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REDUCTION OF THE ENERGY EXPENDITURE WHEN DEWATERING ORE CONCENTRATES WITH A HIGH DEGREE OF FINES

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Abstract

The separation of fine particle solids from ore, coal and mineral concentrates is commonly accomplished with vacuum filters on a continual basis. The desired residual moisture of the filter cake thus built, is however, frequently not achieved, so that additional energy consuming accessory units are often required. Based upon the research work which has been carried out, engineering solutions leading to more economical dewatering of difficult to filter beneficiation concentrates are able to be presented. The mechanical dewatering of a filter cake by means of continual pressure filtration is substantially more advantageous then the use of a combination of inadequate vaccum filtration and following thermal drying. In addition to ascertaining the optimal operational conditions, new methods for the evasion of shrinkage cracks in filter cakes have also been developed, and questions regarding the design of disc- and drum-filters have been investigated.

Introduction

During beneficiation processes of ores, coal and minerals, solid-liquid separation usually follows the flotation phase, whereby the separation of fines from the suspensions is generally conducted with the aid of continually operating vacuum filters.

The largest portion of energy required for the operation of such apparatus is expended in generating and maintaining the driving pressure difference necessary for the filtration. In the case of a large number of suspensions which are difficult to filter, however, the residual moisture of the filter cake remains too high after vacuum filtration, so that additional measures must be taken involving high energy costs.

Limiting of the problem in question

The question of the energy expenditure for the solid-liquid separation is, in its universal formulation, of such a complex nature that at this point, it is necessary to confine the problem to some essential aspects. Because of this, subordinate energy expenditures, for example for the propulsion of the filters and homogenisation of the suspension, within the filter trough are not investigated in detail. Furthermore, only those suspensions are considered, which, from the point of view of vacuum filtration, can be classified as very difficult to filter, and by which the required residual moisture of the filter cake cannot be achieved, even after prolonged drying.

Engineering solutions for the separation of such suspensions include the following:

- additional thermal dewatering in a dryer;
- transition to discontinual or continual pressure filtration.

Although the investigations are mainly concentrated upon drum and disc filters, the greater portion of the discussed aspects may be applied to other filtration systems. The continual filters discussed here can, when installed in a pressure vessel, not only function as pure pressure filters, but also as pressure/vacuum or pure vacuum filters /1/.
The possibility of assisting the vacuum filtration by means of steam is not applicable to the comparison of engineering solutions here because of the above suspension classification.

The influence of chemical additives upon these parameters and the corresponding effects upon the ability of filtration must, within this publication unfortunately also remain unconsidered.

Comparison of the combination of vacuum filter and dryer with the purely mechanical dewatering by pressure filtration

Before the various aspects of the mechanical energy expenditure are to be discussed in more detail, a comparison is to make plain that the purely mechanical dewatering is to be given preference over any type of thermal drying. In this respect, the initial step is to define how the mechanical and thermal energy consumption is to be determined.

Here, the simplified assumption is made, that the technical adiabatic compression work, necessary to compress the air which flows through the cake during dewatering, is the energy expenditure of the mechanical dewatering process. When this energy is related to the mass of produced solids, the specific energy consumption per unit solids mass results

$$w_t = \frac{1}{\eta} \cdot \frac{1}{A \cdot h_K \cdot (1-\varepsilon) \cdot \rho_s} \cdot p_1 \cdot V_1 \cdot \frac{\kappa}{(\kappa-1)} \cdot \left(1-\left(\frac{p_2}{p_1}\right)^{\frac{\kappa-1}{\kappa}}\right) \qquad (1)$$

In order to calculate the required energy for a real application, the specific technical work w_t then has to be divided by the pump efficiency η.

To ensure that the aimed comparison remains independent from the type of pump, the pump efficiency is ideally assumed to be 1. In the same manner, the energy necessary for the thermal drying is determined.

The required thermal energy is a compound of the following constituents:

- heat quantity expended in warming the solids from an initial temperature to the boiling point of the filtrate;
- heat quantity expended in warming the filtrate within the cake to boiling point;
- heat quantity expended in conveying the water from the liquid to the gaseous phase.

The heat quantity involved in heating the air within the cake pores is not considered so that the required specific heat quantity per unit solids mass may then be given as:

$$q = \bar{c}_s \cdot \Delta T + \frac{m_L}{m_s} \cdot \bar{c}_L \cdot \Delta T + \frac{h_d}{m_s} \cdot \Delta m_L \qquad (2)$$

In the following, the comparison between mechanical and thermal dewatering is to be discussed, with the aid of examples from the fields of iron slurry filtration.

For this purpose the measured values used the result from experiments conducted with a laboratory pressure filter apparatus /2/ and a continually operating pilot scale drum filter /1/.

In Fig. 1, the specific dewatering energy is plotted as a function of the filter cake saturation level for a magnetitic iron ore. The energy necessary to boil off the water increases linearly with decreasing saturation.

This line, however, does not pass through the point S = 1 and $w_t = 0$, but at complete saturation, a certain specific energy value exists. This basic value incorporates the warming of the solids and filtrate between 20 °C and 100 °C.

Should, in the case of an insuffficient mechanical dewatering, some of the filtrate already be removed, then the basic value is lower, as the removed filtrate obviously no longer has to be heated. Moreover, the line begins at a saturation level of S < 1.

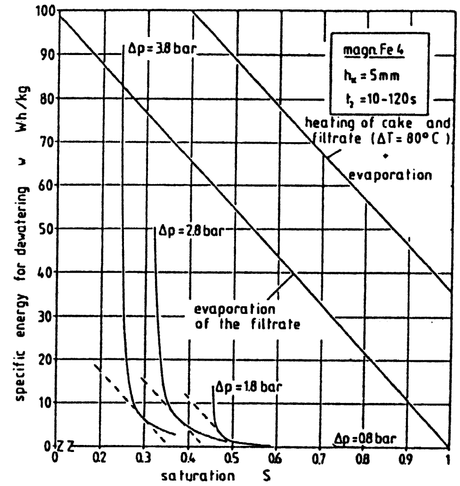

Fig. 1: Comparison between mechanical and thermal dewatering

Contrary to the linearly increasing function trend of the specific thermal energy consumption, the necessary specific mechanical energy increases progressively with falling saturation. In the region between complete saturation and initial air break-through, no air freely permeates the dewatered filter cake and cloth pores.

During the further course of dewatering the air quantity, necessary in order to maintain the driving pressure difference, increases progressively as progressively more pores are rid of the filtrate.

To illustrate this fact, four examples for four different pressure differences are shown in Fig. 1. In each case, the cakes were 5 mm high and the dewatering ceased after 120 s.

It may be observed that whilst an increase of pressure difference considerably reduces the level of saturation the energy expenditure, however, increases.

Each function intersects a certain location, at which the slope of the curves corresponds to those of the thermal energy.

From this point onward, further dewatering required comparatively more energy than the thermal process.

This indicates that especially in the case of pressure filtration when the region of extensive dewatering is reached, the danger exists of allowing an uneconomically large air volume to flow through the cake, just for the sake of reducing the cake's residual moisture by a few tenths %.

However, as far as the continual pressure filtration of difficult to filter suspensions is concerned, the mechanical dewatering even with air permeation generally requires substantially less energy than the thermal drying by means of evaporation.

In connection with these experiments with a pressure drum filter for the filtration of a hematitic iron ore slurry have shown that even at the upper possible limit of pressure difference (Δp = 3.8 bar), approximately 7 times less energy was consumed than with a comparable thermal drying /3/.

The mechanical dewatering of difficult to filter suspensions by means of drum and disc filters

Analysis of the single components of the air consumption

The amount of air which must necessarily be compressed for the operation of a drum or disc filter, in order to maintain the driving pressure difference, depends essentially upon three parameters:

- Machine design;
- Operational settings;
- Product characteristics;

whereby the two latter parameters do not only stand in close interrelationship, but also influence each other in a manner explained in the following.
If one considers the complete air volume flow through a filter, then it will be seen to consist of the following sub-flows:

- Air flow through the partly dewatered filter cake;
- Air flow for the evacuation of the filter cells and the filtrate piping system ;
- Air flow for the assistance of the filter cake removal by means of a compressed air pulse;
- Air losses incurred when removing the solids from the pressure-vessel;
- Air losses due to leakage e.g. at the filter's control head;
- In the case of drum filters, a special zone in the control head can often be found, in which the filter medium is cleaned of adhering particles by means of compressed air from the cell which is blown through the filter cloth back into the suspension.

These single components of the compressed air consumption are to be separately investigated regarding their influence.

Compressed air flow for cloth cleaning

Upon being immersed in the suspension, the filter cell receives a compressed air pulse from a special zone in the control head.

According to the clogging tendency of the filter cloth, the thus resulting air stream into the suspension may be reduced to a point where the filter cloth's permeability noticeably deteriates.

Leakage losses

Leakages can mainly be reduced by careful servicing of the filter apparatus, whereby special attention must be paid to the control head, as a revolving section must be sealed, this being exposed to wear by abration.

Solids transfer

The compressed air loss incurred by the solids transfer from the pressure vessel can be minimised by filling the air-lock chambers of the particular system as full as possible with the moist bulk. Thus, only the gas enclosed within the bulk's pores expands into the atmosphere.

Evacuation of the filter cell and filtrate piping system

The air flow to evacuate the filter cells and the filtrate piping system is largely machine specific and depends upon the particular filter construction in question. The reduction of the cell volume and pipe area can only be conducted to the point where just sufficient filtrate can drain (hydraulic boundary).

Air blow back for the cake removal

The air flow for the assistance of the filter cake discharge must be so dimensioned that a complete cake removal is guaranteed. Particularly in the case of disc filters, the compressed air cake discharge has been comprehensively investigated /4/. The energy required for this is strongly dependent upon the constructive parameters of the machine design. Especially in this area, a large potential for the improvement, regarding many conventional versions, exists.

In order to remove the cake the adhesion forces, which mainly exist due to the fluid bridges between the filter cloth and the particles of the filter cake, must be overcome. This is conducted by the superimposition of inertia and pressure forces caused by the accelleration and simultaneous permeation of the system cake/cloth resulting from a compressed air pulse. The decisive factor here is the speed of pressure increase behind the filter medium. The basic requirements for this is that the path between the pressure tank and the filter cell is short, and that the filtrate piping is dimensioned as large as possible and incorporating a low number of bends.

A further important detail is the rapid opening of the orifice between the filtrate pipe and air blow back zone within the filter's control head. The speed of this procedure is dependent upon the geometry of the overlapping orifices and upon the drum's angular velocity.

As can be seen in Fig. 2, the complete overlapping of the rectangular/rectangular geometry orifices is distinctly more rapid than the conventional circular/circular design. Especially in the case of slowly operating filters, a rapid snap-blow valve is often built into the pipe between the compressed air tank and the control head. This then

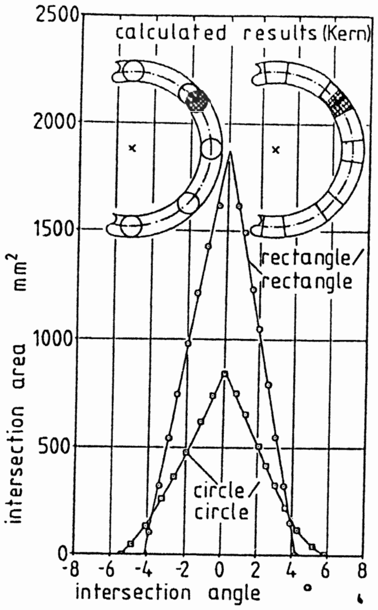

Fig. 2: Opening sequence for the air blow back

opens, when the orifices of the filtrate pipe and control zone just completely overlap.

As can be seen in Fig. 3, the necessary pulse pressure can be reduced by a variety of correctional measures:

- Pre-tensioning of the filter cloth over the cell;
- Reduction of the segment angle, or the application of cloth bands to restrain the filter medium (amplified cloth deformation);
- Reduction of the cell volume.

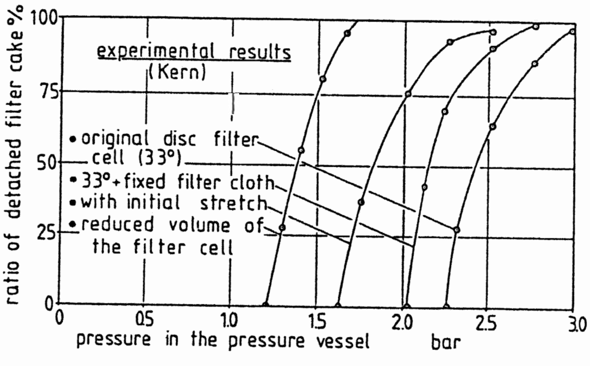

Fig. 3: Possibilities of reducing the blow-back pressure

In connection with this, a further advantage of the pressure filtration over an ineffective vacuum filtration should not be omitted, namely that in the region of the saturation level attained by such filters (S = 0.8-0.9), the largest adhesion forces exist between the cake and the cloth. An extensive reduction of the level of saturation leads to a considerable reduction of the adhesion forces /5/.

Air permeation through the partially dewatered filter cake

This portion of the total air volume flow is of greatest importance for the resulting aggregate energy expenditure. Here, the constructive aspects, the product characteristics and the choice of operating parameters all play a role, from which the constructive features are of greatest significance, especially for disc filters /6/. The filter cake is of a different thickness at various locations, as can be observed in Fig. 4.

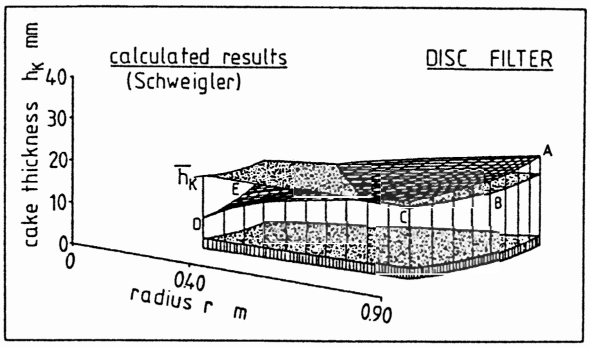

Fig. 4: Cake height distribution over one filter segment area

This cake thickness distribution is a result of the different residence times for each filter segment location within the suspension. The successive positions of a filter cell are illustrated in Fig. 5.

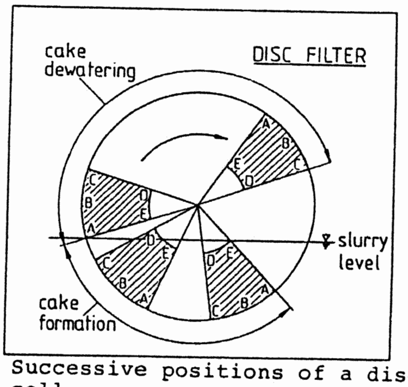

Fig. 5: Successive positions of a disc filter cell

In the first segment position, the filter cake is formed over the whole of the filter area. In the case of long filter cells, the additional influence of increased hydrostatic cake formation in the deeper filter trough regions are also observed.

In the second position, the cell has already partly emerged from the suspension. At this point, the dewatering begins, whereby the cake is still being formed over the sections of the area still submerged.

Because of the different cake heights and dewatering time, a residual moisture distribution is created over the filter area.

The air then preferably permeates the areas of lowest resistance i.e. the thinner and dryer cake sections. If the air throughput as given in Fig. 6 is distributed evenly over the complete cell, then a distinctly higher value results than expected for the case of a homogeneous cake height and residual moisture.

The filter cake homogeneity can be improved by a variety of different measures:

- Reduction of the sector breadth and thereby increasing the number of cells;
- Increasing the depth of submerge, for the relative cake height difference decreases with increasing cake formation time;
- By increasing the pressure difference or reducing the cell volume, the influence of the hydrostatic cake formation is also reduced and the filter cake residual moisture is often homogenized.

Before the optimization of the operating parameters is to be discussed, a phenomenon which plays a dominant role, as far as the energy consumption is concerned, must be mentioned.

Many filter cakes, especially those comprising of extremely fine particles tend to form shrinkage cracks. The air can freely pass through these cracks and in fact, the amount of permeating air is often so large, that the installed compressor capacity can no longer adequately maintain the required pressure difference.

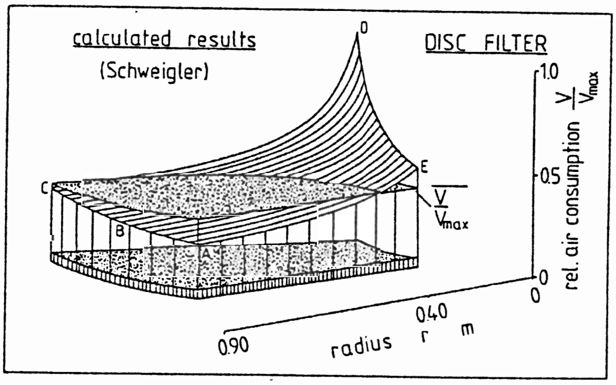

Fig. 6: Air throughput through a cake-covered disc filter cell

Before the optimizing of the operating parameters can be conducted, the shrinkage crack formation must be brought under control. Investigations and suggestions for engineering solutions of this phenomenon also exist /7/.

Cracks occur in filter cakes when the tensile forces created by the fluid bridges between the solid particles can no longer be withstood by the solids structure.

This is especially promoted by filter cake inhomogeneities such as:

- Stratification of extremely fine particles on the cake surface;
- Air, or coars particle inclusions within the cake;
- Wire tensioners for the fixing of the filter cloth upon the drum surface;
- Separating bars between single filter cells.

In a series of cases, the crack formation can simply be avoided by choosing favourable operating parameters (e.g. increased pressure difference).

Another possibility is offered by sub-dividing the complete filter area into a number of smaller sub-sections, upon which the cake may shrink without cracking. As Fig. 7 illustrates, this can be realized by a segmented filter cloth.

The continual pressure filtration process in discussion here, possesses the advantage that it can be equally operated as pure pressure as well as combined pressure/vacuum filtration. In additon to thermodynamic questions (see eq. 1) and the permeation of porous bulks by compressible fluids (see eq. 4), the choice of the required compressor plays a vital role /8/. Whilst water ring pumps for the purpose of generating a vacuum usually operate with an efficiency of $\eta = 0.3$. turbo compressors, for example, can operate at efficiencies of up to $\eta=0.75$. Despite a number of specific operational advantages, the generation of the pressure difference between vacuum and overpressure usually requires more energy than the pure overpressure filtration.

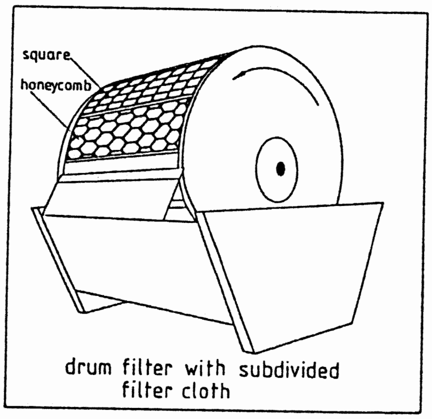

Fig. 7: Filtration with a segmented filter cloth

At this point, the discussion of the operating condition optimization may be conducted. The task is set of attaining a certain filter cake saturation level, e.g. a level typically required for a pelleting process.

As can be seen in Fig. 8, a theoretical infinite number of combinations of cake height, pressure difference and dewatering time exists.

If the dewatering time is held constant, then areas in space result, whereby the drawn lines of intersection incorporate all combinations of pressure difference and cake height by which the required saturation level may be accomplished.

For each of these saturation areas, a corresponding air consumption characteristic area exists, and the decision must be made, which parameter combination leads to the lowest air consumption.

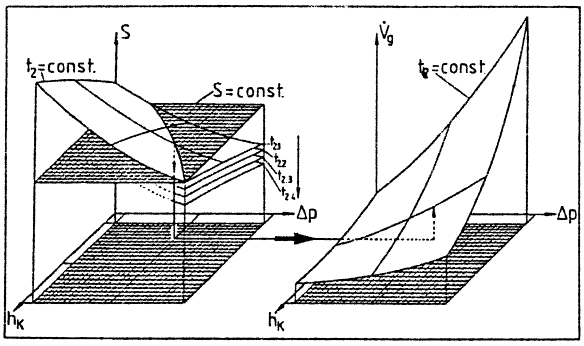

Fig. 8: Characteristic dewatering fields

In order to calculate the most efficient operating parameters, two possibilities exist, depending upon the boundary conditions.

One can mathematically interpolate between two experimentally determined points of a particular area of interest, or one can utilize a physical model, describing the cake dewatering. In order to use the model, certain material functions of the filter cake have to be obtained by measurement. In the case of homogeneous filter cake growth, the decrease of the saturation level dS/dt can be determined by the following formula:

$$\frac{dS}{dt} = \frac{2 . P_c . P_{c,rel,L}(S) - (\Delta p - p_K(S)\ )}{\eta_L . \varepsilon . (h_K + h_{KE})^2} \qquad (3)$$

This formula is dependent upon material functions such as the specific cake permeability P_c, the capillary pressure distribution $p_K(S)$, the porosity ε, the filter cloth influence h_{KE}, the fluid viscosity η_L and operating parameters such as the pressure difference Δp and the cake thickness h_K.

The air volume flow $\dot V_{g,e}$, resulting from the emptied cake pores may also be portrayed as a function of various operating and material parameters:

$$\dot V_{g,e} = \frac{P_c . P_{c,rel,g}(S) . A}{\eta_g . (h_K + h_{KE})} \cdot \frac{\Delta p . p_m}{p_o} \qquad (4)$$

Here, the compressibility of the air is expressed by the pressure difference Δp, the pressure over the cake p_o and the mean pressure p_m.

Extensive investigations with Iron ores, non ferrous, coal and mineral slurries have proven that equations (3) and (4) are correct. The necessary specific energy is calculated by integrating eq. (4) and converting by eq. (1). The aim of optimizing the operating parameters of a filter requires, as boundary conditions, that not only the required saturation level be guaranteed, but also information over the attainable solids throughput. The specific solids mass flow rate is determined from the fundamental equation of cake forming filtration, whereby all of the required material functions have to be experimentally obtained.

$$\dot m_s = \frac{\rho_s . (1-\varepsilon) . A . h_K}{(t_1 + t_2)} \cdot \sqrt{(R_M . P_c)^2 + \frac{2\kappa . \Delta p . t_1 . P_c}{\eta_L}} - R_M . P_c \qquad (5)$$

The filter cake production time is, for the further calculation, estimated as being the sum of the cake formation and dewatering time (t_1+t_2). This portrays the maximum attainable, as the so called "dead time" occurring unavoidably in the case of a real filtration process, are disregarded. Such intervalls are necessary (e.g. for the cake removal or cloth cleaning), and are not identical for different filter equipment. The results of the calculations are illustrated in Fig. 9.

The aim of the calculation was to determine the specific requirement and the expected solids throughput in the instance of the filter cake being dewatered to a degree of S = 0.6. The operating conditions for each

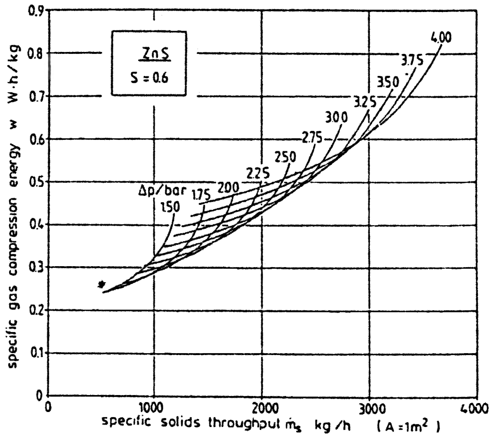

Fig. 9: Filtration condition optimization

respectively constant pressure difference are joined by a curve, and are confined by the lower and the upper limits by cake heights of 5 mm and 30 mm respectively.

Should one wish to increase the specific solids throughput at a constantly held pressure difference, then more energy must be invested in compressing the air. It can be deducted from the physical correlation, that the energy increase is smaller, the lower the influence of the filter medium is upon the filtration. This has also been verified by operational results of a pressure drum filter. Furthermore, these experiments have also shown, that an increase of energy is possible towards lower solids throughputs (i.e. higher cake heights). This is the result of superimposed air leakages, which occur more often at such ranges of operation.

Altogether, a flat minimum can therefore often be achieved for engineering applications. The correlated results of Fig. 9 may be used as reference points for the setting and optimization of a filter's operational condition. Based upon the information contained therein, and with knowledge of the aimed use of the machine the most favourable operating condition for a certain filtration problem may be estimated.

Aspects of the optimizing of complete filter plants

The discussion of the single component air consumption has shown that the energy expenditure of a filter may not only be extensively changed or reduced by constructive measures, but also by the choice of the operating parameters. For the dimensioning or optimization of a complete filter plant, the combination of filters and air compressors must also be taken into consideration.

In order to determine the pressure which a pump is capable of attaining, the complete pressure loss of the plant must be known.

Moreover, in addition to all of the above components, the pressure loss of the piping between the compressor and the filter should also be considered.

The combination of plant and pump characteristics finally allows the optimal operation parameters to be determined.

In order to illustrate these connections, a simplified example is given by Fig. 10 in a qualitative manner.

The example is valid for the operations of a drum filter with a fixed ratio of cake formation to dewatering angle within the control head and with a constant immersion depth of the drum. The correlation between the applied pressure difference and the air volume flow is, in the instance of constant cake height, approximately linear.

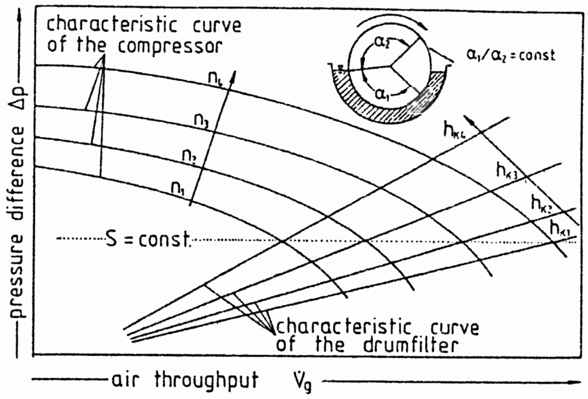

Fig. 10: Plant and pump characteristics of a filtration plant

The cake saturation is nearly independent of the drum's rotational speed and resulting cake height for a fixed control head geometry and depth of drum submergence.

Should therefore the problem exist of attaining a certain degree of saturation, then the complying parameters of operation lie in Fig. 10 upon a horizontal line. In Fig. 10, a number of pump curves for various speeds of compressor revolution have also been added.

With increased pump angular velocity and constant pressure, a larger quantity of air can be conveyed.

From the intersections of pump and plant characteristics with the curve of constant saturation, the available operating parameters may be chosen.

By regarding the efficiency of the pump in question, the required energy may be determined from it's characteristic data.

Summary

The aspects discussed in this publication have illustrated that the energy expenditure, necessary for dewatering difficult to filter suspensions, may be widely varied.

It has been especially proven that the purely mechanical dewatering by means of pressure filtration possesses distinct advantages in comparison to the combined mechanical/thermal process installations.

Furthermore, it has been shown that in the case of the purely mechanical dewatering, the energy requirement can be optimized by a variety of constructive measures and by carefully directed operational parameters.

The aspects discussed here cannot claim to be universally complete and the choice of a particular dewateirng process strongly depends upon the specific conditions prevailing in a certain operational instance. They illustrate, however, important tendencies concerning the running costs of the dewatering with respect to the energy consumption.

Besides other aspects such as high specific throughput rates and corresponding small floor space requirement with comparatively low installation costs, the continual pressure filtration seems to be economically the most interesting alternative to the common processes for the dewatering of difficult to filter suspensions.

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