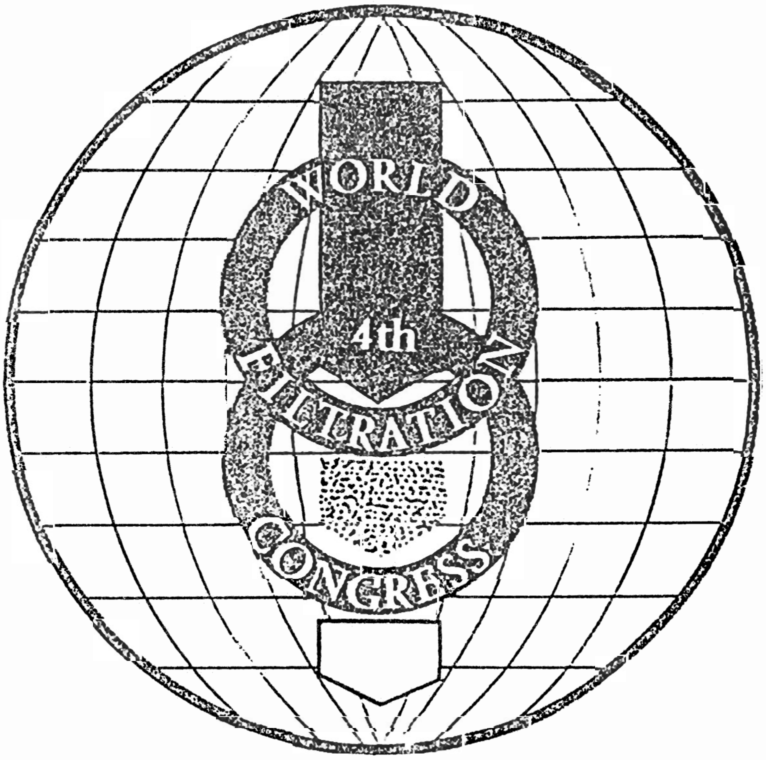
Technologisch Instituut-K.VIV
Mechanical Separation and
Particle Technology

Volume 8

28.(804)

Nur zum persönlichen Gebrauch
Vom Verfasser überreicht

PROCEEDINGS



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

THE INFLUENCE OF DISC FILTER DESIGN PARAMETERS ON CAKE FORMATION, AIR CONSUMPTION, AND RESIDUAL MOISTURE OF FILTER CAKES

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ABSTRACT

Disc filters are often employed for the dewatering of mass products, where high specific throughputs and low cake moisture contents are required. This is only achieved with maximum energy utilization and improved filter performance. Investigations were carried out on industrial filter plants. Analysis of the collected data has shown that dewatering efficiency often depends upon the filter design.

A simulation program for the entire filtration cycle has been developed. The models are based on filtration theory and experimental measurements. The computer simulation allows for calculation of production rate, moisture content and air consumption. This paper demonstrates how suitably developed computer models can facilitate the design of disc filters to reduce cake moisture or to improve filter performance. The goal is to optimize the design of new filters as well as to improve the performance of units already installed.

INTRODUCTION

Disc filters are widely applied in the preparation industry, e.g. iron ore, coal, alumina etc. The decreasing size of the particles in the concentrates to be filtered, as well as increased energy costs require the filter performance to be improved, so that higher throughputs and/or lower cake moisture is achieved with a minimal energy expenditure |1|.

The advantages of the disc filter in comparison with other continuous (i.e. drum or belt) filters, are |2|:

- maximum filtration area per unit floor space
- specific cost per filtration area of 40% and 60% less than for a drum or a belt filter respectively
- large filtration area of up to 50 m^2 per disc and 470 m^2 per unit possible
- minimum downtime for changing disc segments.

On the other hand there are still some problems such as the unequal cake thickness on the segment or the discharge of the filter cake. The uniformity of the cake thickness is important, as it exerts a direct influence on the cake moisture and the air consumption.

Contrary to the rotary drum filter, the disc filter operation and its analysis is more complicated, as the particles are deposited on the segment at a variable distance from the axis of rotation. Tiller and Risbud |3| as well as Rushton |4| have investigated the operation of the disc filter. Their analysis mainly deal with the first step of the filtration cycle and relate the rate of filtrate flow to the process variables.

In many cases, however, the cake moisture is of great importance because of its direct influence upon the thermal drying or transport costs or just the handling of the filter cake. The cake moisture content is determined by the pressure differential, the dewatering time, and the filter cake thickness. Due to the disc filter principle, some of these parameters are not constant for each segment location. The broader their variation over the segment, the lower the filter performance. Although it is known and often evident on filter plants that the cake thickness varies over the segment, its consequences for the dewatering of the filter cake and the vacuum system are underestimated. Investigations were carried out on various disc filter plants and products in Brazil. Analysis of the collected data showed that a wide distribution of cake thickness is accompanied by a cake moisture distribution with differences of up to 4 percentage points on one segment.

A simulation program has been developed to compute cake formation, cake dewatering, and the air throughput. The computerized simulation uses theoretical and phenomenological models. The program can be utilized either to design new and more efficient filters, or to optimize already installed units. It must, however, be distinguished between modifications concerning:

- the reduction of the cake moisture,
- the reduction of the specific energy consumption or
- the increase of the specific production rate.

We believe that his topic is, above all now of pressing importance. Although our research about disc filters is still being conducted, some results will nevertheless be presented. We intend to accelerate the transfer of scientific and laboratory findings to a practical and profitable application.

OPERATION OF THE DISC FILTER

Disc filters consist of a series of discs mounted on a common horizontal shaft. While the shaft rotates, the lower parts of the discs are submerged in the slurry (Fig. 1). Normally, the level of submergence is kept below the axis of the disc, thus avoiding the necessity of sealing. The discs are divided into segments. These segments are individually connected by internal or external tubes on the center shaft to an automatic valve, which separates the vacuum for the filtering and drying zone and the compressed air for the discharging zone. While the filter sectors pass through the slurry, vacuum is applied inside the segments and the filter cake is deposited on both sides. Upon emerging from the slurry, the cake is dried by further suction and is finally discharged by compressed air and/or scraper-blades.

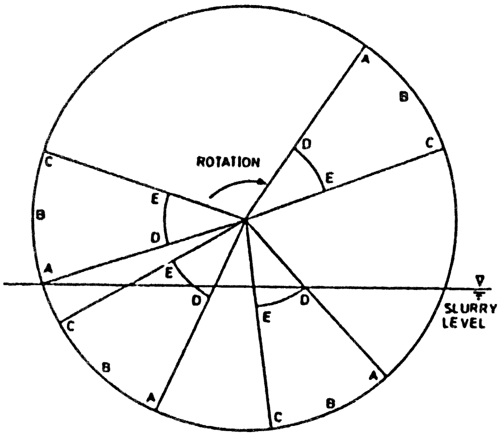

Fig.1: Various positions of segment ACDE

The number of segments per disc varies between 10 and 30. A filter may have up to 15 discs. The filtering area varies between 2 and 470 m^2. Most of the filters operate with a submergence less than 50%, so that it is not necessary to seal the center shaft. This is of practical consequence, as many products are abrasive and users of filter equipment tend to avoid sealings despite the fact that various reliable solutions are available. The disc filter still offers a great potential for improvement [5,6]. In this paper, however, we will limit our discussion to modifications concerning the reduction of cake moisture and air consumption.

SIMULATION OF THE FILTER CYCLE

A simulation program has been developed which facilitates the study of the influences of product, operation and design parameters on the filter performance. In the present simulation of cake formation, Rushton's model was chosen which is based on the filtration equation for incompressible cakes. For the dewatering and the air consumption, the models used are semi-empirical. They use a statistical/empirical approach and are based on experimental data. The objective of the simulation is to optimize the filter performance. With the simulation program it is also possible to predict the influence of design parameters etc. without prior testwork on a filter. The model parameters must then be specified in advance.

CAKE FORMATION

Figure 1 displays two characteristic positions of a segment during its passage through the slurry. In the first position the segment is just completely submerged. Now vacuum can be applied for cake formation, which is the first step of the filtration cycle. If the cake formation is rapid, however, and drying is the governing factor, the cake formation may be initiated even later. The design parameters that can be used to regulate the cake thickness are firstly the apparaent submergence and secondly the locations of the bridge blocks in the filter valve. Together they give the so-called effective submergence; a value which is not constant as will be explained later. The hydrostatic head is also taken into account, as it varies with the difference in heights of the slurry level and the point under consideration. Its influence also depends upon the form and the internal volume of the segment and whether the filtrate is immediately withdrawn or not.

In the second position, the segment has partially emerged from the slurry. Cake deposition has ceased at point E and the portion above the slurry surface. In this stage point E already starts drying whereas the points A,B,C and D not yet above the slurry's surface are still forming a cake. Thus each point on the segment is subject to a different set of filtration conditions during one filter cycle.

By means of the computerized simulation, we can, for example, calculate the cake thickness at any location of the segment In our case the segment is subdivided into 441 locations. Thus we can determine the cumulative distribution of any variable (cake thickness, moisture content, air throughput etc.) on the segment. The data used in the simulation are presented in Table 1. They refer to a pellet feed filter plant. The cake and medium resistance were determined in laboratory tests.

R_1:	0.4 m	R_m:	$1.00\ 10^{10}$ 1/m
R_2:	0.9 m	R_c:	$8.03\ 10^{12}$ 1/m^2
SD:	10	μ :	0.001 Pa.s
AS:	38 %	ρ_p:	2314 g/l
B :	0,02 m	n :	0.5 rpm
P_f:	0.30 bar	α_1:	5 deg. (point E)
P_d:	0.75 bar		

Table 1: Parameter values

With the aid of numerical plotting, we can even illustrate how the cake appears on one side of the segment. The filter cake in Figure 2 is shown with the leading edge in the foreground. In this specific instance, a blank strip at the leading and the trailing edges is used to avoid cohesion between the individual cakes, and thus to improve the cake discharge. At the point E the cake thickness, given in mm, is lowest because of the shortest cake formation angle on the sector. The cake thickness increases from the inner radius and the leading edge to the outer radius and the trailing edge. The maximum is achieved in point A which has the longest cake formation angle. The result is a cake thickness distribution. The plane parallel to the segment represents the average cake thickness obtained by integration over the filtering area. Only an absolutely uniform cake would appear so. The later the vacuum is applied after complete submergence of the segment and the more effective the hydrostatic head, the less uniform the cake.

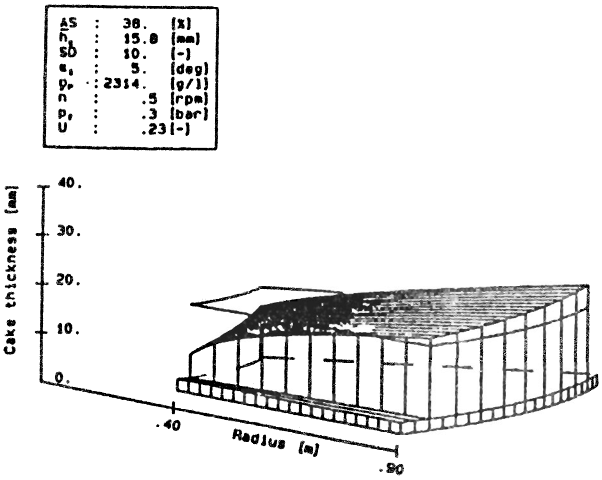

Figure 2: Cake distribution on one segment side

A comparison between the results obtained by simulation and actual measured values is given in Table 2. As far as cake thickness is concerned, the difference is insignificant and within the variation due to the filter operation.

Location on segment		A	E
$h_{c,meas.}$	mm	20.0	7.9
$h_{c,calc.}$	mm	20.4	8.2
$mc_{meas.}$	%	10.7	6.9
$mc_{calc.}$	%	10.2	6.3

Table 2: Comparison of measured and calculated data

CAKE MOISTURE

In many cases, the problem arising in filter plants is the unsatisfactory moisture content of the filter cake. The higher the cake moisture, the higher the cost for thermal drying or transport. Handling of the filter cake or subsequent processes may additionally suffer as a result of high cake moisture. Considering the cake moisture, it is important to realize that the average moisture content mc_{av} of the values determined for each point on the segment, is less than the overall moisture content mc_{ov} of the discharged cake. The overall moisture content is the mean value with respect to the cake thickness and therefore takes into account the cake thickness distribution. This is expressed in the following equation:

$$mc_{av} = \frac{\Sigma mc_i}{N} \leq \frac{\Sigma mc_i . h_{c,i}}{\Sigma h_{c,i}} = mc_{ov} \; ,$$

$$i = 1 \ldots N$$

The average and the overall moisture content are only identical for a uniform cake thickness. Therfore the cake moisture does not only depend upon operating and product data such as pressure differential, particle size, drying time etc. but also upon the thickness distribution of the cake.

Analogeous to the cake formation, each point on the segment is subjected to individual dewatering conditions (Fig.1). As the discharge occurs for all points simultaneously, those points emerging first from the slurry have a wider dewatering angle and therefore more time for drying. The thinner the cake the longer its dewatering time and vice versa.This kind of superimposition of both effects - the distribution of the cake thickness and the distribution of the drying time - is most undesirable.

Two graphs of cake moisture as a function of an abbreviated correlating factor (t_2/h_c^2) describing the superimposition of both effects for two products with different dewatering kinetics are illustrated qualitatively in Figure 3. The dryingtime t_2 is proportional to the dewatering angle α_2 and the square of the cake thickness is proportional to the cake formation angle α_1. The corresponding term α_2/α_1 relates two design parameters and is independent of the speed of the filter.

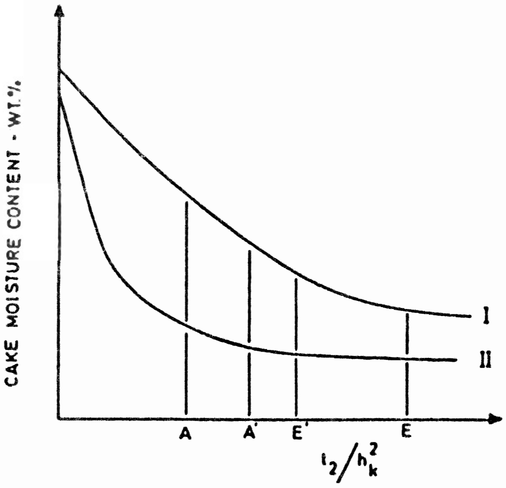

Figure 3: Cake moisture correlation

Produkt I will be more affected by the filter design than product II, because the gradient within the values calculated for the points A and E on the segment is higher. The moisture in point E has already accomplished its minimum,whereas the portion around A is still very humid. The overall cake moisture lies much closer to the moisture of point A as already explained. This means that for product I the filter design can be improved to reduce the cake moisture. The distance between the points A and E in this figure can indicate the filter's dewatering performance. With a good filter, these two extreme points (A' and E') would be much closer. Depending on this graph, the problem may or may not be apparent, so that a filter design cannot be judged in general, but only in relation to the product to be filtered.

AIR CONSUMPTION

The air flow rate through the cake, as well as the total air volume is strongly related to the dewatering kinetics and the dewatering time. Typical air flow rate curves for different cake thicknesses are shown in Figure 4. As illustrated in Figure 3, there is a dewatering optimum which is past the knee of the curve. Once the cake moisture has reached its asymptote, the air rate also approaches its asymptote correspondingly. Any further drying means that excessive horsepower is wasted by surplus vacuum pump operation without an adequate improvement in moisture reduction. High air flow rates in the inner parts of the cake can be responsible for a reduced vacuum and thus drying capacity is additionally lost for the thicker cakes.

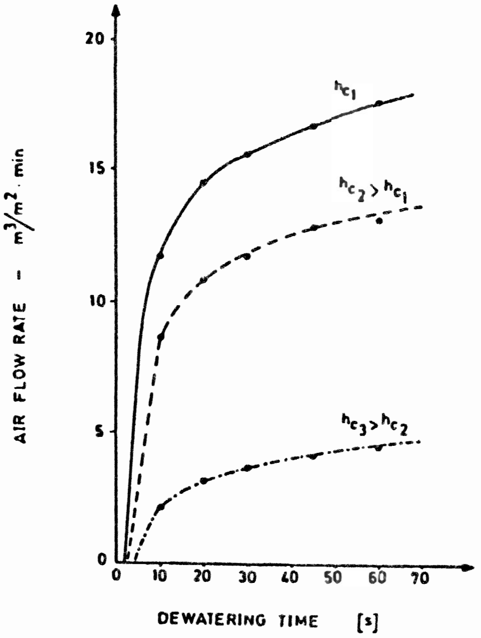

Figure 4: Air flow rates for coarse material measured on a laboratory filter cell

Although the measurement of the cake thickness and the moisture content at any point of the filter segment presents no particular problem, this cannot be said for the air flow rate. From laboratory tests, however, a relationship between cake thickness, its local moisture and the correlating air flow rate can be obtained (Fig. 4). The semi-empirical model is then used in the simulation. As a consequence of the cake thickness and the respective dewatering time distribution, the air consumption again varies over the whole segment dramatically. A typical result of the simulatin is shown in Figure 5. The local air consumption is related to the maximum value for better plotting. Corresponding to the cake thickness distribution, the relative air consumption has a maximum in point E where the cake is thinnest and a much lower level for the other cake location. The air consumption is even less uniform than the cake thickness.

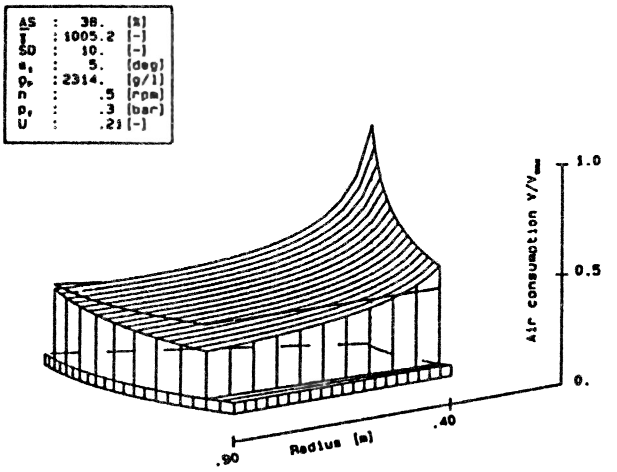

Figure 5: Relative air consumption V/V_{max}

The total air volume consumped during the dewatering determines the number and the size of the vacuum pumps and thus the filtration costs. Consequently filter and vacuum pump should always be considered together as parts of a system and not individually. Practical experience has shown that the specific air consumption for a disc filter is higher than that of a drum filter, where the cake is more uniform.

EXPERIMENTAL INVESTIGATIONS

Investigations were carried out on several industrial disc filter plants in Brazil to measure the actual performance of various disc filters in operation. The cake thickness and the moisture content of the filter cake were determined at predetermined segment locations. Additional tests on a laboratory scale filter were conducted to determine product parameters such as the cake and filter medium resistance, cake porosity and the air flow rate as a function of cake moisture.

In table 3 the maximum and minimum values of cake thickness and cake moisture are shown to illustrate their variation over a segment. These results were obtained under "normal" operating conditions. Various products, such as aluminium hydroxide, bauxite, iron ore and apatite, were all tested, thus avoiding product specific results. The particle size distribution differed substantially from product to product. Bauxite consisted of particles only 20% smaller than 44 microns (325 mesh) whereas one pellet feed was of particles 97% smaller than 44 microns. All filters but one had 10 segments per disc. The apparent submergence varied between 38% and 44%, whereas cake formation often started after the 6:00 o'clock position. None

product	density of solids	particle size	segments per disc	aparent submergence	cake thickness min/max	moisture content min/max	maximum moisture difference
-	g/cm^3	x<44µm	-	-	mm	%	%(abs)
Alumina	2.35	40	10	44	19.0-23.3	11.91-15.52	3.61
Apatite	3.20	32	10	40	18.0-23.6	12.94-16.55	3.61
Bauxite	2.60	20	10	40	19.6-25.0	13.20-16.52	3.32
Iron Ore	5.26	62	10	38	8.0-20.0	6.70-10.70	4.00
Iron Ore	5.26	62	10	42	8.4-13.8	7.90- 9.50	1.60
Iron Ore	4.90	94	10	42	22.0-32.0	9.60-10.80	1.20
Iron Ore	5.07	97	16	40	10.4-15.0	9.00- 9.46	0.46

Table 3: Data from different disc filter plants

of the filters was equipped with center shaft sealing. The difference of the moisture content on one segment varied from 0.46 to 4.00 percentage points between point A and point E. The overall moisture content was closer to the upper value as explained above. The higher the number of segments per disc, or the higher the submergence of the disc, the smaller the differences. In the case of the alumina, the cake was quite uniform but the dewatering was poor due to high hydraulic resistances within the filtrate system. The differences in filtration data, obtained from the various filter plants, are of tremendous economical interest and also illustrate that the problems discussed in connection with the pellet feed cake are not restricted to a single product.

MODIFICATIONS OF THE FILTER DESIGN

In the following, modifications of the filter design concerning the formation of the filter cake, the reduction of cake moisture content as well as air consumption are to be discussed. The modifications concern the design of new filters as well as existing industrial units. From the various design parameters, we will concentrate on the submergence of the disc and the number of segments.

As demonstrated above, a wide cake thickness distribution can result in a poor and unequal dewatering of the cake as well as an excessive air consumption. The solution to this problem is the formation of a cake of a uniform thickness. Modifications leading to increased specific production rates, such as increasing the effective submergence, are partially implied but will not be discussed in detail.

By means of the simulation program, trends are obtained for an improvement of the filter performance by a modification of the design parameters. As far as possible the results obtained on filter plants are presented. The data used here refer to the one mentioned in Table 1.

SUBMERGENCE OF THE DISC

In most cases the maximum slurry depth is fixed by the necessity of a certain clearance between the surface and the axle bearing,unless a sealing is used on the shaft. If the dewatering is the controlling factor when sizing the filter, the apparent submergence is often low, in order to obtain a maximum dewatering angle. The inner portion of the segment enters, only for a short duration, into the slurry. If the submergence is low and the cake formation starts just before emerging, the cake will be less uniform as shown before in Fig. 2.

To show the influence of the increase in submergence, the cumulative distribution of the cake thickness is illustrated in Fig. 6. For a submergence of 38% the cake thickness varies from 4.9 mm to 20.9 mm. This is the broad distribution from the cake shown in Fig. 2. Increasing the submergence to 42% (here maximum apparent submergence without sealing on the center shaft) yields a narrower distribution from 7.2 mm to 20.6 mm, while the average cake thickness of 15.8 mm is maintained by bridge block adjustment. Without changing the bridge block positions but increasing the submergence to 50%, the average cake thickness is augmented by 47% from 15.8 mm to 23.3 mm. The distribution becomes even narrower with a minimum thickness of 19.6 mm and a maximum of 26.4 mm. Thus, when increasing the submergence, a higher production and a more uniform cake results. A further increase in production would be obtained by a wider cake formation angle. In cases where a reduction of cake moisture is desired, the average cake thickness (production) can be maintained by adjusting the bridge blocks in the filter valve.

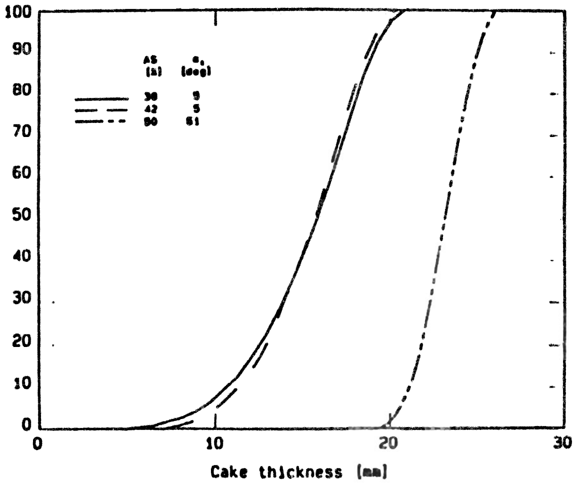

Figure 6: Cake thickness distribution

The computed overall moisture contents of the pellet feed cakes for a submergence of 38% and 42% only slightly differ (8.98% and 9.01%), although the dewatering time is reduced by the increased slurry level. An increase in cake moisture could be expected, but this is compensated by the narrower cake thickness distribution. In Fig.7 the corresponding cake moisture distributions are illustrated. For a submergence of 50%, the residual moisture rises to 10.6%, as the cake thickness is much higher and the dewatering time shorter. This means that an optimum submergence exists. As a consequence to the more uniform cake thickness, the cake moisture distribution is quite narrow.

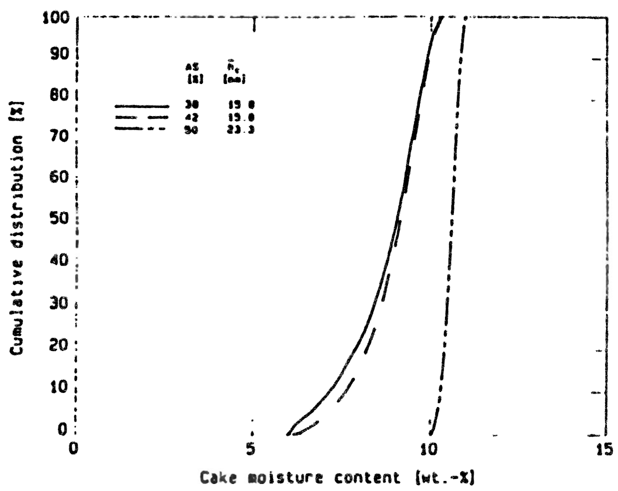

Figure 7: Cake moisture distribution

The increase of submergence from 38% to 42% realized on a pellet feed filter plant, yielded a more uniform cake (see Table 3) and the specific production rate rose by approximately 20%. In addition, the overall moisture content was reduced simultaneously by 0.5 percentage points. This is quite astonishing when one considers the increase in production.

The relative air consumption V/V_{max} also becomes more uniform as the submergence rises, as illustrated in Fig. 8. With the low apparent submergence of 38% the ratio V/V_{max} is less than 0.33 on half of the segment. For a submergence of 42% the air consumption is more uniform (V/V_{max}=0.47). For the higher cake obtained with a submergence of 50% the distribution becomes even narrower. On 50% of the filtering area the ratio V/V_{max} is already 0.77. It is obvious from Figures 2, 4 and 5 that the more uniform, or the higher the cake, the less the absolute air consumption.

On the filter plant, no air rate measurements could be realized. A vacuum increase, however, of 8 mbar was observed, which may be a result of the reduced air consumption and the more uniform dewatering. The higher vacuum partially compensates the reduction in dewatering time. An increase in vacuum

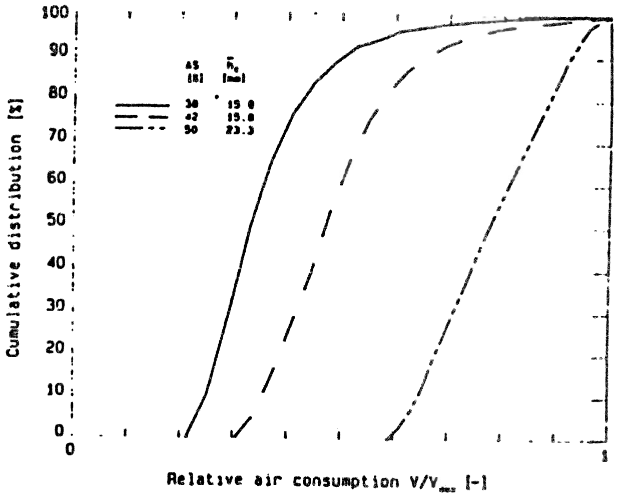

Figure 8: Relative air consumption distribution

has also been observed on other filters, where the submergence was raised in order to increase the production rate, whilst maintaining the cake moisture level. A reduction of the air consumption means that filter plants can be operated with less vacuum pumps thus considerably reducing energy costs.
An increase in submergence, if inidicated for the product, is simple and unexpensive to realize even on installed units.

NUMBER OF SEGMENTS

The number of segments per disc is a fixed design parameter. As shown in Table 3 only one disc filter type had 16 instead of 10 segments. Rushton has already theoretically verified, that, by increasing the number of segments the throughput of the filter can be increased |4|. It is obvious from Fig. 1 that a higher number of segments will reduce the differences between the leading and the trailing edges. Therefore the cake will be more uniform.
In addition to this, the higher the number of disc segments, the longer the drying time. Thus again reducing the cake moisture. With 10 segments, the overall moisture content is 8.98%. With 30 segments the cake moisture is reduced to 8.46%. With 50 segments this value decreases to 8.39%. The corresponding cake moisture distributions are shown in Fig. 9. This means that by increasing the number of segments the moisture content can be reduced. The potential for improvement, however, decreases with the number of segments. In Table 3 the filter with 16 segments has the least difference in moisture content on each segment.

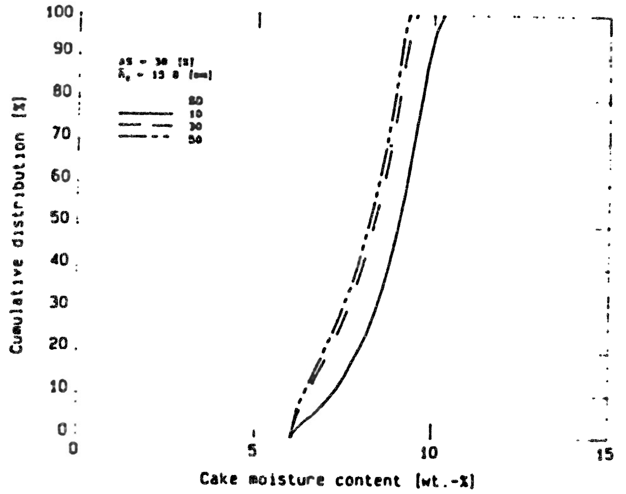

Figure 9: Cake moisture distribution

Analogeous to the submergence increase, it is obvious that the distribution of the local air consumption will get narrower with an increasing number of segments. The absolute air consumption will decrease with a more uniform cake.

GENERAL CONCLUSIONS AND PRACTICAL CONSIDERATIONS

The disc filter offers many advantages compared to other continuous filters. Due to the disc filter principle, the cake thickness on the segment is not uniform. The cake thickness distribution provokes cake moisture and air consumption rate distributions. The broader the distributions, the lower the filter performance. High residual moisture contents and excessive air consumption are the consequences. These problems are often caused by improper filter design. Selected modification of this, however, can improve the filter performance. Promising results were obtained on a pellet feed filter plant. Although the intended serie of modifications has not been concluded, a reduction of 0.5 percentage points and simultaneously a 20% increase of the production were achieved. In alumina filter plants, modifications concerning the throughput, yielded increases of up to 100%. An optimization of the filter design is also necessary, should the aim be to use such a filter in a pressure vessel for hyperbaric vauum filtration, otherwise the problems appear more drastically.

A simulation program was developed to investigate the influence of the design parameters on the filter performance without prior testwork. The results are useful for the design engineer as well as the plant operator. Investigations carried out on industrial filter plants as well as trends obtained by simulation are summerized in the following:

1) The design of the filter can be optimized to improve the filter performance by

   - increasing the number of segments
   - increasing the submergence
   - using packages on the center shaft

2) Already installed filter units can be improved concerning the reduction of cake moisture content (a) as well as the increase of throughput (b) by

   - increasing the submergence (a,b)
   - optimizing the bridge blocks locations (a,b)
   - using packages on the center shaft (a,b)
   - increasing the cake formation angle (b)

In the near future, measurements of the local segment air consumption will be realized. Further ideas to improve the filter performance as well as the influence of other design parameters, such as the segment volume and shape, will be investigated on a newly developed disc filter pilot plant. The filter can be operated with both vacuum and pressure of up to 4 bar.

The modular structure of the simulation program allows the individual models to be subsequently modified, and as more data is accumulated, more precise empirical relationships can be defined. This additionally enables predictions to be formulated without the necessity of experimental work. The simulation program described above is not limited in its application to disc filters. A large part of the program is equally applicable to drum or belt filters. The design and operating parameters will of course differ from filter to filter.

ACKNOWLEDGEMENT

The authors wish to thank the Bundesministerium für Forschung und Technologie (BMFT), the Deutscher Akademischer Austauschdienst (DAAD), and the Karlsruher Hochschulvereinigung for financial support of this project.

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Nomenclature

AS	apparent submergence	%
B	width of blank strip	m
h_c	cake thickness	mm
mc	moisture content	wt.-%
mc_{av}	average moisture content	wt.-%
mc_{ov}	overall moisture content	wt.-%
N	number of locations	-
n	filter speed	rpm
p_f	vacuum during formation	bar
p_d	vacuum during dewatering	bar
R_1	inner radius of segment	m
R_2	outer radius of segment	m
R_m	resistance of filter medium	1/m
R_c	cake resistance	$1/m^2$
sb	segment per disc	-
t_2	dewatering time	s
V	air consumption	m^3/m^2
α_1	cake formation angle	deg
α_2	cake dewatering angle	deg
μ	viscosity	Pa·s
ρ_p	density of slurry	kg/m^3