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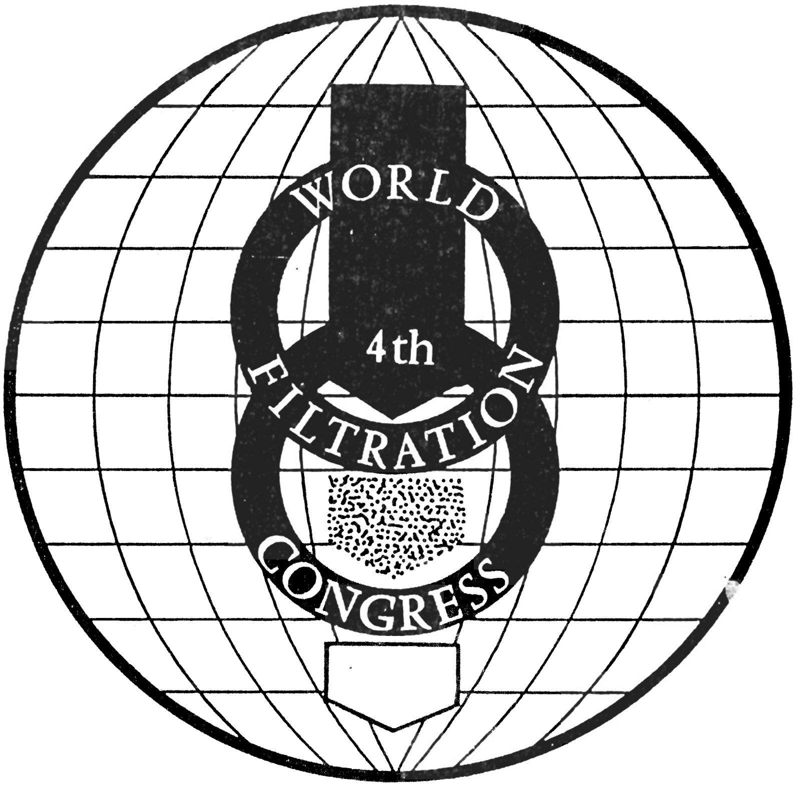

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CONTINUOUS PRESSURE FILTRATION : CALCULATION METHODS FOR CAKE FORMATION AND CAKE DEWATERING.

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ABSTRACT

The continuous pressure filtration is a method for solid-liquid separation which allows to attain large mass through puts and low residual moisture contents. The advantages are especially obvious with "difficult" suspensions characterized by a large amount of fine particles, as can be found in the beneficiation industry.

The process "Filtration" represents an extensive section in designin of plant flow sheets, by chosing the apparatus equipment, and by the estimation of running costs. Therefore, it becomes more and more important to find methods for an exact and extensive computation of this technique on the basis of some laboratory or pilot plant experiments.

The presented paper demonstrates which filtration-specific values have to be determined experimentally (e.g. cake permeability, porosity, filter medium resistance). The influence of these values on the computation of the cake forming, of the mass throughput, and on the lay-out of the filter apparatus size is discussed. Under the assumption of the validity of Darcy's law for fluid flow through porous media it is deduced how and to which extent the basic equation for the cake forming filtration is practicable also in the region of over-pressures.

The calculation method for describing the cake dewatering is on the one side based on a mass bilance around the filter cake, and on the other side on some characteristic values which depend upon the solids, the filtrate, the filter-cloth, the filtercake discharge, and the like. The applicability of the theoretical model is proved by a lot of test results. The computability of the dewatering phase allows to find the optimal process parameters which depend on the process conditions.

With the presented calculation methods it is possible - apart from the fact to be able to compute the performance of continuous pressure filtration plants - to compare the efficiency of the continuous filtration process with competitive filtration processes.

Recently the continuous cake forming pressure filtration is gaining increasingly in importance in the field of operational solid-liquid-separation as a purely mechanical and therefore energy saving separation process. After more than 30 years tedious development the continuous pressure filtratin has had a successful break-through in the eighties. The causes for this process were on the one hand the ever increasing high level energy costs and the persisting tendency in the field of mass products to separate increasingly finer solids and therefore to dewater filter cakes with higher portions of fine pores. On the other hand the pressure filtration has developed through independent projects of some apparatus manufacturers, and was brought into operation. Parallel to this, since 1980, the continuous pressure filtration with pressure differencers $\Delta p < 4$ bar is being dealt with in a unique way from a comprehensive scientific engineering point of view at the Institute für Mechanische Verfahrenstechnik und Mechanik of the University of Karlsruhe. The tests are being carried out according to laboratory means as well as practical means in pilot tests. In Fig. 1 the flow sheet of such a pressure filtration plant is illustrated. The main characterising item is a conventional vacuum rotary filter which is istalled completely in a pressurized room. The aim of these research activities was and is, to provide a basis for the dimensioning and optimising of continuous operating pressure filtration plants and their components |1|. One of the main areas of application of the continuous pressure filtration is in the benefication industry. For this reason mainly mineral slurries were used in the experimental tests. In addition to a number of sulphide

List of filtered products

provenance	$x_{50,3}$ |µm|	$Q_3(x<10µm)$ |%|
Type Iron Ores		
CVRD (Brasil)	26	21
Orinoco (Venezuela)	32	23
Tilden (USA)	12	45
LKAB (Sweden)	33	20
OEMK (USSR)	33	23
Sulphide Ores		
ZnS/Sachtleben (FRG)	26	31
PbS/Preussag (FRG)	18	29
CuS/El Teniente (Chile)	26	22
FeS_2/Aznacollar (Spain)	50	50

provenance	$x_{50,3}$ |µm|	$Q_3(x<10µm)$ |%|
coals		
Ruhrkohle (FRG)	63	15
Sasol (South Africa)	30	-
Spars		
$BaSO_4$ (FRG)	3,5	90
CaF_2 (FRG)	22	25
Tailings		
Nilz (Iran)	12	38
Italsider (Italy)	10	50
Phospate		
(Maroc)	-	-
Foods		
Starch CPC (FRG)	16,5	11

Tab. 1: List of filtered products (extract)

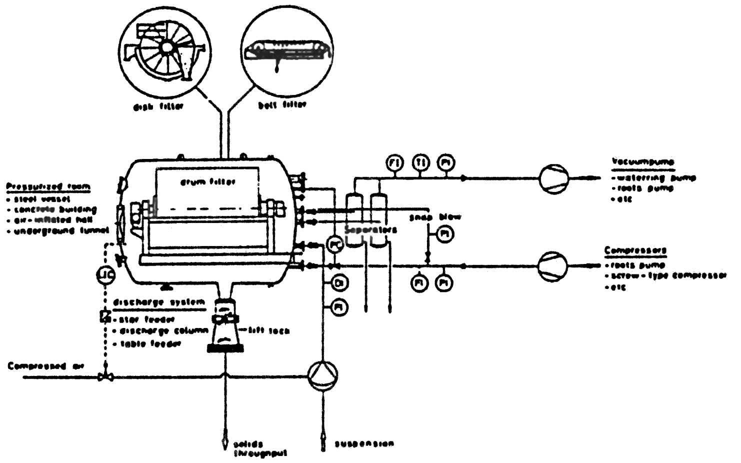

Fig. 1: Flow-sheet of a pressure filtration plant; filtration appratus: drum filter (disk filter, belt filter)

ores different iron-ores, coals, siderites and tailings were filtered (see Tab. 1). The tests were always carried out in accordance to field conditions on a conventional drum filter. The analysis of the complete filtration process shows that for the dimensioning of a pressure filtration unity mainly the 3 partial processes

- cake formation
- cake dewatering
- gas throughput

have to be calculabe. (A washing of the filter cake is to be excluded here).

The not less important process phase "cake removal" is determined, at least by the conventional method using a scraper with air jet impulse, by the choice of the filter cloth and is therefore still an empirical process. Cake formation and cake dewatering are these parts of the process through which the pressure filtratin reaches its efficiency. If the filtration pressure difference is increased by otherwise constant operational conditions, then an increase in the rate of cake formation and a decrease in the residual moisture content can be expected.

The gas through-put through the cake is a compulsory result of the dewatering process. It is therefore only effect and not cause. The gas through-put represents the expense size of the continuous pressure filtration which is to be reduced and permits in the case of comparable processes an examination of the profitability.

This paper examines more closely the possibilites and limits of the calculable design of the partial processes: that means the cake formation and the cake dewatering phase. The largely calculable control over these operations by varying parameters is required, to enable the pressure filtration to emerge out of the empiric stage. The partial process "gas through-put" is not dealt with in this paper.

CAKE FORMATION

The deposition of the solid portion of a suspension on a filter cloth under the effect of a pressure difference Δp can, as well as the subsequent increase of the filter cake be seen as a laminar one-phase flow process through a porous bulk. Darcy's law of flow can therefore be applied. The derivable basic equation of the cake forming filtration results for the cake height on a rotary filter in

$$h_K = \sqrt{\left(\frac{R_M}{r_c}\right)^2 + \frac{2.\kappa\ .\Delta p.\alpha_1}{r_c\ 360\ n}} - \left(\frac{R_M}{r_c}\right)^2 \qquad (1)$$

For a rotary filter with z cells it therefore follows for the specific solid throughput related to the filter area:

$$\dot{m}_s = h_K\ .\ (1.\varepsilon)\ \ .\ \rho_s\ .\ n \qquad (2)$$

It is hereby assumed that a intermediary suspension is filtered |2| and that the filter cake structure is mainly homogeneous.
In the vacuum filtration practice the assumption is widely spread that by a suitable choice of filter cloth the filter cloth resistance R_M can be neglected against the whole resistance of the cake. From the results of the pressure filtration investigation values of cloth resistance were calculated which, if not taken into consideration, would have caused severe mistakes in the dimensioning. According to the test results the filter cloth resistance increases nearly linear when the pressure difference was risen. If in the general cake formation equation (1) the parameter R_M is replaced through the linear approximation equation for the filter cloth resistance

$$R_M = m_M\ .\ \Delta p + b \quad 0.8\ \text{bar} < \Delta p < 3.8\text{bar} \qquad (3)$$

then is obtained

$$h_K = \sqrt{a^2.\Delta p^2 + b.\Delta p} - a.\Delta p \qquad (4)$$

$$\text{with}\quad a = \frac{m_M}{r_c}$$

$$b = \frac{2.\kappa.t_1}{\eta_L.r_c}$$

This equation, a root-type function, is suitable to describe the experimental cake formation results under varying pressure differences (see Fig. 2).

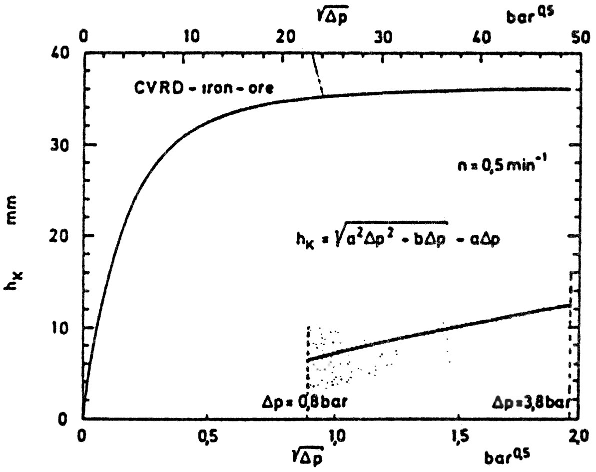

Fig.2: Course of the cake formation equation (4)

The mathematical discussion of (4) shows that the curve for large arguments $\sqrt{x}$ (upper scale in Fig. 2) approaches a horizontal asymptote. In the pressure area of interest Δp < 4 bar the curvature can however be replaced with sufficient exactness by a straight line (lower scale in Fig. 2). The conclusion can be drawn, that for interpolations the experimentally determined cake height values can be shown as a function of $\sqrt{\Delta p}$ and that the quality of the results can be judged by the expected course of the straight line.

The linear method of representation can not however be used as an evidence for the validity of the simplified cake formation theory ($R_M << r_c.h_K$) |3|. In this sense the specific solids throughput $\dot{m}_s$ (see (2)) as a demonstrative size shows the necessity of emphasising the consideration of R_M during scale-up. In the following Tab. 2 exemplary solid throughput values are specified which were calculated:

- from vacuum filtration results and subsequent linear scale-up $\dot{m}_s \sim \sqrt{\Delta p}$ according to the simplified cake formation theory and
- under inclusion of the R_M-values determined by the pressure filtration tests.

The table accentuates the resulting mistake and the consequences by the determination of the filter area to filter a given suspension rate.

Generally,, it can be stated that for the purpose of calculations during dimensioning the cake formation by the continuous pressure filtration can satisfactorily be described by the known equations (e.g. |3|). The representation with columns in Fig. 3 shows distinctively for 5 benefication products the improvement in productivity of the filter cake by applying pressure filtration. It can be seen from the diagram that the throughput rate increases with the increase of the pressure difference where the rate of the increase obeys predominantly the theoretical proportion.

DEWATERING

In recent years the mathematical consideration of the dewatering process has developed some promising models. The investigation into the dewatering theory by | 4| based on the model of relative permeability of the filter cake for liquid and gas showed that it is not permissible to describe the dewatering behaviour of a technical bulk by just one characteristic material function.

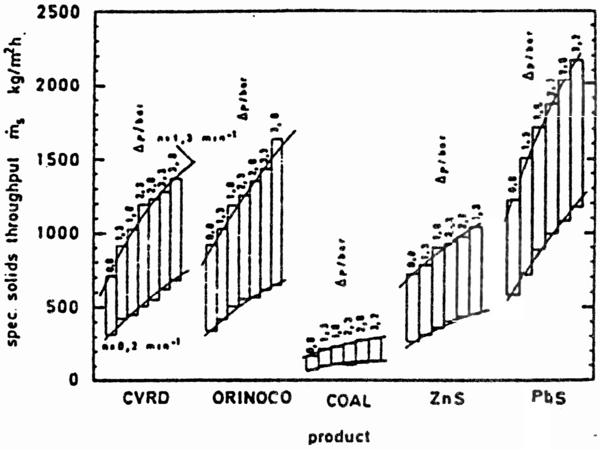

Fig. 3: Result of the solids throughput for 5 concentrates (see Tab.1)

The method to calculate the dewatering process after |5 | depends on the one hand on a mass balance around the filter cake and on the other hand on a number of characteristic values, which depend on the solid, the filtrate, the filter cake removal etc. The capillary pressure diagram of dewatering has hereby a fundamental significance which should be determined under practice proofed conditions e.g. in a laboratory-type pressure filter cell after |6 |.

The dewatering coefficient Ø which was gained from this model

Δp	bar	0,8		1,8		2,8		3,8		
$\dot{m}_s$	kg/m^{2}h	757	146	1136	219	1416	273	1650	318	R_M=f(Δp =0,8bar)
$\dot{m}_s$	kg/m^{2}h	575	146	882	196	966	239	1315	264	R_M=f(Δp)
$\Delta\dot{m}_s$	kg/m^{2}h	-	-	254	23	450	24	335	54	
$\frac{A_{F,nec}}{A_{F,calc}}$	-	1	1	1,29	1,12	1,47	1,14	1,25	1,20	
		CVRD	coal	CVRD	coal	CVRD	coal	CVRD	coal	

Tab.2: Consequences of the simplified cake formation calculation method (Hyperbar vacuum filtration, n = const.)

$$\varnothing = \frac{P_C \cdot (\Delta p - p_K)}{(1-S_r) \cdot \varepsilon \cdot \eta_L} \quad \frac{t_2}{(h_K + h_{K,E})^2} \qquad (5)$$

combines the relevant influence values functionally. The cake height h_K is supplemented by the aequivalent cake thickness $h_{K,E}$ which is an adequacy for the flow resistance in the marginal layer "cake-cloth".

The applicability of the resulting definitive equation to describe the moisture content during dewatering assumes ideal bulk properties for example $\varepsilon \neq f(h_K)$ and that the reduction of the driving pressure difference resulting from capillary pressure increase during dewatering can simplified be taken into consideration through a characteristic mean value $\bar{p}_K$.

Filtering comparatively coarse grained solids with less capillary pressure increase, the mean capillary pressure $\bar{p}_K$ can be substituted by the entry capillary pressure $p_{K,E}$ which corresponds to a lowest reduction of the driving pressure potential.

Using pressure filtration for separation and dewatering of fine grained solids results in saturation values in the fine capillary filter cake which corresponds with capillary pressures in size of the dewatering pressure difference | 7 | . In this case the dewatering model resp. the assumption of the permissibility of a mean capillary pressure fails. Only by taking the real capillary pressure function $p_K = f(S)$ into account the saturation can be calculated. This interdependence is usually unknown in the limits of pilot scale dimensioning tests.

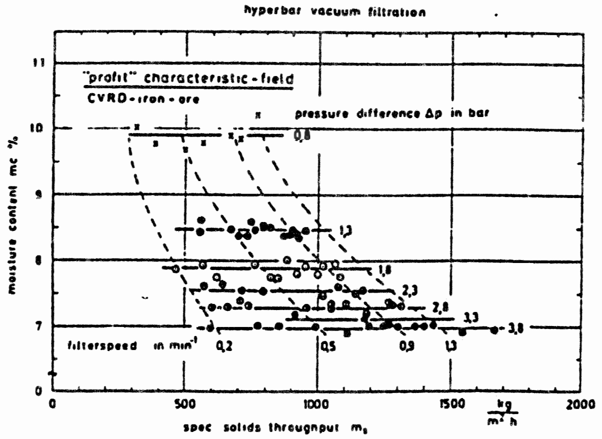

Fig.4: Characteristic field of pressure filtration:
$mc = f(\dot{m}_s, n, \Delta p)$

The method of characteristic fields for demonstrating presents itself as a promising alternative to illustrate pilot test results advantageously in the sense of interpolation. The residual moisture content is shown in direct dependence to further dimensioning values. Such a characteristic field is shown in Fig. 4 on the example of the so-called "profit"-diagram of the pressure filtration of an iron-ore. The graphs emphasise how the increase in pressure difference improves the residual moisture content and at the same time the solid throughput can be increased. The diagram conveys two characteristic distinguishing features of the dewatering during continuous pressure filtration: On the one side the residual moisture content decreases in a product-specific way to higher pressure differences, whereby the improvement rate becomes increasingly smaller; in the other case the residual moisture content remains constant by steady pressure difference and varied filter speed. The fact "mc-constant" during varied filter speed is a characterstic of the cake forming rotary filtration. It allows for a given relation

$$\frac{\text{cake forming time}}{\text{dewatering time}} = \frac{\text{cake forming angle}}{\text{dewatering angle}}$$

$$= \text{constant} \qquad (6)$$

which is determined in the control head of the rotary filter, the determination of a residual moisture content value which is independent of the filter speed and only valid for given pressure difference.

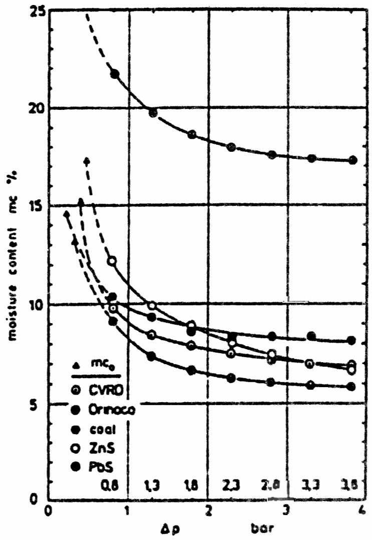

Fig. 5: Moisture content as a function of pressure difference for 5 concentrates (α_1/α_2 = const.)

The plotting of the mean residual moisture content values thus determined over the filtration pressure difference allows on the basis of only few experimental curve values, as shown in Fig.5 on the basis of the 5 beneficiation products, the interpolative determination of a filtration pressure difference for a filter with a given control head geometry. The discussion of the residual moisture content as function of the filtration pressure difference shows with the aid of Fig. 5, that except for the ZnS-ore, in the limits of the given pressue area, the dewatering potential is more or less exhausted.
In the case of the ZnS-ore after further pressure rise a further significant residual moisture content improvement has to be reckoned with, as is to be observed in the distinct downward slope at the end of the graph.

On the basis of such immediate result illustrations can now without restrictions and scale-up correction factors be determined by which pressure difference a stipulated residual moisture content can be reached, which solid throughput principally can be gained resp. which filter set up must be chosen for a given production rate.

SUMMARY

The knowledge won during the investigation of the continuous pressure filtration represents a justifiable applicable tool for the dimensioning of industrial filtration plants. On the basis of both fundamental engineering scientific investigations and intensive collection of results out of the industrial solid/liquid-separation, a know-how has been set up which permits, even through simplified laboratory-tests, the prediction of the success of a future pressure filtration process. With the aid of the proven and newly developed calculation methods a reliable scale-up can be practised. The design of an industrial plant will still take place on the basis of pilot scale tests.
It is hereby necessary to keep the test demand to a minimum. In order to fulfill this order simple laboratory test methods as the hand filter plate tests (e.g. for filter cloth choice) and pressue filter cell tests (e.g. to determine the capillary entry pressure) will be referred to; on the other hand the mathematical equations serve to dimension from a minimal number of tests the machines and apparatus to handel a given product flow. This procedure is schematised in Fig. 6 in a flow sheet.

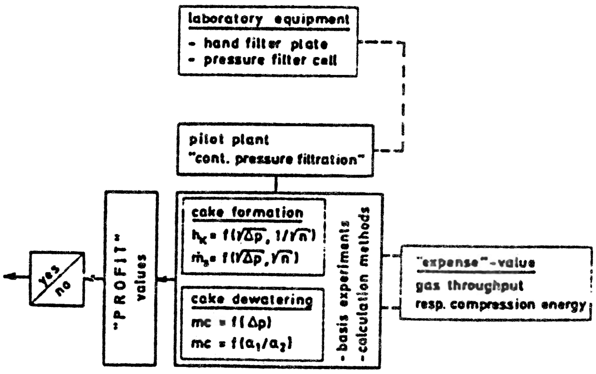

Fig. 6: Procedure of the "profit"-calculation of a pressure filtration process

The sound functioning of the continous pressure filtration is as well as the solution of the problems shown dependent on a series of apparatus information such as control head leckage, suspension feed, cake removal etc. The discharge of the moist, cohesive and in the case of beneficiation products extreme abrasive filter cake out of the pressurized room occupies in this connection a special position. A fundamental requirement for the employment of the pressure filtraiton is a practice proofed solution of the bulk discharge |8,9|.

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FORMULAE

A_F	filter area
h_K	cake height
$h_{K,E}$	aequivalent cake thickness
mc	moisture content
m_M	slope of the function $R_M=f(\Delta p)$
$\dot{m}_S$	spec. solid-throughput
n	filter speed
P_c	cake permeability
p_K	capillary pressure
$p_{K,E}$	entry capillary pressure
$Q_3(x)$	cumulative distribution of volume
R_M	filter medium resistance
r_c	spec. filter cake resistance
S	saturation
S_r	remanent saturation
t_2	dewatering time
x	particle diameter
$x_{50,3}$	mean, characteristic particle diameter
α_1	cake formation angle
Δp	pressure difference
ε	porosity
η_L	liquidviscosity
κ	concentration parameter
ρ	solid density
$\emptyset$	dewatering parameter