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Dewatering of iron ore slurry by a ceramic vacuum disc filter

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Ceramic vacuum disc filters are used widely for dewatering iron ore slurries in mining industry. The scale of iron production processes is typically very large which means that small changes in the operation of the filter can have a significant impact on the overall effectiveness of the process. Some of the variables that determine the performance of ceramic disc filters are the rotation speed of the disc, the level of slurry in the feed basin, the vacuum level applied during the filter cake formation and dewatering stages and the solid concentration as well as the temperature of the feed slurry.
This paper introduces an experimental study that was carried out to determine the influence of several process variables on the performance of the ceramic vacuum disc filter. Experiments were performed by a laboratory scale leaf test equipment and the obtained results where then scaled to describe the operation of an industrial scale filter. Overall capacity of the filter and residual moisture content of the iron ore cakes were used for describing the performance of the filter. The results were utilized for creating regression models which were successfully used for discovering the most significant process variables and for estimating the effects of those on the operation of the filter.

1. Introduction

Ceramic vacuum disc filters are used to dewater a wide variety of different kinds of mineral concentrates in the mining industry. The construction and operation principle of ceramic disc filters are pretty similar to the conventional disc filters but the difference is that the filter cloths are replaced here by microporous ceramic segments. As these segments are immersed into the slurry under vacuum, the filtrate is drawn through the ceramic elements and the filter cake forms onto the external surfaces of those. When the segment rises from the slurry basin, the dewatering of the filter cake begins due to the vacuum that continues to draw the liquid from the cake into the segment. The moisture content of the cake decreases until the vacuum is broken and the cake is discharged by a scraper. The main advantage of ceramic disc filters when compared to the conventional ones is that there is no air flow through the discs at any point of the cycle due to the capillary forces acting in the pores. The vacuum losses are therefore much lower which means that also the vacuum pumps required for ceramic filters are significantly smaller than the ones required for conventional disc filters.

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One of the most important applications of ceramic disc filters is the dewatering of iron ore slurries. The production capacity required in this kind of processes is normally very large and it is therefore important to optimize performance of the filter by considering all of those operation parameters that influence the overall efficiency of the separation process. The performance of ceramic disc filters is affected by variables such as the rotation speed of the disc, the level of slurry in the feed basin, the pressure difference applied during the filter cake formation and dewatering stages and the solid concentration as well as the temperature of the feed slurry. The target of this study was to determine the main effects of these variables on the dewatering of iron ore slurry.

2. Materials and methods

Preliminary sizing and estimation of performance characteristics of ceramic disc filters are typically performed by using a relatively simple leaf test equipment. Main parts of this equipment are a mixing tank and a small (150 mm × 100 mm × 25 mm) ceramic element which is connected to a vacuum source. The idea is that the element mimics a small area of a disc in full scale filters. During the laboratory tests, the ceramic element is first immersed into the mixed slurry for a certain time which corresponds to the cake formation time in a full scale unit. After this, the test plate is lifted from the slurry but the vacuum is still maintained inside the test plate for a predefined time to imitate the dewatering stage. The cake is scraped off the plate immediately after the desired drying time and analyzed to get the filter capacity and residual cake moisture content. The durations of the cake formation and dewatering stages in full scale disc filters are determined by the rotation speed of the disc and by the height of the slurry surface in the basin. The corresponding immersion and drying times to be used in the laboratory tests must therefore be calculated separately for each rotation speed and slurry level.

The material that was used in the laboratory experiments was iron ore that was obtained directly from an industrial process as dry powder. Mean particle size ($d_{4,3}$), which was measured with Coulter LS 13 320 laser diffraction analyzer, was 21.0 µm (d_{10} = 6.3 µm, d_{50} = 19.8 µm and d_{90} = 82.7 µm). The dry iron ore was mixed with tap water to produce the slurries with the desired solid concentrations for the filtration tests.

Table 1 lists the five variables which were of interest in this study and it also shows the operation ranges that were decided for each variable before starting the experiments.

Table 1 Variables and variable levels for the experiments

Variable	Low level	Average	High level
Temperature of the slurry	20 ºC	40 ºC	60 ºC
Solid concentration of the slurry	50 w-%	60 w-%	70 w-%
Pressure difference during filtration and drying	0.500 bar	0.725 bar	0.950 bar
Cycle time of the disc	60 s	45 s	30 s
Slurry level from the center shaft of the disc	- 400 mm	- 300 mm	- 200 mm

Even if the leaf tests are very easy and quick to perform, discovering the real influences of all five variables is a challenging task and it requires an efficient testing strategy and analysis method to be applied. Statistical design of experiments and empirical regression modelling are suitable tools for this kind of studies and by using these techniques, the influence of a large number of process variables on several product characteristics can be reliably and objectively determined with a relatively small amount of test runs. In addition, it is also possible to detect and take into account the interactions between the studied variables in the optimization stage of the process.

The test plan for the experiments carried out in this study was created by following the basic principles of full factorial designs. Before creating the plan, it was decided that two of the variables (temperature and solid concentration of the slurry) should be investigated at three levels while two levels would be enough for the rest of the variables. This means that the full factorial design consisted of 72 ($= 3^2 \cdot 2^3$) tests. In addition to these tests, it was decided that a certain amount of center points was also needed in the design in order to detect the possible nonlinearities during the modelling part. After adding 9 center points into the initial full factorial design, the overall amount of experiments in the final test design was 81.

3. Results and discussion

The target of this study was to determine the influence of the five process variables on the capacity of the filter and on the residual moisture content of the filter cake. The experimentally determined capacities ($kg_{Dry\ solids}/m^2h$) and cake moisture contents (*w-%*) for all 81 tests are presented in Figures 1 and 2. The conditions of the experiments can not be seen from these figures (except the solid concentration of the slurry) but the figures show the structure of the data and the variation between the test results. The capacities, which are presented in Figure 1, varied from about 350 to 5000 kg /m^2h and the highest values were found in those experiments which were carried out using the slurry with the highest solid concentration. The residual cake moisture contents shown in Figure 2 range from about 6.2 to 10.3 w-% and the average moisture content seems to be the highest when the solid concentration of the slurry was the highest.

Figure 3 shows an example of the influence of temperature and solid concentration of the slurry on the capacities and moistures. Fairly obvious trends can be seen in this figure in such a way that the capacity increases with increasing temperature and increasing solid concentration whereas the cake moisture content increases with decreasing temperature and increasing solid concentration. All other conditions except the temperature and solid concentration were maintained constant in these experiments.

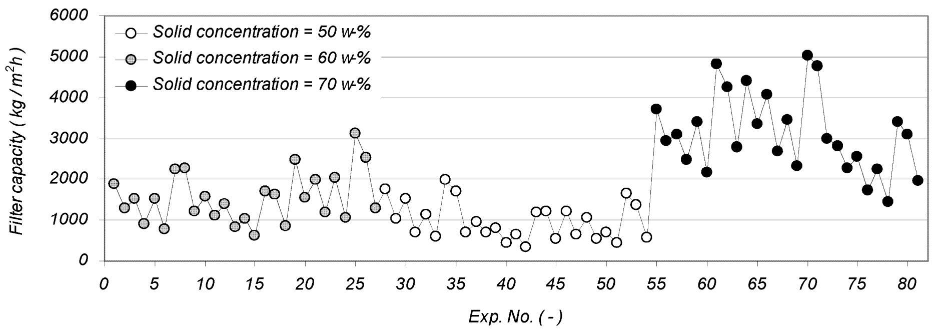

Figure 1 Experimentally determined filter capacities for the 81 tests

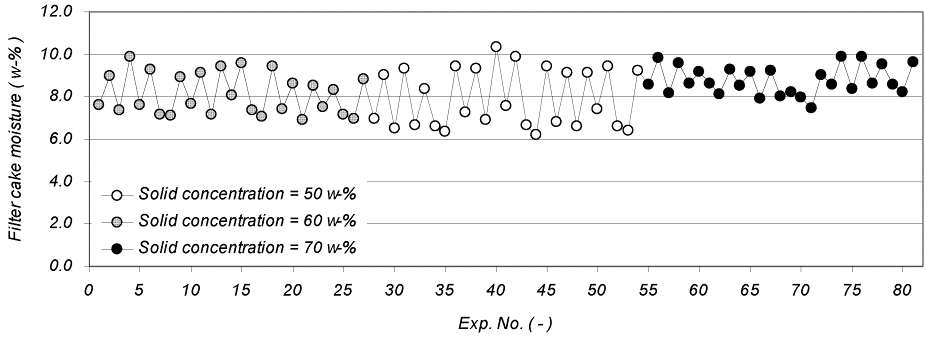

Figure 2 Experimentally determined filter cake moisture contents for the 81 tests

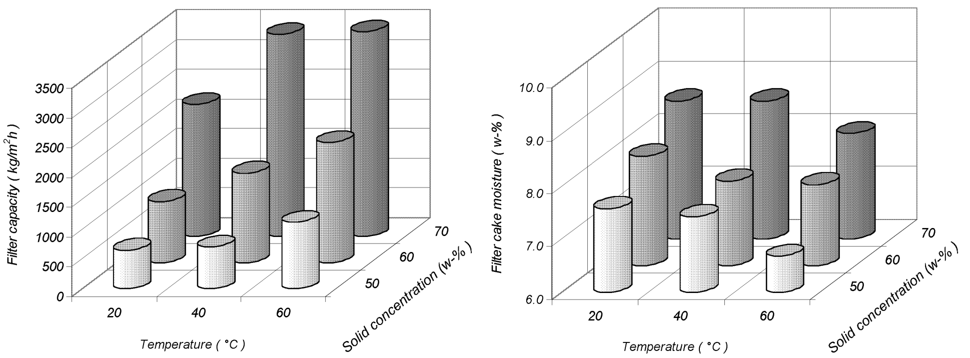

Figure 3 Examples of the influence of slurry temperature and solid concentration on filter capacities and filter cake moisture contents. Pressure difference in these tests was 0.725 bar, cycle time was 45 seconds and slurry level from the center shaft of the disc was – 300 mm.

The results obtained from the 81 experiments were used for creating regression models separately for both of the studied responses, i.e. filter capacity and cake moisture. The models that are introduced in this paper are linear main effect models of form:

$$y = \beta_0 + \beta_1\, T_{slurry} + \beta_2\, c_{slurry} + \beta_3\, \Delta p + \beta_4\, t_{cycle} + \beta_5\, h_{slurry} \tag{1}$$

where
- y is the response (capacity or moisture content), (kg_{solids} / m^2h or $w\text{-}\%$)
- $\beta_{0 \ldots 5}$ are the regression coefficients
- T_{slurry} is the slurry temperature, (°C)
- c_{slurry} is the solid concentration of the slurry, (*w-%*)
- Δp is the pressure difference during the filtration and dewatering, (*bar*)
- t_{cycle} is the cycle time, (*s/round*)
- h_{slurry} is the distance of the slurry surface from the center of the disc, (*mm*)

Figure 4 illustrates the predictions obtained with the models that were created by using all the data obtained from the 81 leaf tests. This figure shows the filter capacities and residual cake moisture contents that were predicted by applying the regression models against the values obtained experimentally. Therefore, if the predictions given by the models were perfect, all the data points would lie on the diagonal line. Figure 4 also shows the correlation coefficients *(R^2)* which are fairly good for both models. It can, however, be noticed that there is some scattering around the diagonal line in both models. This is caused either by the experimental inaccuracy or by the fact that linear main effect models cannot explain the studied phenomena perfectly due to significant interactions between the variables or due to the nonlinear behavior of some variables. The form of the regression models can be modified in these cases by adding components that take into account the deviations from the perfectly linear behavior. It was found out for example in this case that the correlation coefficients of both models could be increased above 96 % by taking into account the interactions between the variables and by adding some quadratic components that explain the nonlinear behavior. One disadvantage of this kind of more complicated models is that the influence of individual variables on the responses becomes much more difficult to estimate.

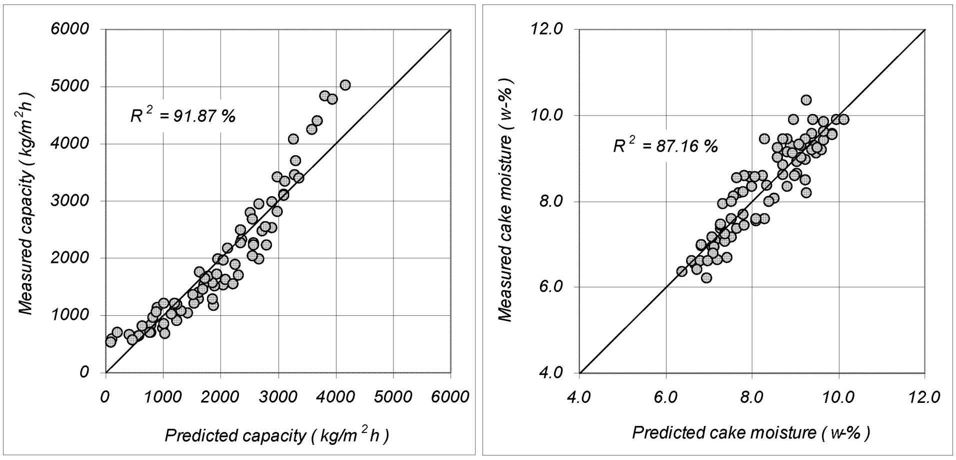

Figure 4 Measured vs. predicted – diagrams for the linear main effect models created for the filter capacities and cake moisture contents

The main effects of single variables in the investigated range can be calculated by using the coefficients of the main effect models and these are presented in Table 2.

Table 2 Main effects of the studied variables on the capacity of the filter and on the moisture content of the filter cakes

Variable	Range	Main effect on filter capacity	Main effect on filter cake moisture
Slurry temperature	20 ºC ⇒ 60 ºC	+ 748 kg/m^{2}h	- 0.59 w-%
Solid concentration	50 w-% ⇒ 70 w-%	+ 2351 kg/m^{2}h	+ 0.96 w-%
Pressure difference	0.50 bar ⇒ 0.95 bar	+ 1081 kg/m^{2}h	- 1.86 w-%
Cycle time	30 s ⇒ 60 s	- 430 kg/m^{2}h	+ 0.16 w-%
Slurry level	- 200 mm ⇒ - 400 mm	- 245 kg/m^{2}h	- 0.27 w-%

As can be seen from Table 2, an increase in the slurry temperature from 20 °C to 60 °C increases the filter capacity by an average of 748 kg/m^{2}h and decreases the cake moisture content by an average of 0.6 w-%. This can be explained mostly by the decrease in the viscosity of water with increasing temperature. Increase of solid concentration of the slurry increases the capacity and also increases the cake moisture content. The explanation for the increase in moisture content is that the dewatering stage becomes less efficient when the cake thickness increases. Also the pressure difference has a significant and easily understandable influence since the capacity increases and cake moisture content decreases as the pressure difference increases. The influences of cycle time and slurry level are not as large as the influences of the other variables but also those seem to behave in a predictable manner.

Comparison between the effects of the investigated variables reveals that capacity is mostly influenced by the solid concentration of the slurry and by the pressure difference. These are also the variables that have the largest effect on the cake moisture contents.

4. Conclusions

The target of this study was to determine the main effects of five different variables on the dewatering of iron ore slurry by a ceramic disc filter. According to the achieved results, regression analysis could be used to determine the influences of the chosen variables. The models provided valuable information regarding the magnitude of the changes caused by the variations in the variable levels on the performance of a ceramic disc filter. The models could also be successfully used for detecting the most important process parameters. This information can be used either for selecting the optimal variable combinations for further tests or for optimizing the operation of the filter.