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ADDENDUM

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INFLUENCE OF THE DISC FILTER DESIGN ON THE DISCHARGE OF THE FILTER CAKE BY AIR BLOW-BACK

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The filter cake is removed from the filter cloth by static pressure and/or inertia forces. The main influencing parameters for the discharge due to static pressure alone are the permeability of the filter cake and the mass flow of compressed air per unit filter surface area.
The decisive factors for the cake removal by inertia forces alone are the mass flow per unit cell area and the volume increase of the cell as a function of the cell pressure. Discharge improvements can be accomplished by larger pressure vessels, pressure lines with a larger diameter; control valve geometries with large intersection zones and fast overlap; with filter cells of small cell angle and interior volume, and with filter cloths with a high module of elasticity.

INTRODUCTION

In order to remove the cake formed during filtration, compressed air from a pressure vessel is fed into the filter cell over a compressed air line (see Fig. 1). As a result of this, a pressure rise (which should be as fast as possible) occurs inside the filter cell, accelerating the filter cloth and its adhering cake outwards. When the cloth has been inflated by a few millimeters, it reaches its full outward expansion and decelerates again, this slowed movement leading to an even faster pressure increase within the cell. From the deceleration and increased internal cell pressure, both inertia and pressure forces act upon the cake, causing it to be detached from the surface of the cloth at the point where the adhesion forces are overcome. This process is known as reverse flow cake discharge.

As soon as the pressure within the filter cell exceeds that of it surroundings, air issues through the cake into the atmosphere. This air loss impedes the pressure rise and hence the cake discharge. The quantity of air loss depends upon the permeability of the filter cloth and cake, its level of saturation with liquid and the pressure difference. Provinding that the mass flow through the filter cake is smaller than that which can flow through the filtrate piping system into the cell, the pressure within the cell will increase. Considering a fixed cell volume (taking the cloth inflation into account), the pressure rises to a point where the mass air flow into the cell equals that flowing out through both the cloth and cake. This is the maximal attainable cell pressure. Should this pressure be greater than the adhesion tension between the cake and cloth, then a static cake dislodgement,

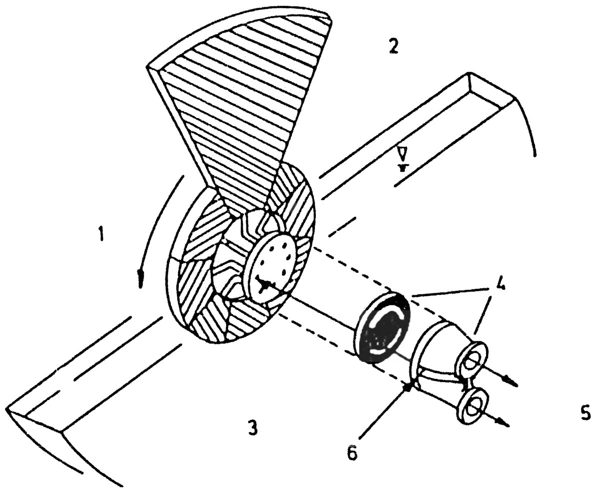


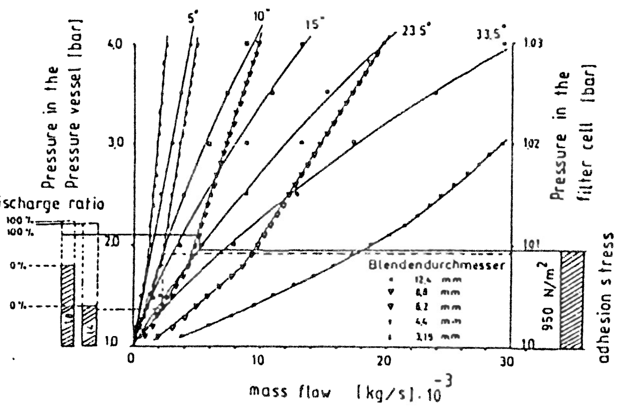
Fig. 1: Schematic of a disc filter

1	Discharge zone	4	Control head and disc
2	Dewatering zone	5	Vacuum connection
3	Cake formation zone	6	Compressed air connection

solely due to an overpressure within the cell, is possible.

The prerequisite for this is that the cloth's pressure loss is negligibly small, as this stresses just the cloth and not the cake. In the case of a correctly chosen material, its pressure loss is indeed considerably smaller than that of the cake. Should, however, the cloth blind during operation, then its pressure loss may increase substantially and hence impair the cake discharge.

In Fig.2, the equilibrium pressure resulting from the inward and outward flowing gas quantitiy is determined. In this graph, the vessel pressure (left coordinate) is plotted as a function of the mass flow through the filtrate piping, i.e. mass flow entering the cell (These are the calculated plots which are close together). The different mass flows were accomplished with the aid of various aperture-stops built into the air line. The corresponding aperture-stop diameters are given in the key at the bottom right of the figure. Additionally, the cell pressure



Experiment on a pilot filter | Linkage of experiments to calculations | Experiment with Laboratory equipment

Fig.2: Determination of the pressure necessary to remove the cake by means of static overpressure

(right coordinate) is plotted as a function of the mass flow through the cake (escaping mass flow). This was measured experimentally for a variety of cell angles (5 ° - 33,5 °). The results of these measurements for a flotation coal and with different filter areas are also illustrated in Fig. 2, the accompanying cell angle being given at each curve.

In order to determine the overpressure necessary to remove the cake, the adhesional stress of the flotation coal was measured at the filter cloth (value at the side of the right coordinate). In the case of the flotation coal used for the investigations, this amounted to 950 N/m^2. If the pressure within the filter cell attains this value, then the cake can be removed from it by means of the overpressure alone. For this pressure, the mass flow through the filter cake was determined as a dependent function of the cake permeability for the 22,5 ° cell, in that the adhesion force was drawn over the left of the 22,5 ° curve. This mass flow must exist at the filter cell. The vessel pressure necessary in order to accomplish this, depends upon the filter cell piping. In Fig. 2, this pressure has been determined for a 6,2 mm aperture-stop. Here, the mass flow is drawn perpendicularly up to the curve for the 6,2 mm aperture-stop, and the accompanying vessel pressure read from the left coordinate.

The necessary vessel pressure for the experimental 10° cell is determined analogeously (broken line), whereas the horizontally running upper line portion has been lowered somewhat for the purpose of clarity, as this otherwise coincides with the line drawn for the 22,5 ° cell.

In order to be able to compare the calculated and measured neccessary vessel pressures, the experimentally determined values have been given at the left coordinate for the 22,5 ° and the 10 ° cells. The measured values are given by the histogram at the left of the diagram, the stated pressures being those at the start of cake discharge. Whilst for the 10 ° cell the calculated value of the pressure at which cake dislodgement begins, corresponds quite well with that measured, large deviations occur in the case of the 22,5 ° cell. Because the mass flow rates differ, despite the fact that both cells possess the same volume (the 10 ° cell being twice as thick) the pressure rise within the 10 ° filter cell must occur more slowly. For a larger mass flow per cell volume, made possible by a higher vessel pressure, the intertia forces are indeed more pronounced so that the filter cake is dislodged from the 22,5 ° cell before the static overpressure reaches the value at which the cake can be discharged by this alone. In the case of the 10 ° cell, a complete cake removal by means of the static overpressure alone is not possible, as when the filter cloth reaches a certain degree of inflation, cracks appear in the cake through which the air can issue. The permeability of the filter cake increases abruptly with crack formation and thus influences the cake release.

Suitable measuring equipment is often at disposal in industrial filter apparatus for the measurement of the gas mass flow which escapes through the cake during the application of the compressed air blowback. However, as long as the gas throughput in the vacuum zone is known (or estimated from the vacuum pump's characteristic curve) a rough estimate of this is at least possible in that the permeability of the cake determined at the vacuum zone is applied to the pressure pulse period.

PRESSURE RISE WITHIN THE FILTER CELL, NOT CONSIDERING AIR-PIPING LOSSES AND FILTER CLOTH MOVEMENT

The air flow out of the continually filled and periodically emptied pressure vessel is decisive for the pressure rise within the filter cell. This flow depends mainly upon the dimensions of the vessel (and its pressure), the piping and the filter cell.

The calculation of the air flow (without taking frictional losses of the piping into account) promptly lead to important facts about the pressure rise within the filter cell. The mass flow through the control-head and the pressure in the filter cell are plotted in figs. 3 and 4. This calculation portrays an estimation of the maximal possible mass flow, on the assumption that the control head abruptly opens the air feed to a pre-determined diameter and that no frictional losses occur.

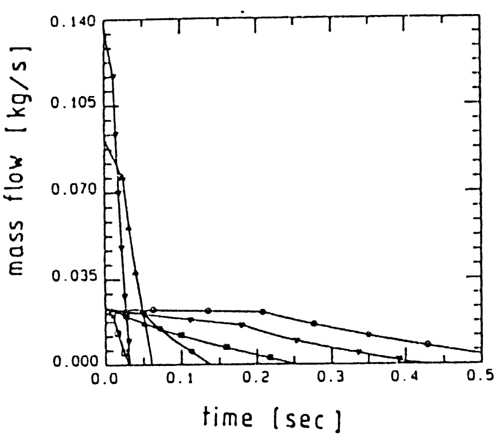
The plots are made for 7 examples. The corresponding values for pressure, volume, vessel temperature, piping diameter and filter cell volume are correlated in Table 1.

Whilst line 2 contains unfavourable values, more appropriate parameters are given in lines 3-5 respectively, whereby the vessel volume and the piping's cross sectional area are each related to the number of simultaneously operated filter cells. Line 3 is for a larger pressure vessel, line 4 for a larger piping diameter and line 5 for a reduced cell volume. In line 6, the parameters are all favourable and the last line shows a comparison for a filter cell with pre-ventilation, in which case the filter cell is allowed to fill to atmospheric pressure before being pressurized with compressed air.

An enlargement of the pipe diameter leads to a considerable increase in the pressure rise, at the cost of a higher air consumption, as the mass flow also increases. A reduction of the cell size leads to

	vessel pressure	vessel volume	pipe diameter	vessel temperature	cell pressure	cell volume
Symbol	$p_{K,o}$	V_K	d_R	T_K	$p_{z,o}$	V_7
dimension	bar	Liter	mm	^oK	bar	Liter
pilot filter	4	23	17	298	0	0,93
poor dimensioning	2	50	25	298	0	40
larger vessel	2	300	25	298	0	40
larger pipe diameter	2	50	50	298	0	40
small filter cell	2	50	25	298	0	10
favourable dimensioning	3	300	50	298	0	10
pre-ventilated	2	50	25	298	1	40

Table 1: Numerical values of the filter dimensioning for the examples given by figs. 2 and 3



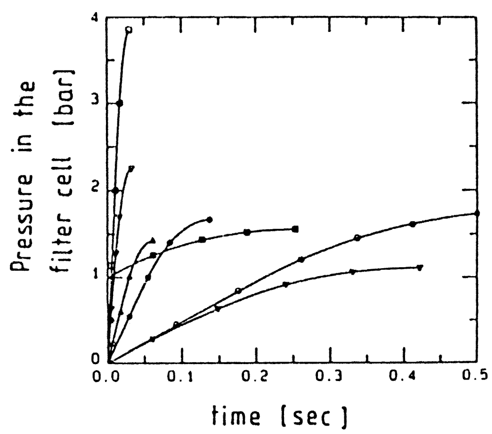


Fig. 3 and 4:

Gas mass flow through the disc filter and pressure trend within the filter cell as a function of time, assuming that frictional losses are negligible

- □ Pilot filter
- ▼ disadvantageous design
- o large vessel
- △ wide pipe diameter
- ● small filter cell volume
- ▽ advantageous design
- ■ filter cell filled up with atmosphere before blow back

a steeper pressure rise and a reduction of air consumption. This proves that the cell volume should be as small as possible as long as a certain size is no prerequisite (e.g. for other purposes such as filtrate storage during the cake formation phase).

In order to save time and compressed air when pressurizing the filter cell, this is allowed to fill to atmospheric pressure before applying the blow-back. The filter cloth movement then immediately begins at the start of the pressurization phase and thus at a low air flow rate. This means that smaller inertia forces act upon the filter cloth and therfore the preventilation of the cell is not of advantage, but often quite the opposite. One exemption of this, however, is given by the case where the cake discharge occurs by means of a "quasi-static dislodgement", i.e. due to a static internal cell overpressure alone.

INFLUENCES OF THE PIPING LOSSES OF INDUSTRIAL FILTERS ON THE AIR FLOW

The piping losses of industrial disc filters differ significantly from one another due to individual constructive features. The length of piping generally lies between 500 and 6000 mm, their diameter between 30 and 80 mm. Thus, with a pipe friction number of λ = 0,022 (d/K approx. 10^3), the piping losses are between 0,14 and 4,4 as can be seen in Table 2. Should the pipes be of slightly rusty cast-iron, then these values can easily be several times larger.

In addition to this, the losses due to 90 ^{o} manifolds are also relevant. These losses, depending upon the number of such manifolds built into the system and their diameter (given by Table 3), are between 0,36 and 2,34.

Whilst the losses due to piping and manifolds cannot be avoided, they should be kept as small as possible by short pipes of a generously dimensioned diameter. Tables 2 and 3 guide over the order of magnitude of the loss values for piping without branches on insertions. Often, however, considerable losses occur within the pipes due to abrupt transitions and due to incrustations.

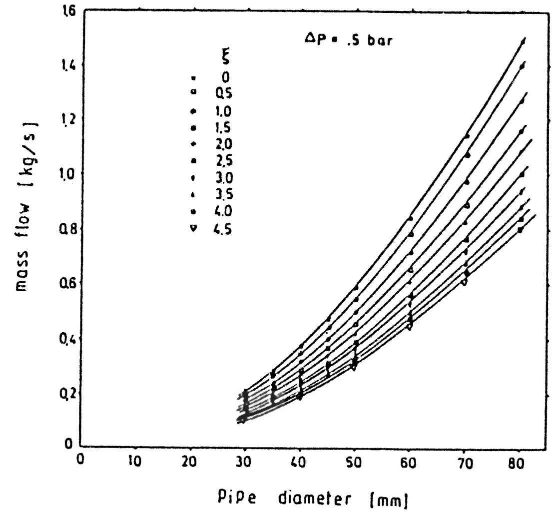


Fig. 5: Function of the mass flow to the piping diameter for various coefficients of resistance

In order to illustrate the influence of the piping losses, the mass flow through pipes as functions of the pipe diameters is given in fig. 5 for a variety of resistance coefficients, at a pressure difference of 0,5 bar. The ratio of frictionless

pipe length	Pipe diameter (mm)							
(mm)	30	35	40	45	50	60	70	80
500	0.37	0.31	0.28	0.24	0.22	0.18	0.18	0.14
1000	0.73	0.63	0.55	0.49	0.44	0.37	0.31	0.28
1500	1.10	0.94	0.83	0.73	0.66	0.55	0.47	0.41
2000	1.47	1.26	1.10	0.98	0.88	0.73	0.63	0.55
2500	1.83	1.57	1.38	1.22	1.10	0.92	0.79	0.69
3000	2.20	1.89	1.65	1.47	1.32	1.10	0.94	0.83
3500	2.57	2.20	1.93	1.71	1.54	1.28	1.10	0.96
4000	2.93	2.51	2.20	1.96	1.76	1.47	1.26	1.10
4500	3.30	2.83	2.48	2.20	1.98	1.65	1.41	1.24
5000	3.67	3.14	2.75	2.44	2.20	1.83	1.57	1.38
5500	4.03	3.46	3.03	2.69	2.42	1.83	1.57	1.38
6000	4.40	3.77	3.30	2.93	2.64	2.20	1.89	1.65

Table 2: Piping loss coefficients of industrial disc filters

numbers of	Manifold as per DIN 2605		
manifolds	Standard (N)3	Standard (N) 4	Standard (N) 5
1	0.39	0.37	0.36
2	0.78	0.74	0.72
3	1.17	1.11	1.08
4	1.56	1.48	1.44
5	1.95	1.85	1.80
6	2.34	2.22	2.16

Table 3: Loss coefficients of industrial disc filter piping

to friction impeded mass flow is a measure of the pipings' quality.

COMPARISON OF DIFFERENT INTERSECTION AREAS IN THE CONTROL VALVE

Considering slowly rotating filters without a rapid snap-blow valve, a substantial quantitiy of compressed air can escape through the cake into the atmosphere before the whole pipe cross-section is exposed to the flow at the control valve. In the case of rapidly rotating filters (disc filters were operated at speeds of up to 6 rev/min within the scope of this and other projects) the opening time is less than 1/3 sec so that here, one must take care that within the initial period, an adequate compressed air quantity can flow into the filter cell.

The compressed air line is under pressure up to the control valve. The passage into the filter pipe system is opened to the compressed air in a manner depending upon the rotary speed of the filter and the control geometry. The air flows through the control valve and the filtrate pipe up to the filter cell. The mass flow of the air depends upon the geometry of the intersection area.

In the simplest case, this is executed by intersecting the filtrate feed pipe with the compressed air line. Provinding both pipes are of circular cross-section, the area of intersection corresponds to that of two overlapping circles (Fig. 6a). An improvement of the cake discharge can be accomplished by means of constructive improvements to the inlet valve geometry. For example, the gradient of the intersection area of the rectangular valve (as shown in Fig. 6c) can be observed to be significantly steeper. In order to improve older filters, constructed with a circular pipe intersection, the control zones may be subsequently modified to cresents, as shown in Fig. 6c.

A comparison of the illustrated control geometries shows that in the instance of a circular/circular intersection, the opening sequence occurs progressively. For the slot and cresent forms, however, the intersection occurs linearly with a rapid opening, the trend of the opening functions being approximately the same for both. Therefore, modern disc filter control valves are designed with such slots. Older disc filters having a circular/circular overlap geometry may be modified to a cresent form, thus enabeling almost the same opening characteristics to be attained.

INFLUENCE OF THE FILTER CELL UPON THE PRESSURE RISE

The pressure rise gradient as a function of the cells' bulge volume is a critical parameter for the cake discharge. From this depends the compressed air quantity which must be introduced into the cell in order to attain a certain cell pressure. The pressure within the filter cell as a function of the cloths' bulge volume is given in Fig. 7.

The curves of the necessary vessel pressure (bar) required to completely remove the cake from the cloth of the pilot filter apparatus poses as a parameter the filter cell angle.

It is clearly evident that with increasing cell angle, the compressed air quantity necessary to accomplish a certain cell pressure increase. Large cell angles thus require longer control valve opening times for identical piping and hence slower rotational filter speeds and large compressed air quantities.

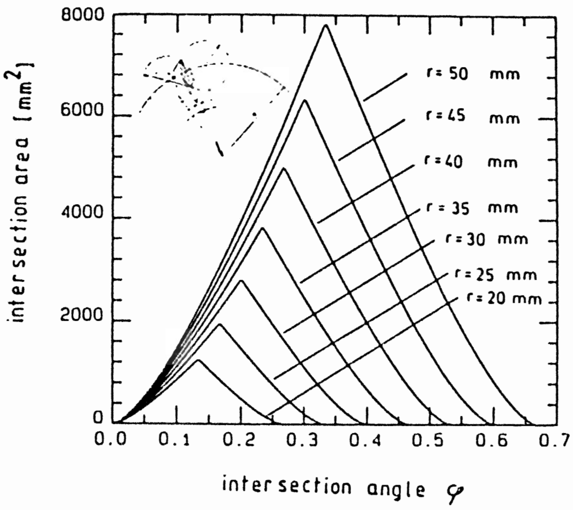


Fig. 6a: Different control valve geometries

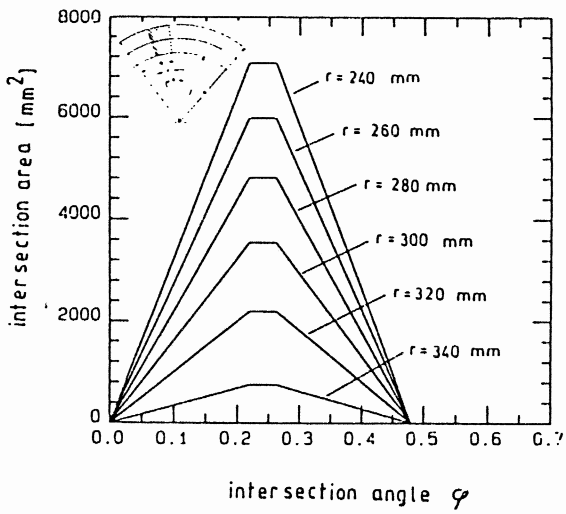


Fig. 6b

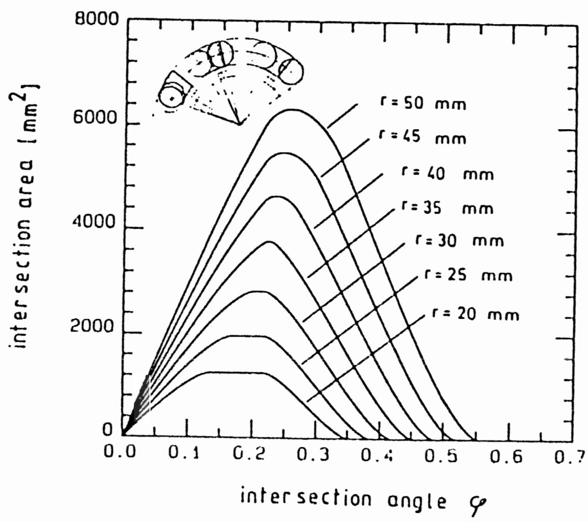
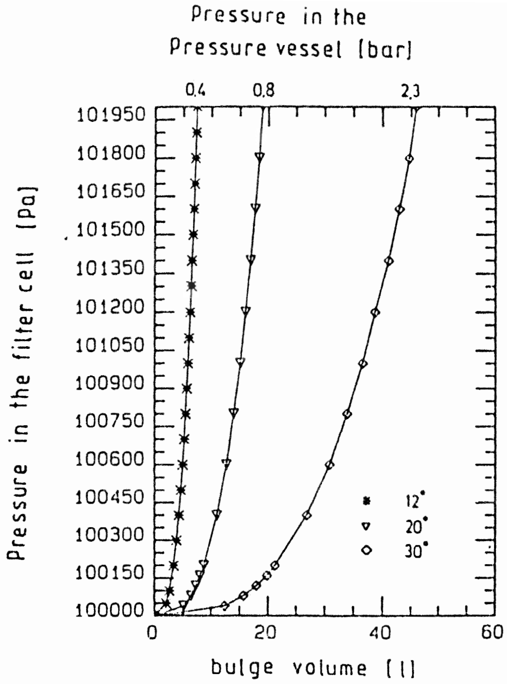


Fig. 6c



- Fig. 7: Results of the calculation of the equilibrium pressure as a function of the filter cloths' bulge volume for different filter cell angles

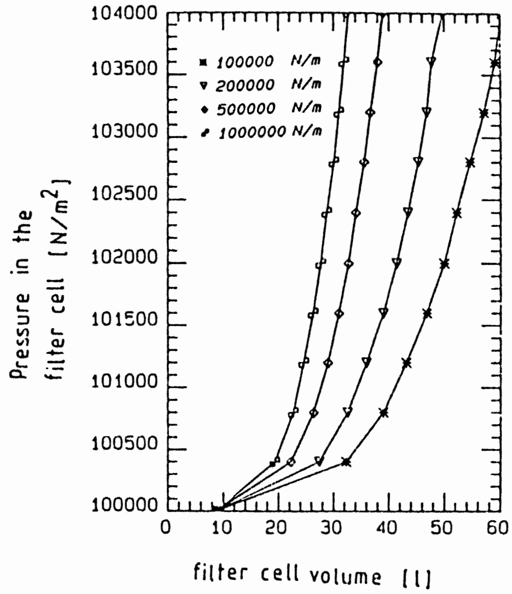


Fig. 8: Mathematically determined influence of the module of elasticity upon the cell pressure trend, as a function of the filter cloth's bulge volume

The reason for this behaviour is that the perpendicular forces acting upon the cloth can only be withstood when the cloth bulges outwards. The radius of the bulge decreases, however, with increasing span lengths.

In Fig. 8, the pressure within the filter cell is plotted as a function of the filter cloths' bulge volume for cloth modules of elasticity of 10^5, 2×10^5, 5×10^5 and 10^6 N/m, the filter cloths used for the adhesion force measurements being within this region. The force generated by the tensioning apparatus is related to the breadth of the cloth stretched over it. The calculations for Fig. 8 were conducted for a 20 ° filter cell of 1,8 m length with an unstretched cloth. The figure shows that the module of elasticity can largely contribute to the rapid cell pressure increase. Should the compressed air supply not be adequate, the choice of a filter cloth with a large module of elasticity can lead to an improved cake discharge.

The filter cloth may be pre-stressed over either its length on breadth, or can be left loose. Fig. 8 shows an example of a pre-stressing over the cloths' breadth. Here, the filter cloth angle is 1% or 2% larger or smaller than that of the filter cell respectively. The module of elasticity of the cloth is 5.10^5 N/m and the length of the filter cell is 1,8 m. The cell pressure is again plotted as a function of the cloth's bulge volume. The middle curve represents the instance were the cloth simply lay flat upon the cell without any pre-stress. Upon stretching the cloth by just approx. 1%, a significant increase of pressure rise results, which can be of advantage to a system with an underdimensioned compressed air supply. However, the cloth with an angle 0,5% larger than that of the cell may also be advantageous. It offers a large region where the pressure hardly increases. Here, a high filter cloth velocity can be attained, whereby sharp deflections with sudden pressure rises create rapid filter cloth decelerations.

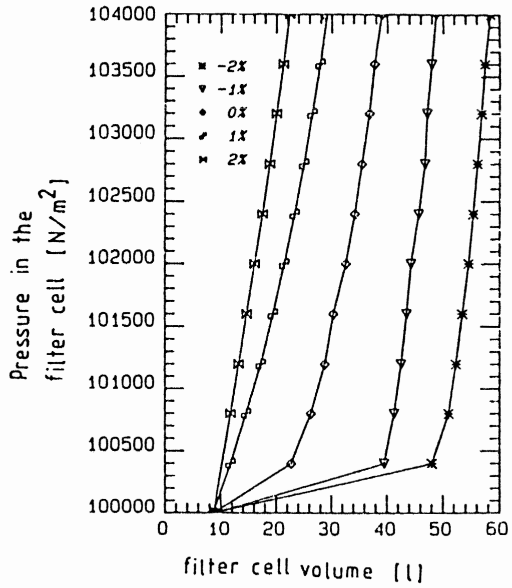


Fig. 9: Functions of the calculated pressure in the filter cell over the bulge volume for different filter cloth breadth pre-stresses.

Here, however, a large air consumption over a relatively long period must be at disposal, which cannot be accomplisheed by slowly rotating industrial apparatus equipped with the normal control valve. This is only possible by means of a largely dimensioned , rapidly opening solonoid valve (a so-called snapp-blow valve).

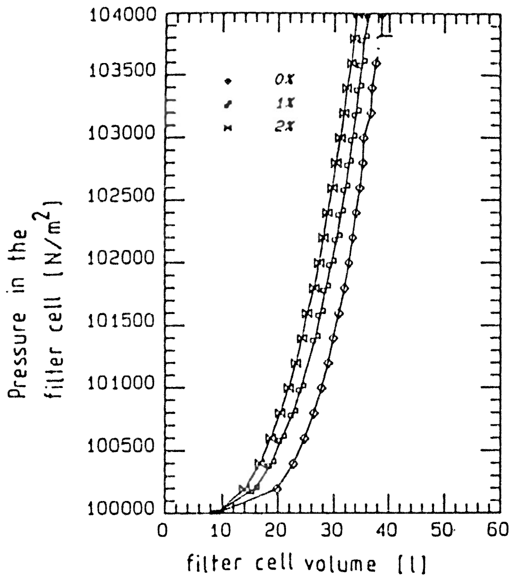


Fig. 10: Functions of the calculated pressure in the filter cell over the bulge volume for different filter cloth length pre-stresses

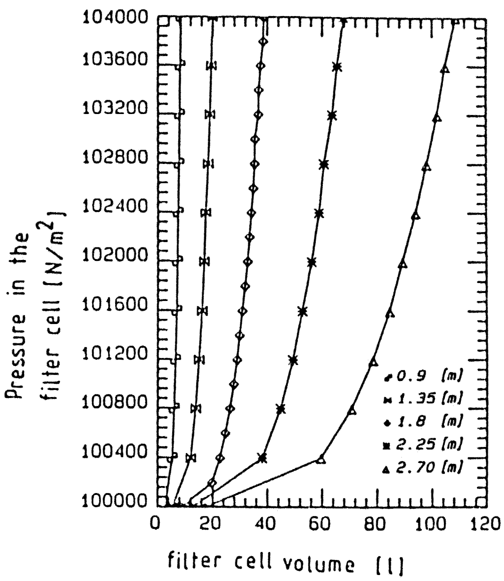


Fig. 11: Pressure in the filter cell as a function of the bulge volume for different filter cell lengths.
angle = 22.5 °
cell thickness = 20 mm

The pre-tensioning over the cloth's length is portrayed in Fig.10. It can be seen that the cloth stress over its length is not all that important. A significant effect is only to be accomplished with unrealistically high tensions. In order to gain better results, the cloth must be sub-divided into a number of segments over its breadth. Not only is the tension over the cloth's length, but also that over its breadth is limited by the plastic deformation of the cloth material.

From data supplied by filter cloth manufacturers, an elongation of 2-3% should not be exceeded. The pressure within the filter cell over the bulge volume increases much slower when the length of the cell is extended (Fig. 11). This is not caused by the elongation of the fibres over the cloth's length, as the strain is largely carried by the cross-fibres as shown in Fig. 10.

The cause lies in the cell area enlargement and the elongation of the cross-fibres at the upper cell section.

Fig. 12 shows finally, the experimental results for cell angles of 33 °, 22.5 ° and 10 °. The absicssa represents the pressure in the compressed air reservoir and the ordinate, the mass ratio of discharge filter cake to filter cake deposition. The 33 ° cell only begins to release the cake at 2.3 bar and will not throw off the entire cake below 3.0 bar. A reduction of the cell angle to 22.5 ° leads to a considerably lower discharge pressure. The 22.5 ° cell begins to discharge at a pressure of 0.4 bar and throws the filter cake completely off at 1.3 bar.

The thickness of two filter cells were also varied. The 22.5 ° cell (narrow) was constructed half as thick as normal, and the 10 ° cell (conical) was made half as thick and with a conical form. Therefore, the 22.5 ° cell (narrow) and the 10 ° cell both comprised the same volume, but different cell angles. The different angles are made apparent by the gas losses through

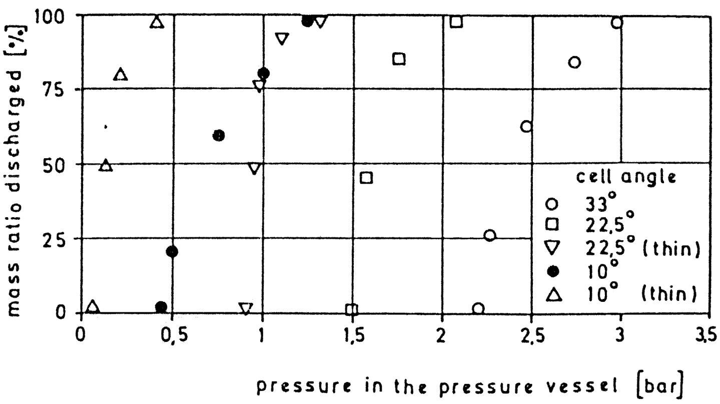


Fig. 12: Comparison of different filter cells

33 ° cell	10 ° cell
22.5 ° cell	
22.5 ° cell (narrow)	10 ° cell (conical)

the filter cake. This effects the necessary pressure at the beginning of the cake discharge, which increases from 0.4 to 0.8 bar. The pressure necessary to fully remove the cake from the filter cell in approx. 1.3 bar, whereby the inertia forces necessary to remove a 5 mm thick cake depends upon the cell volume. Here, the cell volume is the same in both instances.

The best cake discharge results were obtained by the conical 10 ° filter cell, as this allowed an even more uniform pressure rise over the cell's length, and because of the smaller cell volume, a faster pressure increase.

Literature

/1/ Gösele, W.
Filterapparate - Eine Übersicht
Aufbereitungstechnik 1977/5

/2/ Stahl, W.
Die Grenzen der Steigerung von Durchsatz und Trenneffekt bei Vakuumdrehfiltern und ihre Einflüsse auf die Konstruktion
Vortrag Achema 1979

/3/ Stahl, W., Kern, R.
Neuere apparative Entwicklungen bei kontinuierlichen Vakuumfiltern - Möglichkeiten der Anpassung und Verbesserung älterer Filter
GVC-Tagung Filt. techn., Wiesbaden 1983

/4/ Tiller, F.M., Crump, J.R.
How to Increase Filtration Rates in CJontinuous Filters
Chem. Eng. 6, 183-187, 1977/1

/5/ Stahl, W., Breuer, U., Krappmann, F.
Ein neuartiges Scheibenfilter für die Massengut-, Aufbereitungsindustrie
Erzmetall 32, 69-74, 1979

/6/ Kern, R., Stahl, W.
The Discharge of Filter Cakes
Solid/Liquids Symposium of the Filtration Society 1984/4

/7/ Morris, K., Millington, C.A.
Modelling Fabric Filters
Filtration & Separation, 1983/11

/8/ Robel, H.
Haftvermögen von feuchten, festdispersen Systemen
Wiss. Z. Techn. Hochsch. Magdeburg, 1982/8, 26
79-83