedure is repeated until the entire filter cake has been removed.

The detachment of the filter cake takes place under normal stresses which arise through centrifugal acceleration and is vertical to the filter cloth surface. The centrifugal force depends on the speed of the rotor and is easily calculated.

EVALUATION OF MEASUREMENT RESULTS

The tensile strength of the filter cloth is calculated according to the following equation:

$$\sigma_A = \frac{m_{s,w} \cdot r \cdot \omega^2}{A} \qquad (1)$$

In this equation, $m_{s,w}$ equals the mass of the moist filter cake, r is the distance between the filter cloth and the rotor axis, ω is the angular velocity and A is the surface of the filter medium.

To illustrate the adhesive force distribution on the filter cloth surface, the ratio of the detached filter cake as opposed to the entire cake is plotted versus the adhesive force in figure 4. The width of the adhesive stress distribution range varies greatly according to the saturation level of the filter cake.

Filter cakes with a high saturation level have a steep distribution curve. The liquids in these filter cakes are distributed in such a way that a uniform capillary pressure is formed. The distribution of adhesive stress in completely saturated filter cakes cannot be established with the measurement methods used. The filter cake is thrown off as a whole.

The distribution range of adhesive stress on more extensively demoisturized filter cakes is very wide. There are obviously liquid surfaces with locally different saturation and capillary pressure levels. Only filter cakes which are almost dry are detached as a whole. The adhesive stress is so low that the filter cake fractures into small pieces after having been thrown off.

At a specific decremental mass ratio, the adhesive stresses associated with various saturation levels are taken from figure 4 and plotted in figure 5. Figure 5 illustrates the adhesive stress versus the saturation level of the filter cake using the decremental mass ratio as a parameter.

The adhesive stress versus the saturation curve has a maximum which depending on the filter cloth can represent various degrees of saturation. Thus, the levels of the maxima also vary.

Adhesive stresses diminish when the saturation values are high. This characteristic is reflected in the fact that certain filter cakes, which are removed by compressed air, are not separated from the filter cloth until it releases small amount of filtrate in the boundary layer between the filter cloth and the filter cake. A water absorption capacity of the filter cloth can be useful for the removal of the filter cake.

Calculation of Integral Adhesive Stresses

The design of the filter cloth, the distribution of particle sizes, the pore sizes of the filter cloth and the local saturation all contribute to the distribution of the adhesive forces. Thus, various parts of the filter cake are formed which adhere to the filter cloth in different ways. During exposure of the thin filter cake to centrifugal forces, some zones of the filter cake may detach individually. Shear stress arises between the layers with diversified adhesive forces of thick filter cakes. To detach the entire filter cake, the integral average of the adhesive stress versus the filter surface is crucial.

The integral adhesive stress average is calculated from the adhesive stress distribution which has been established by measuring thin filter cakes. The measured adhesive stress distribution is calculated over the filter surface through numeric integration according to the following equation:

$$\bar{\sigma}_A = \frac{1}{m} \cdot \sum_{i=1}^{n} \sigma_{A,i} \cdot \Delta m; \qquad (2)$$

$\bar{\sigma}_A$ is the integral average of the adhesive force, A is the filter surface, $\sigma_{A,i}$ is the adhesive force of a single part of the filter cake and m is the specific surface mass of the filter cake. Figure 6 shows the integral averages of various filter media versus saturation.

THEORETICAL APPROACHES FOR THE CALCULATION OF ADHESIVE FORCES

Adhesive forces and their relation to particle agglomeration has been extensively treated in several publications |1-23|. Rumpf and Schubert |21| compared various binding agents between individual particles and plate structures. Schubert |22| published experiment results and theoretical descriptions of tensile strength in moist bulk entities. Robel |23| describes the adhesion of moist dispersed-solids compounds on boundary surfaces.

Rumpf |15| contributed figure 7 in which the calculated adhesive forces of spheres adhering to a flat surface are plotted over the diameter of the sphere. The forces of the liquid bridge are 4 times greater than the Van der Waals forces, the adhesive forces do not influence the detachment of moist filter cakes. They are always far smaller than the forces which arise from liquid bridges.

Liquid bridges (in the scope of capillary condensation up to a saturation level of 0.4) greatly influence particle adhesion. If these forces are known, the tensile strength of moist agglomerates with a saturation level below 30% can be theoretically calculated according to Rumpf's equation:

$$\sigma = \frac{1-\varepsilon}{\varepsilon} \quad \frac{F}{x^2} \qquad (3)$$

ε is the porosity of the agglomerates, F is the adhesive force between the particles at the contact points, and x is the diameter of the spheres which form the agglomerates. When more than 80% of the cavity volume between the particles is filled with liquid, the tensile strength can be established from the capillary pressure. According to Schubert's relation

$$\sigma = S.P_K \qquad (4)$$

in which S stands for the level of saturation and p_K for the capillary pressure.

In figure 8, the capillary pressure and the tensile strength of a moist bulk entities versus the saturation level were established by Schubert. As opposed to the measurements of adhesive stress of filter cloths in figure 6, the curve has a maximum value close to the saturation level 1. One reason for this shift of maxima in figure 6 lies in the definiton of the saturation level. The adhesive stress in figure 6 is plotted against integral average of saturation level of the filter cake. However, the local saturation level in the boundary layer between the filter cloth and the filter cake determines the adhesive stress. It is difficult to establish with instrumentation.

Comparative tests with a manually operated filter show that filter cakes which are scraped off under vacuum pressure always have less moist residues than those which are removed after the vacuum has been stopped. The saturation level of the filter cake on the filter cloth is increased by having the cake soak up the water in the cloth. The exact value of the saturation in the boundary layer is unknown; however, the decrease of the maxima to lower saturation values corresponds with this value.

THE INFLUENCE OF THE DRYING PROCESS ON ADHESIVE FORCES

Adhesive stresses can also be shifted by the type of demoisturization. Figure 9 shows the adhesive stress of filter cakes which were immediately detached in the pressure filter after drying, and those which were dried for 20 to 30 minutes in the centrifuge at a normal speed or dried in the pressure filter, and then thrown off. Since the surface of the filter cake is dried from the inside, there is a gradient of the saturation versus cake height. Thus, filter cakes are developed which, although they have the same saturation average, have different adhesive stress values. This clearly shows that the type of drying process used can influence adhesive stresses.

The following must be observed when evaluating the measured values in figure 6: When comparing the adhesive stress points of different filter cloths, it cannot be differentiated whether filter cloths with an average saturation level have different saturation levels in the boundary layer, or whether different adhesive forces are generated when the boundary layers have identical saturation levels. Thus, the influence of the filter medium on the adhesion of the filter cake already starts when the filter cake is being formed and lasts beyond the drying process up until the filter cake is attached to the filter cloth. Even if it is possible to determine the adhesive stress from the distribution of particles and liquids, the influence of the filter medium on distribution itself remains unclear.

It is highly improbable that a theoretical model will be developed in the near future which would accurately forecast the development, the saturation and adhesion of the filter cake. To acquire data interest for technical applications, we are striving for an empirical correlation of the influence of the filter medium on the adhesive properties with a typical product. For the time being, general behavioral patterns cannot be expected for this process. It is important to establish how filter cloth parameters which are found in technical lists of filter cloth manufacturers influence adhesion.

THE INFLUENCE OF FILTERING CYCLES ON ADHESIVE STRESSES

Adhesion can be influenced by changes in the filter cloth which develop during filtering cycles. To observe this process, 30 filter cakes were made with each filter cloth under identical conditions. Figure 10 shows the integral average of adhesive stress versus the number of filtering cycles of various selected filter cloths. In general, the filter cloth's adhesive stress changes considerably. Variations in adhesive force have been observed, especially during the introductory phase, in almost all the filter cloths examined. Four examples of possible adhesive stress curves are shown in figure 10a - 10d.

Figure 10a illustrates a filter medium with a low increase of adhesive stress versus the number of cycles. Even the weight of the filter cloth, which was also measured to determine the embedment of particles in the fabric, changed very little during the entire experiment. The filter medium in question has a smooth surface.

The adhesive forces of another filter cloth shown in figure 10b are very small. Adhesion increases unsteadily during the process and levels off at a higher value.

In figure 10c, the adhesive forces of the new filter cloth are relatively high but they only grow little during the experiment. This can be attributed to a filter medium with a textured surface, with which the filter cake is interlaced. During the experiment, a layer of fine particles was observed on the filter cloth.

A very smooth cloth was used in the fourth experiment shown in figure 10d. The variation of the adhesive force is clearly seen, and the average adhesive stress grows. The filter cake is totally thrown off in certain sections and elsewhere, a thin layer remains.

THE INFLUENCE OF INDIVIDUAL FILTER CLOTH PARAMETERS ON ADHESION

Table 1 illustrates the measured values of 14 filter coth types. The cloth designations are listed from top to bottom.

The characteristics of the filter cloths and the measured values of the adhesive force are listed from left to right. The adhesive force values are those needed to throw off 80% of the filter cake, when its water saturation is such that the adhesive force is at its highest.

Cloths with a low bubble point (Cloths 1-4) generate little adhesive stress. These cloths have a pore size which is approximately identical to the largest suspended particles. Cloth number 4 does not seem to be consistent. However, when just taking the bubble point into consideration, it seems more porous than it actually ist. The permeability of this cloth to air is only half as great as cloth number 1. Open filter cloths all have low adhesive force values.

When using fine-pore cloths, the adhesive force depends on other filter cloth parameters. Cloths made of polyprobylene and cloths with a twill weave is only used in combination with polypropylene if the adhesive stress is much higher than average. The increased adhesive stress is attributable to the polyprobylene material. As opposed to the twill weave, the braided weave has a much lower adhesive stress.

Calculation of influence factors by averaging

First, measures are calculated according to one common characteristic of the filter cloth. For example, the average of all monofilament cloths or the average of all cloths made of polypropylene. These values are listed in the first column of table 2. The values in the second column are established by grouping the characteristics of the filter cloths. For example, the thread group is composed of monofilament, multifilament, and a mixture of mono/multifilament characteristics. The characteristic with the highest adhesive stress is picked from each group. It is then related to the other characteristics. The factors of the reference quantity are equal to 1.

Note: The type of thread and the finishing process have practically no influence on the adhesion of the filter cake. They are all very close to 1. Braided weaves as opposed to twilled weaves and polyester and polyamid 6.6 cloths as opposed to cloths made of other material have noticeably lower adhesive force values.

The influence of the fabric type is calculated by taking the adhesive force values in table 1 and dividing them by the factor of the fabric type in table 2. The result is illustrated in table 3.

The results in table 3 give the factors for table 4.

When comparing the various filter cloths, it is clear that the fabric type is the just about the only factor which influence adhesive forces. The remaining fluctuations in the adhesive force vary by +/-3%. In table 2, the multifilament weave was more successful than the monofilament weave.This can be attributed to the fact that both multifilament cloths are made of 6.6 polyamide. If the influence of fabrics is taken into account, the monofilament weave has an advantage. However, it is not very distinct,and is partially be caused by the pore size or the finishing process. Further calculations, however, will not provide more conclusive forecasts.

As already mentioned above, open filter cloths lie below the average in terms of adhesive force. Compared to the monofilament cloths, the multifilament cloths have a higher adhesive force value. Cloths with a high bubble point are further analysed in table 5.

This table lists the average of cloths 5 to 14, based on individual cloth characteristics. The influence of other cloth parameters increases when the bubble point is high. Regarding filter cloth finish, the stabilized cloths with a braided weave and made of polyester are superior. The most important factor is the fabric.

The measured values in table 6 are again based on polypropylene, as in table 3. The related factors are found in table 7. This table shows the importance of the weave type in thick filter cloths; however, the braided weave has a lower adhesive force.

A stabilized dense cloth finish is favorable. Obviously, calendering of dense cloths reduces the intermesh of the filter cake with the filter cloth. This effect is not as important for fine-meshed cloths. Calendering fine cloths produces a very smooth surface on which the filter cake can adhere without any loss of adhesion through filter cloth pores.

Summary

To examine the influence of cloth parameters on the adhesive force of filter cakes, filter cakes made of CVRD iron ore were cultivated on 14 different filter media and detached by means of a centrifuge. The dependence of adhesive

forces on water volume of filter cakes was measured. As a result, adhesive force saturation maxima between 0.6 and 0.9 were established. Depending on the filter cloth, the adhesive force maxima reached values between 3000 and 30,000 N/m^2.

Saturation levels between 0.1 and 0.9 revealed a wide distribution range of adhesive stress. The adhesive stress of different parts of one filter cake varied by one magnitude.

These experiments helped establish the integral average of adhesive forces between the filter cake and the filter medium, and attribute the filter cloth parameters with a statistical method. The result was that the material has the greatest influence on adhesion. Wide-meshed filter cloths have a lower adhesive force than dense cloths. Besides the fabric type,the weave type is also important for dense cloths. Calendering is more advantageous for wide-meshed cloth and stabilization for dense cloth.

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Formulae

A	surface	: m^2
F	force	: N
m	mass	: kg
p	pressure	: N/m^2
r	radius	: m
S	saturation level	: -

Δ	difference	: -
ε	porosity	: -
σ	stress	: N/m^2
ω	angular velocity	: 1/s

Indices

A : adhesion
K : capillary
S : solid
w : wet

Table 1: Measurements

No.	Filter cloth designation	Thread type	Weave	Material	Bubble point mmWs	Adhesive force N/m^2
1	NY5003 W-TEX	multifilament	twilled	PA 6,6	< 35	4130
2	PP1005 K-115	monofilament	twilled	PP	35 - 40	3600
3	NY1005 K-105	monofilament	twilled	PA 6,6	35 - 40	4000
4	NY5500 W-TEX	multifilament	twilled	PA 6,6	< 35	7200
5	PE 88 K-80	monofilament	braided	PE	75 - 80	5200
6	PP1001 K-79	monofilament	twilled	PP	65 - 75	10550
7	PP 88 K-72	monofilament	braided	PP	85 - 100	8650
8	PP1550 K-53	monofilament/ multifilament	twilled	PP	100 - 120	8400
9	NY 43 W-46	monofilament	braided	PA 6,6	100 - 120	6950
10	GD 88 K-55	monofilament	braided	PA 12,12	105 - 120	4200
11	GD 1050 K-57	monofilament	twilled	PA 12,12	100 - 120	10300
12	LX 1050 K-39	monofilament	twilled	LX	130 - 150	9000
13	PE 76 W-41	monofilament	braided	PE	130 - 150	3200
14	PP 1050 K-36	monofilament	twilled	PP	115 - 150	8480
Average (+/- 2594)						6704

Table 2: Influence factors which arise from the average of the measured values

Characteristic	Average M(i)	Factors f1(i)=M(i)/M
monofilament	6739	1.00
multifilament	6325	0.98
monofilament/multifilament	8400	0.99
calendered	7238	0.94
stabilized	5370	1.00
twilled	7442	1.00
braided	5640	0.76
PA 6,6	5900	0.62
PA 12,12	7250	0.80
PP	7936	1.00
PE	4200	0.47
LX	9000	1.00
BP < 100	6190	0.85
BP > 100	7219	1.00
Average	6775	+/- 0.19

Table 3: Values based on polypropylene

No.	Filter cloth designation	Thread type	Weave	Material	Bubble point mmWs	Adhesive force N/m²
1	NY5003 W-TEX	multifilament	twilled	PA 6,6	36	6661
2	PP1005 K-115	monofilament	twilled	PP	38	3600
3	NY1005 K-105	monofilament	twilled	PA 6,6	46	6452
4	NY5500 W-TEX	multifilament	twilled	PA 6,6	52	11613
5	PE 88 K-80	monofilament	braided	PE	68	11064
6	PP 1001 K-79	monofilament	twilled	PP	73	10550
7	PP 88 K-72	monofilament	braided	PP	96	8650
8	PP1550 K-53	monofilament/ multifilament	twilled	PP	107	8400
9	NY43 W-46	monofilament	braided	PA 6,6	107	11210
10	GD88 K-55	monofilament	braided	PA 12,12	109	5250
11	GD1050 K-57	monofilament	twilled	PA 12,12	112	12875
12	LX1050 K-39	monofilament	twilled	LX	149	9000
13	PE 76 W-41	monofilament	braided	PE	154	6809
14	PP1050 K-36	monofilament	twilled	PP	175	8480
Average (+/- 2661)						8615

Table 4: Influence factors based on the values related to polypropylene

Characteristic	Average	Factors
monofilament	8540	0.94
multifilament	9137	1.00
monofilament/multi-filament	8400	0.92
calendered	8432	0.94
stabilized	8938	1.00
twilled	8626	1.00
braided	8597	1.00
PA 6,6	8984	1.00
PA 12,12	9063	1.00
PP	9020	1.00
PE	8937	1.00
LX	9000	1.00
BP < 100	8370	0.94
BP > 100	8861	1.00
Average	8779 +/-272	+/- 0.03

Table 5: Influence factors of the values of dense cloths

Characteristic	Average	Factors
calendered	8043	1.00
stabilzed	5075	0.63
twilled	9563	1.00
braided	5640	0.59
PA 6,6	6950	0.76
PA 12,12	7250	0.79
PP	9200	1.00
PE	4200	0.46
LX	9000	0.98
PB < 100	8133	1.00
PB > 100	6730	0.83
Average	7383	+/- 0.27