Experimental study on the influence of selected process variables on the separation of a fine particle suspension with a pilot scale decanter centrifuge

Kinnarinen Teemu, Häkkinen Antti

This is a Final draft version of a publication

published by Taylor & Francis

in Particulate Science and Technology

DOI: 10.1080/02726351.2013.811708

Please cite the publication as follows:

Kinnarinen, T., Häkkinen, A., Experimental study on the influence of selected process variables on the separation of a fine particle suspension with a pilot scale decanter centrifuge, Particulate Science and Technology, 2013, 31:603-611. DOI: 10.1080/02726351.2013.811708

Experimental Study on the Influence of Selected Process Variables on the Separation of a Fine Particle Suspension with a Pilot Scale Decanter Centrifuge

TEEMU KINNARINEN* and ANTTI HÄKKINEN
LUT Chemistry, Lappeenranta University of Technology,
P.O. Box 20, FI-53851 Lappeenranta, Finland
*Corresponding author tel: +358 40 5621398, E-mail: teemu.kinnarinen@lut.fi

Decanter centrifuges are used widely in the chemical and process industries for dewatering and classification of solid-liquid suspensions. The most important applications of this class of centrifuges are found in wastewater sludge treatment and in pigment production. The objective of this study was to investigate the operation of a pilot scale decanter centrifuge in a challenging dewatering application. Dewatering tests were performed using fine-particle slurries consisting of water and various concentrations of kaolin. In addition to the solid concentration of the feed, the feed rate of the suspension and the differential speed between the bowl and the conveyer screw were also chosen as variables. The experimental conditions were selected according to a factorial test design and the responses monitored included the production capacity (productivity) of the decanter, the solid contents of the cake and the centrate, as well as the time that was required for the stabilization of the test unit. The results obtained clearly showed that the studied variables have a significant influence on the performance of the dewatering process. The variables were also able to explain the dewatering results at a high level of statistical significance. The repeatability of the experiments was, in most cases, good: on average, the relative standard deviations for the productivity and the solid contents of the cake were 6.0 % and 0.5 %. It was also apparent that random variations in the feed conditions may have a remarkable and long-lasting impact on the operation of the centrifuge.

Keywords Decanter centrifuge, Kaolin, Dewatering, Fine particle processing, Modeling

1. Introduction

Decanter centrifuges are used for the separation of solids from liquids, even at high solids concentrations, by means of sedimentation accelerated by the centrifugal force (Sutherland 2005; Day 2005). On the other hand, a relatively good degree of clarification of the centrate can also be obtained (Sutherland 2005; Leung 1998). In the pigment industry, for instance, decanter centrifuges are used for classification of solids, in order to obtain the desired particle size distribution.

A decanter centrifuge contains two rotating elements, i.e. a solid bowl that acts as the sedimentation medium, and a helical screw that is used to remove the sedimented solids from the conical end of the bowl (Day 2005; Records and Sutherland 2001). In addition to the variables considered in this paper, several other factors may have an influence on the operation of the device. These factors include, for instance, the bowl speed, the depth and length of the pool, and feed temperature (Day 2005).

One of the greatest advantages of decanter centrifuges is that they are suitable for dewatering hard-to-filter slurries containing fine particles (< 1 μm) (Leung and Shapiro 1999; Langeloh and Bott 1996). However, in most cases, decanter centrifuges cannot produce cakes with moisture contents as low as filters. The relatively high solid content of the centrate is also an issue worth consideration.

Kaolin clays are very hydrophilic and contain large amounts of fines, causing difficulties in the solid-liquid separation stage (Leung *et al.* 1999) and thus increasing the dewatering cost (Besra *et al.* 2000). During the last decade, high-speed decanter centrifuges have been increasingly used to separate such suspensions with fine particles (Merkl and Steiger 2012). The solid concentration of the cake in decanter centrifuges can be increased by using a device with a steeper beach angle or a longer beach zone, a higher rotation speed, or a lower differential speed between the screw and the bowl (Leung and Shapiro 1999; Nesterovich *et al.* 1989). However, high gravitational force together with steep beach angle makes the solids transportation in the decanter more difficult (Langeloh and Bott 1996; Leung 1998). Furthermore, a significant improvement in the settling rate and cake dryness for kaolin can be obtained using an appropriate flocculant (Besra *et al.* 2002, 2003, 2004).

In this study, a pilot scale decanter centrifuge was used for the dewatering of kaolin suspension. The operation of the decanter, with respect to selected key operational variables, was investigated according to a fractional experimental design. Operational limitations and problems encountered are also discussed.

2. Materials and methods

2.1. Equipment and slurry preparation

The decanter centrifuge used in the experiments was a pilot-scale device manufactured by Alfa Laval (type P2-220). The bowl diameter, length and beach angle were 280 mm, 980 mm, and 10°, respectively. The centrifuge was located approximately 3 meters above the slurry tank and the separated fractions were collected in containers below the device.
The dry kaolin clay (ρ = 2600 kg/m^3) used for the preparation of the feed slurry was supplied by J.M. Huber. Titanium dioxide was present as an impurity in a very small quantity (< 1%) in the solid powder. The slurry pH and feed temperature were 7.4 and 25 °C, respectively for all tests. A fixed amount of water was mixed with different amounts of dry solids to form a batch of slurry for each test. The slurry (approximately 1 m^3/test) was mixed with a propeller impeller in a large tank for over 10 minutes prior to each test run. Since the number of experiments was 27, the total volume of slurry separated was about 27 m^3 and the total mass of solids consumed during the test series was over 2000 kg.
The volumetric size distribution of the solid particles was measured with Beckman Coulter LS 13320 laser diffraction analyzer. Two different samples were analyzed and three parallel runs performed for both samples. The average characteristics of the solids were as follows: D_{mean} = 7.5 µm, D_{median} = 6.2 µm, D_{10} = 1.1 µm, and D_{90} = 15.93 µm.

2.2. Experimental design

Statistical experimental design was applied to maximize the value of the results for modeling purposes. The variables in the experiments were 1) solid concentration of the feed, 2) pump speed, and 3) differential speed between the centrifuge bowl and the conveyor screw. These variables were selected as the critical process parameters for two reasons. First, they were relatively easy to change, and second, they were known to have a major impact on the operation of decanter centrifuges. Variables 1) and 2) directly determine the throughput rate of solids, while Variable 3) has, perhaps most importantly, an effect on the cake dryness (Day, 2005; Merkl and Steiger, 2012). However, a prerequisite for stable operation of a decanter is that these variables are in balance with each other. Some other important factors such as the rotational speed, pool depth and beach angle were held constant. The amount of solid material corresponded to a solid concentration in the range of 4.7 to 8.9 % in the slurry. The pump speed was varied within the range of 10 to 20 Hz, which corresponded to a feed rate of 420 to 1190 kg_{slurry}/h. The differential speed between the bowl and the conveyor screw ranged from 5 to 15 rpm. In the experimental plan shown in Fig. 1, numbers 2 and 4 represent the number of parallel test runs conducted for each experiment. The experimental plan was modified from the original full factorial design as preliminary tests showed that, under certain conditions, the centrifuge was operating outside of its range of application. Since the slurry contained lots of fine particles, there was a marked risk of blocking the centrifuge with solids. The most extreme operating conditions, especially high solid concentration together with low differential speed, would have caused the torque to rise too high. Repeatability of the experiments could be evaluated, because each test was performed at least twice.

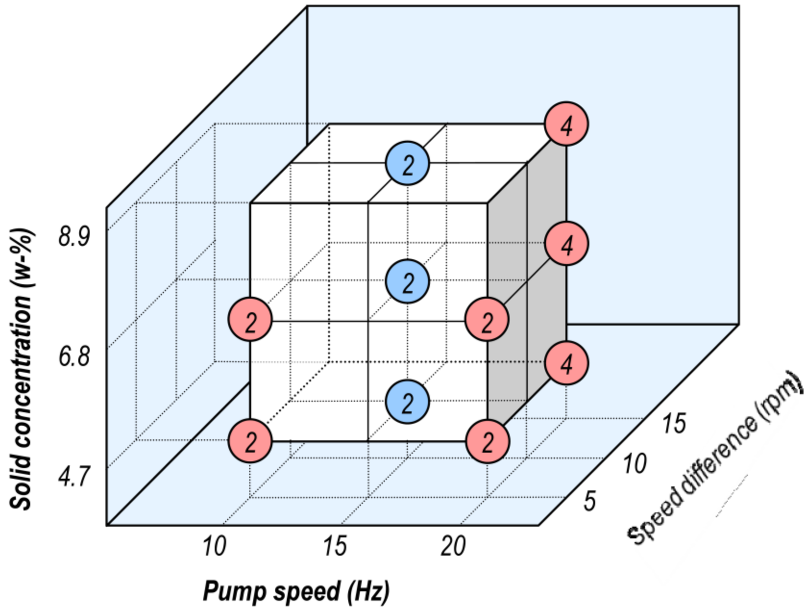

Figure 1. Illustration of the experimental plan.

2.3. Sampling procedures and sample analyses

Samples from the feed slurry were taken from a pipe between the feed pump and the decanter centrifuge. Feed samples were taken three times during each test run: in the beginning, halfway and at the end. Samples of centrate and cake were taken at equal time intervals from the open ends of the discharge hoses located about 3 meters below the device. The number of samples taken (3 to 7) depended on the duration of the test run. Each sample was analyzed for solid content by drying in an oven at 105 °C for 36 hours. Furthermore, the cumulative masses of the cakes and the centrates were manually recorded once per minute during the experiments.

3. Theory and calculations

3.1. Theory of centrifugal sedimentation

Separation in a decanter centrifuge is based on a density difference between the solid and the liquid. The high rotation speed of the centrifuge bowl causes the particles to move radially towards the wall of the bowl at accelerated velocities. The settling rate depends on the properties of the solid and the liquid. Additionally, the rotation speed and the distance (i.e. radius) from the centrifuge axis affect the rate of sedimentation.
In centrifugal devices, including decanter centrifuges, a single particle is subjected to the centrifugal force F_c , which is a product of the mass (*m*) of the particle, radius of rotation (*r*) and the square of the angular velocity (ω) of the centrifuge (Records and Sutherland, 2001).
The radial velocity V_s of a particle of diameter d_p is approximated by the modified Stokes' law according to Eq. (1). This equation is valid when the solid concentration is so low that interaction between the settling particles can be considered negligible. In this study, the highest solid concentration used was 8.9 %, which probably means that settling of particles was, to some extent, hindered.

$$V_s = \frac{\Delta\rho d_p^2 r\omega^2}{18\mu} \tag{1}$$

where $\Delta\rho$ is the density difference between the solid and the liquid and μ is the dynamic viscosity of the liquid. Generally, calculations based on various modifications of Stokes' law apply best to fine particles that are moving slowly (esp. when $Re < 0.2$).
In the case of centrifuges, it is conventional to use the cut size x_{50} of particles to describe the efficiency of separation. The cut size x_{50} corresponds to 50 % on the so called grade efficiency curve. Regarding the distances in the separation zone, according to its definition, the radius r_{50} divides the annulus between the liquid surface (radius r_1) and the inner wall of the centrifuge (radius r_2) into two equal areas.
The cut size x_{50} is generally derived from the grade efficiency function and becomes

$$x_{50}^2 = \frac{Q}{2\pi LK}\ln\left(\frac{2r_2^2}{r_2^2+r_1^2}\right)\frac{1}{r_2^2-r_1^2} \tag{2}$$

where Q is volumetric flow rate of the liquid, L is the length of the separation zone, K is the sedimentation constant (definition below).
The sedimentation constant K is expressed as

$$K = \frac{\Delta\rho\omega^2}{18\mu} \tag{3}$$

It is also possible to calculate the cut size x_{50} based on the liquid residence time K_2, which is defined as the ratio of the effective volumetric capacity of the centrifuge bowl and the volumetric flow rate of liquid through the centrifuge. Hence the equation is

$$x_{50}^2 = \frac{1}{2KK_2}\ln\left(\frac{2r_2^2}{r_2^2+r_1^2}\right) \tag{4}$$

Equations 1-4 and a more detailed description of the theory of centrifugal sedimentation can be found in the book written by Svarovsky (1981). The equations apply especially to vertical tubular centrifuges. Since the gravity is typically negligible compared to the centrifugal force, the above equations can be used in order to evaluate separation in decanter centrifuges as well.

3.2. Calculation of operational values

In this study the productivity, P, of the decanter centrifuge is defined as the mass flow of dry solids removed as cake (Eq. 5):

$$P = \frac{m_{DS,cake}}{t_{batch}} = R\frac{m_{DS,feed}}{t_{batch}} \quad (5)$$

where $m_{DS,cake}$ is the mass of dry solid collected in the cake fraction during the batch time t_{batch}, solids recovery R is the proportion of the dry solids in the feed $m_{DS,feed}$ that finds its way into the cake.
Solid contents, C_s, of the feed, cake, and centrate are simply calculated from Eq. (6) after drying the samples in a heating chamber at 105 °C.

$$C_s = \frac{m_{dry\ cake}}{m_{wet\ cake}} \quad (6)$$

4. Results and discussion

4.1 Productivity, solid contents, and stabilization time

The centrifuge was operated batch-wise, i.e. each test run was continued until the 1 m^3 slurry tank became empty. Depending on the chosen operation conditions, the duration of one experiment was 36 - 117 min. The productivity varied from 14 to 80 $kg_{dry\ solids}$/h and the solid content of the cake varied from 69 to 72 %. It is important to note that the productivity is not only a product of the feed rate and the feed solid concentration. This results from the fact that a varying proportion of the solid (74-90 %) was collected from the cake outlet, with the rest removed with the centrate. The solids content of the centrates produced varied from 0.8 to 1.8 %. The mass flow of the centrate was, however, many times higher than that of the cake, which means that the recovery rate should always be considered when estimating the productivity based on the feed rate. The highest productivity (80 $kg_{dry\ solids}$/h) was obtained using the combination of the maximum values of the variables: feed concentration = 8.9 %, feed rate of the slurry = 1190 kg_{slurry}/h, and differential speed = 15 rpm. Respectively, the minimum values of the variables resulted in the lowest productivity.
Only a moderate variation in the solid contents of the cake was observed. The minimum solid content of 69 % was obtained at the minimum values of the variables, i.e. feed concentration of 4.7 %, pump speed of 10 Hz, and differential speed of 5 rpm. The maximum solid content of 72 % was achieved under conditions where the feed concentration was 6.8 %, the pump speed was at the maximum (20 Hz), and the differential speed was at the minimum (5 rpm). The solid contents of the cakes from all experiments are presented together with the corresponding productivities in Fig. 2 and show only a weak correlation between the two.

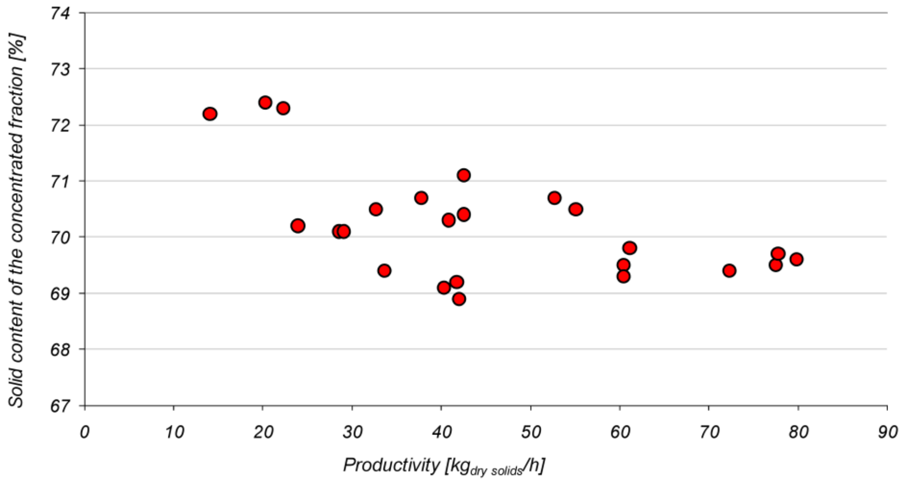

Figure 2. Solid content of the cake as a function of the productivity of the decanter centrifuge.

The production capacity (Fig. 3) of the decanter centrifuge was largely dependent on the solid concentration of the feed slurry and the feed rate. That is self-evident, because a decanter centrifuge is basically just a flow-through device with the purpose of dividing the feed slurry into solid and liquid fractions. There is, however, one factor affecting the capacity that makes it much more difficult to predict: the clarity of the liquid fraction. It is possible, especially when very fine solids are present in the slurry, that a relatively large proportion of the solids find their way into the liquid fraction.

As Fig. 3 shows, the repeatability of the experiments was better when the feed rate was lower. It is apparent that a high feed rate results in a larger variance of the measured production capacities, but much more tests would be required to investigate this further. In many cases, the repeatability regarding the capacity was not especially good; the differences in capacities obtained for two parallel tests were typically 5-10 kg of dry solids per hour. The relative standard deviations for parallel experiments varied from 0.6 % (4 tests, the highest differential speed) to 21.8 % (2 tests, the lowest differential speed). The average of all these relative standard deviations was 6.0 %. After excluding the most potential outlier (21.8 %), the value can be reduced to 4.2 %, which can be regarded as good. For solid concentration of the cake and centrate (Figs. 4 and 5) the differences in the results were smaller.

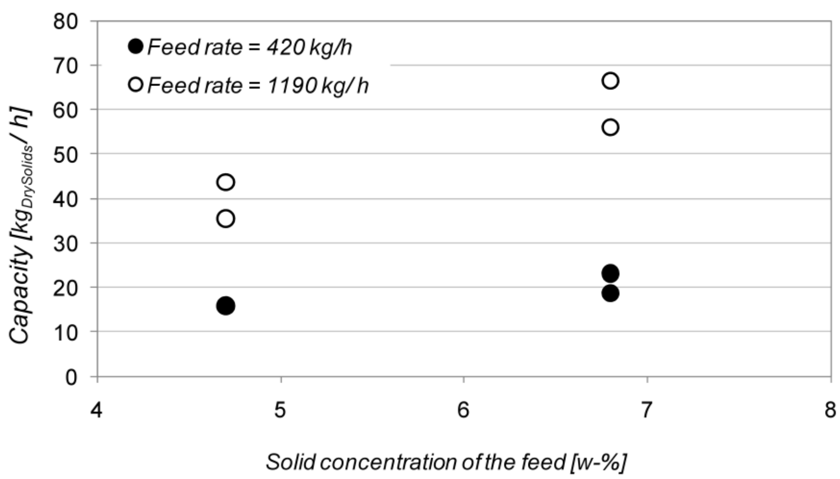

Figure 3. Production capacities obtained by using two solid concentrations of the feed (4.7 % and 6.8 %) and two feed rates of the slurry (420 kg/h and 1190 kg/h). The differential speed was constant (5 rpm).

Fig. 4 presents the solid concentration of the cake of the decanter centrifuge. It can be clearly seen in Fig. 4 that a lower differential speed between the bowl and the screw conveyor yielded a lower moisture content in the cake. The moisture content was slightly increased when the solid concentration of the feed slurry was the lowest, 4.7 w-%. Increasing the feed solid concentration from 6.8 to 8.9 w-% did not observably impact on the solid content. With respect to the solid content of the cake fraction, the repeability of the experiments was excellent. Taking all tests into account, the relative standard deviation from the mean was 0.5 %. Removal of the most potential outlier reduced the value to 0.2 %. In Fig. 4, results of the combination of the lowest differential speed and highest feed concentration are missing, because the safety limits of the device did not allow performing experiments under such conditions.

The recovery of solids was strongly influenced by the feed solid concentration and the feed rate. In the case of ideal separation, there would be no solids in the centrate. According to Fig. 5, the solid content in the centrate was typically less than 1 w-%. Application of the highest feed rate (1190 kg/h) resulted in a considerable increase of solids in the centrate, compared with the lowest feed rate of 420 kg/h. The solid concentration of the feed, similarly, had a marked effect on the mass proportion of solids in the centrate. The decline in the clarity of the centrate is most likely caused by 1) the more severely hindered settling and 2) the increased amount of particles that are too fine to settle during the residence time. It was observed that the differential speed was the most important variable responsible for differences in the purity of the centrate between the trials. However, there was no significant correlation between the differential speed and the solid content of the centrate.

As Figs. 3-5 show, obtaining a high capacity will require both a high solid concentration of the feed slurry and a high feed rate. That is, however, likely to dramatically reduce the solid recovery. The calculated solid recovery ratios (i.e. the ratio between the mass of solids in the cake and the mass of solids in the feed slurry) were in the range of 0.74 to 0.90. The main conclusion from this is that the production rate of a decanter centrifuge must be carefully optimized in order to avoid migration of solids into the centrate. It is apparent that a sufficient level of solid recovery could be obtained by recirculation of the centrate, or by using another decanter centrifuge or perhaps a filter for separating the fines from the liquid.

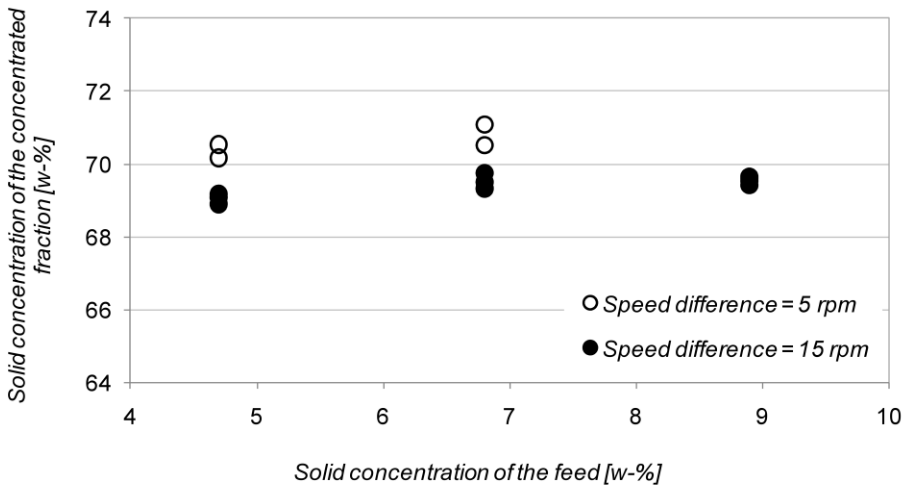

Figure 4. Solid concentration of the cake at different solid concentrations of the feed slurry (4.7, 6.8, and 8.9 %). Differential speed = 5 rpm or 15 rpm. The feed rate was constant 1190 kg/h.

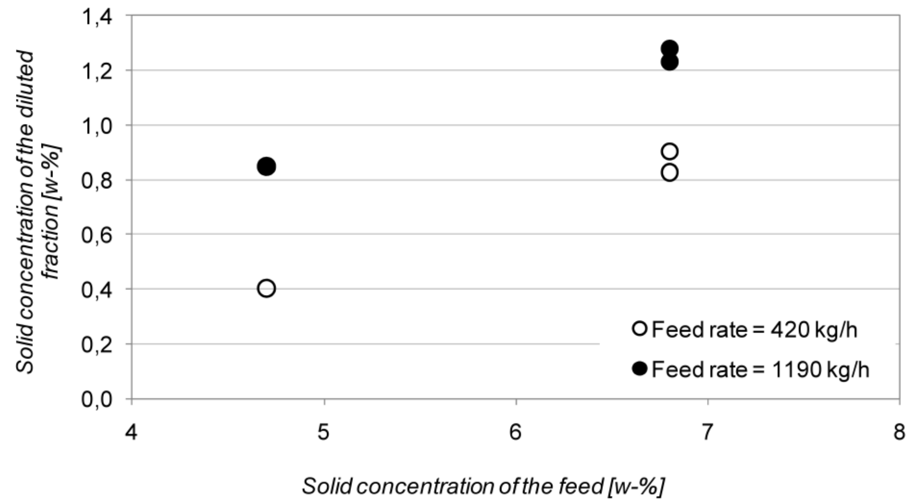

Figure 5. Solid concentration of the centrate at two solid concentrations of the feed slurry (4.7 and 6.8 %). Feed rate = 420 kg/h or 1190 kg/h. The differential speed was constant 5 rpm.

The stabilization time of a decanter centrifuge is commonly defined as the time required for the solid fraction to begin to discharge from the solids outlet at a constant rate. An example result is illustrated in Fig. 6. During the initial period of the operation, the solid concentration in the centrate can increase significantly until stable operation is achieved (Minaker, 1995). In all experiments, the production rate of the centrate became constant before the production rate of the cake stabilized. At the highest feed rate and differential speed, production of the liquid fraction was stabilized very rapidly, in less than one minute.

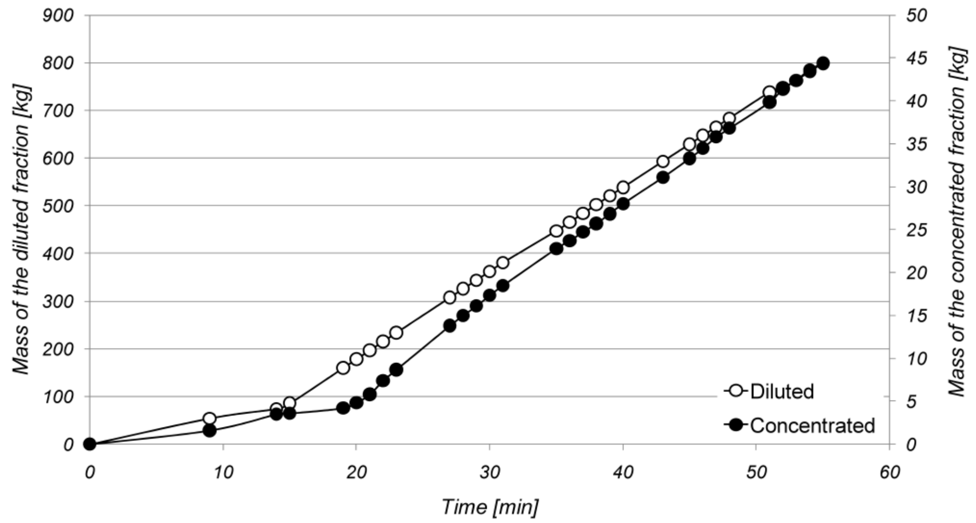

Figure 6. Estimation of the stabilization time. Solid concentration = 4.7 w-%, feed rate of the slurry = 1190 kg/h, differential speed = 15 rpm. In this case the stabilization time is approximately 20 min.

In some experiments, the operation of the centrifuge was not stabilized. The experimental run presented in Fig. 7 was stopped after 66 minutes, because the operation was still unstable. It is important to be able to produce both fractions at a constant rate, in order to minimize the variation in product quality, which in this case means that the solid content of the fractions should not vary significantly. It can be observed in Fig. 7 that the production rate of the cake sharply increased after 35 minutes of operation, which unavoidably resulted in lower solid content of the product.

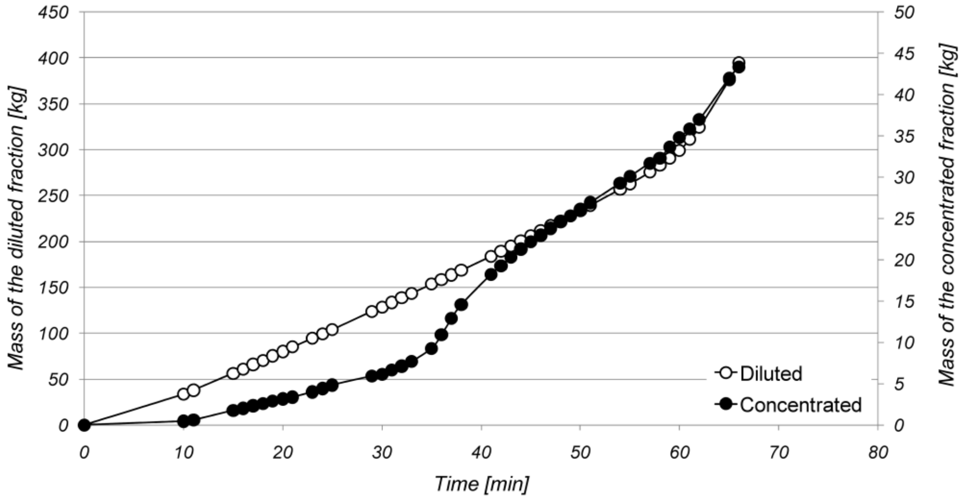

Figure 7. An example of unstable operation of the decanter centrifuge. Solid concentration = 8.9 %, feed rate = 420 kg/h, differential speed = 5 rpm.

Increasing the feed rate from the minimum (420 kg/h) to the maximum (1190 kg/h) reduces the stabilization time by several minutes. The main reason for this is faster filling of the decanter, which consequently reduces the time required to obtain a constant cake discharge rate. The influence of solid concentration and differential speed on the stabilization time is smaller, except while operated under the most difficult conditions at high solid concentration and low differential speed.

4.2 Regression analysis

Linear regression analyses were performed using Microsoft Excel and the regression models were visualized by using the LabTop software (Häkkinen *et al.*, 2009). In the models, the feed concentration was expressed as *w-%*, pump speed as *Hz*, and the differential speed as *rpm*. The models can be used for predicting the resulting productivities (*P*) and solid contents (C_S, C_L) within the examined range of the variables. The model for stabilization times is excluded because of its low correlation coefficient and a relatively poor degree of statistical significance. The linear main-effect models obtained by regression analysis for the four different responses were:

$$P\left[\frac{kg}{h}\right] = 7.49(c_{solids}) + 1.70(speed_{pump}) + 1.63(speed\ difference) - 49.75$$

$$C_s\ [\%] = 0.16(c_{solids}) - 0.073(speed_{pump}) - 0.143(speed\ difference) + 71.92$$

$$C_L\ [\%] = 0.18(c_{solids}) + 0.022(speed_{pump}) + 0.011(speed\ difference) - 0.43$$

All of the process parameters investigated had a positive effect on the productivity when increased. As the differential speed was increased, wetter cakes were obtained; this is a well-known fact about decanter centrifuges (Leung, 1998). The highest solid concentrations of the cakes were obtained at low pumping speeds, whereas the residual solids in the centrate were increased with higher feed rates. The R^2 values for productivity, cake solid content, centrate solid content, and stabilization time were 0.96, 0.89, 0.81, and 0.30, respectively. This means that the productivity could be very well predicted by the simple model and a rough prediction of solid contents of the different fractions is also possible. Based on the obtained *F*-test statistics, on the other hand, all the three variables explained differences in the results at a *p*-value lower than 0.001, which indicates a high level of statistical significance. Modeling of the stabilization time, however, could not be carried out successfully using a simple linear model and the available experimental data. Differences between the modeled and measured values of different responses are shown in Figs. 8-10, in which the diagonal lines represent ideal cases, i.e. perfect predictability by the models.

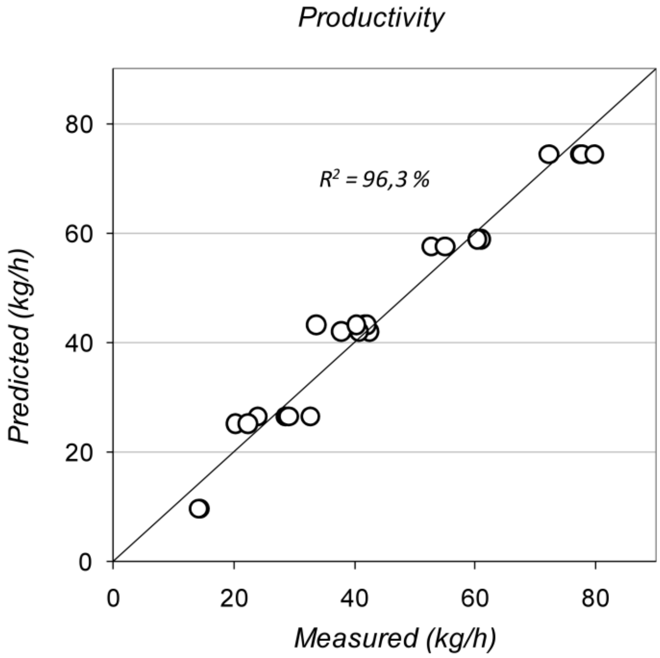

Figure 8. Measured and predicted values for the productivity.

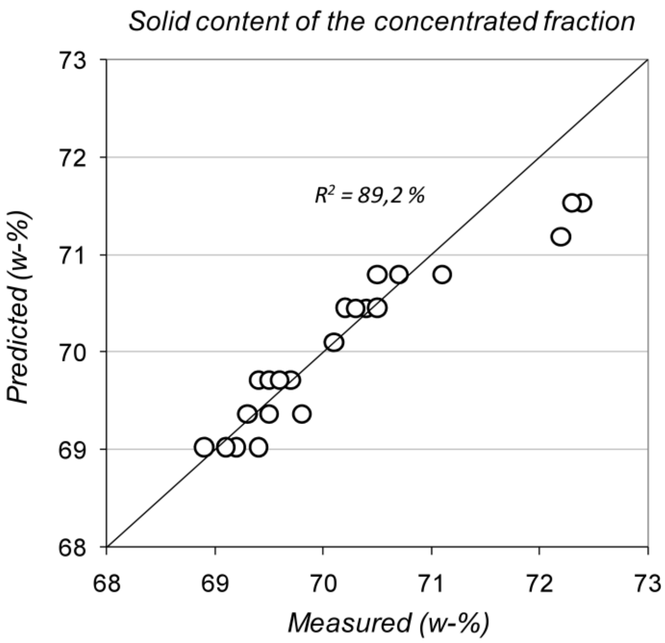

Figure 9. Measured and predicted solid contents of the cake (the concentrated fraction).

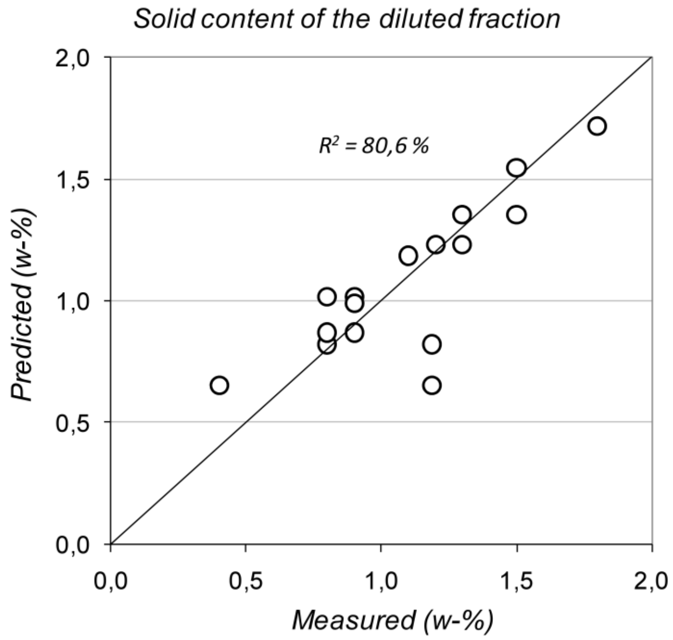

Figure 10. Measured and predicted solid contents of the centrate (the diluted fraction).

The stabilization time could not be accurately predicted by the regression model. The *p*-values used to evaluate the statistical validity of the different components in the regression model are presented in Table 1. Lower *p*-values indicate better statistical significance. It can be seen that in the case of stabilization time, the commonly used limit for statistical significance at 95 % confidence level, $p = 0.05$, is exceeded with respect to all variables.

Table 1 *p*-values obtained by regression analysis.

Variable	Productivity	Solid content of the concentrated fraction	Solid content of the diluted fraction	Stabilization time
Solid content (feed)	$7.6\cdot10^{-13}$	$5.2\cdot10^{-2}$	$7.5\cdot10^{-8}$	$5.5\cdot10^{-2}$
Pump speed	$2.1\cdot10^{-6}$	$9.9\cdot10^{-2}$	$7.2\cdot10^{-2}$	$9.9\cdot10^{-1}$
Speed difference	$3.9\cdot10^{-7}$	$9.5\cdot10^{-4}$	$2.5\cdot10^{-1}$	$2.0\cdot10^{-1}$
Intercept	$7.6\cdot10^{-10}$	$1.2\cdot10^{-30}$	$8.8\cdot10^{-2}$	$1.4\cdot10^{-3}$

A summary of the regression models is presented in Table 2, showing the influence of each variable on the productivity and solid contents of the produced fractions. The main effects of the variables on the output values were calculated by multiplying the variable range (4.2 w-%, 10 Hz, 10 rpm) by the coefficient of the variable shown in the regression equation for each output. For instance, increasing the feed solid content by 4.2 w-% (from 4.7 w-% to 8.9 w-%), would result in a value for productivity that is 31.5 kg/h higher. The stabilization time is not presented in Table 2, because its R^2 value was too low, indicating poor predictability by the model.

Table 2 Main effects of the studied variables on the productivity and on the solid contents of the cake and the liquid fraction.

Variable	Range	Main effect on productivity	Main effect on solid content of the concentrated fraction	Main effect on solid content of the diluted fraction
Feed solid content	4.7 w-% → 8.9 w-%	+ 31.5 kg_{solids}/h	+ 0.67 w-%	+ 0.76 w-%
Pump speed	10 Hz → 20 Hz	+ 17.0 kg_{solids}/h	- 0.73 w-%	+ 0.22 w-%
Differential speed	5 rpm → 15 rpm	+ 16.3 kg_{solids}/h	- 1.43 w-%	+ 0.11 w-%

An example visualization of the created regression models is presented in Fig. 11 A-C, showing the predicted productivity at different combinations of the experimental variables. As mentioned above, the productivity could be increased by increasing the differential speed and the feed rate, i.e. pump speed (Fig. 11 A-B). Therefore the maximum productivity was achieved using the highest differential speed of 15 rpm and the maximum pump speed of 20 Hz. An increase in the solid content of the feed slurry also had a positive influence on the productivity of the device (Fig. 11 B-C).

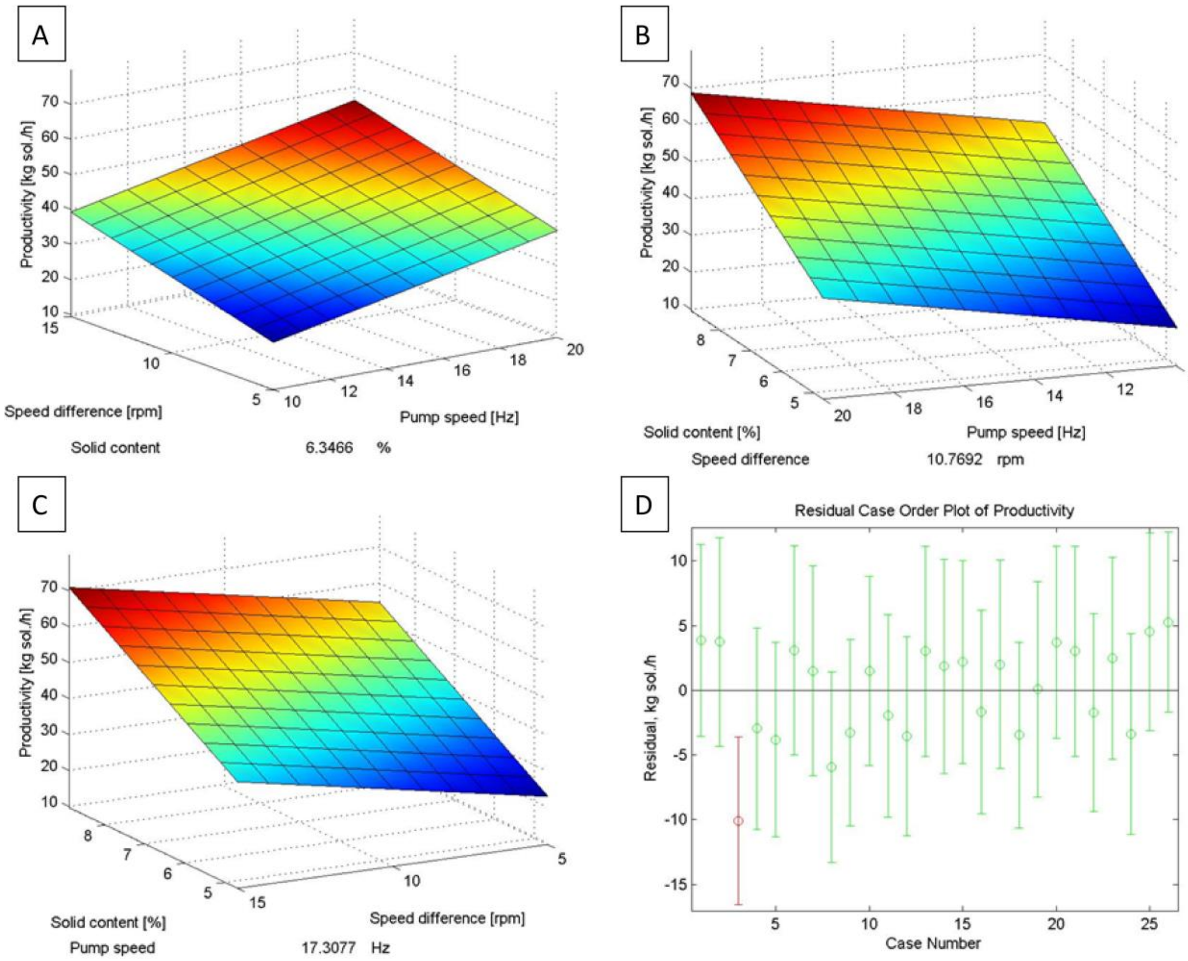

Figure 11. Visualization of the results for the productivity (A, B, C) and the residuals (D).

The residual case plot for observing potential outliers in the results is shown in Fig. 11 D, in which the horizontal line drawn at zero should lie within the range of the confidence intervals

(95 %) of the test points. According to the plot, the only clearly recognizable outlier in the case of productivity model is Test 3.

5. Conclusions

In the present study, the effect of feed solid concentration, feed rate, and differential speed between the centrifuge bowl and the conveyor screw on the operation of a pilot-scale decanter centrifuge has been investigated. The influence of these variables on the productivity, solid contents of the fractions, and stabilization time of the device has been evaluated and regression models created to analyze the results in more detail. The obtained productivity of the decanter varied quite significantly, from 14 to 80 $kg_{D.S.}$/h, whereas the solid content of the cake (69-72 w-%) was less susceptible to changes in the evaluated operational parameters. The maximum solids recovery was 90 %, which is a good result for a single-stage separation without coagulant addition.

The pilot-scale decanter centrifuge could not be properly run using combinations of the highest solids loading (8.9 % w/w) and the minimum differential speed (5 rpm). The slope of the curve for the cake product accumulation was not stabilized under these conditions. However, these difficulties could be eliminated by using higher differential speeds. The solid content of the feed was observed to have the largest impact on productivity and the required stabilization time of the device, whereas the solid content of the produced cake was most affected by the differential speed. In general, the pilot-scale decanter centrifuge was observed to be suitable for dewatering of fine-particle slurries with different solid concentrations. The solid content of the centrate was mostly influenced by the solid loading so that the highest clarities of the centrate were obtained at the lowest solid loadings. With the help of the created regression models, it was possible to predict the productivity and to roughly predict the solid contents of the cake and centrate. The linear regression model was unable to successfully predict the stabilization time.

References

Besra, L., Sengupta, D.K., Roy, S.K. 2000. Particle characteristics and their influence on dewatering of kaolin, calcite and quartz suspensions. *International Journal of Mineral Processing* 59: 89-112.

Besra, L., Sengupta, D.K., Roy, S.K., Ay, P. 2002. Flocculation and dewatering of kaolin suspensions in the presence of polyacrylamide and surfactants. *International Journal of Mineral Processing* 66: 203-232.

Besra, L., Sengupta, D.K., Roy, S.K., Ay, P. 2003. Influence of surfactants on flocculation and dewatering of kaolin suspensions by cationic polyacrylamide (PAM-C) flocculant. *Separation and Purification Technology* 30: 251-264.

Besra, L., Sengupta, D.K., Roy, S.K., Ay, P. 2004. Influence of polymer adsorption and conformation on flocculation and dewatering of kaolin suspension. *Separation and Purification Technology* 37: 231-246.

Day, N. 2005. Centrifuge focus: evaluation, testing and optimization. *Filtration & Separation* 42(6): 22-24.

Häkkinen, A., Huhtanen, M., Ekberg, B., Kallas, J. 2009. Software for improving the efficiency of test filtration tasks, *Proceedings of the 22nd Annual American Filtration & Separations Society Conference*, Bloomington, MN, USA.

Langeloh, T., Bott, R. 1996. Discharge of solids from decanting centrifuges. *Filtration & Separation* 33(8): 701-711.

Leung, W.W.-F. 1998. *Industrial centrifugation technology*. McGraw-Hill Inc., New York.

Leung, W.W.-F. 1998. Torque requirement for high-solids centrifugal sludge dewatering. *Filtration & Separation* 35(9): 883-887.

Leung, W.W.-F., Shapiro, A.H., Yarnell, R. 1999. Improvements in the classification of fine-particle slurries using decanter centrifuges. *Filtration & Separation* 36(9): 32-37.

Leung, W.W.-F., Shapiro, A.H. 1999. Dewatering of fine-particle slurries using a compound-beach decanter with cake-flow control. *Filtration & Separation* 36(10): 49-56.

Merkl, R., Steiger, W. 2012. Properties of decanter centrifuges in the mining industry. *Minerals & Metallurgical Processing* 29(1): 6-12.

Minaker, V.E. 1995. Prospects for future developments in screw-conveyor sedimentation centrifuges (decanters): a discussion. *Chemical and Petroleum Engineering* 31(4): 200-207.

Nesterovich, A.A., Kuz'min, A.G., Noskova, L.A. 1989. Intensifying dehydration in decanter screw centrifuges. *Chemical and Petroleum Engineering* 25(11): 611-614.

Records, A., Sutherland, K. 2001. *Decanter centrifuge handbook*. 1st edition. Elsevier Advanced Technology, Oxford, UK.

Sutherland, K. 2005. Centrifuge focus: solids removal – the options. *Filtration & Separation* 42(6): 16-20.

Svarovsky, L. 1981. *Solid-liquid separation*. 2nd edition. Butterworth & Co Ltd.