Korean J. Chem. Eng., **25**(5), 1165-1169 (2008)

The development of a high functional continuous filtration system for sericite powders

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(*Received 5 November 2007 • accepted 30 March 2008*)

Abstract−A cake-less continuous filtration equipment has been developed based on an evaluation of inorganic powder slurry characteristics by many kinds of measurement methods, such as a sedimentation test under gravity and a hydrostatic pressure test. We have been developing a high-performance cake-less filtration system in which a condensed inorganic powder slurry layer maintains its fluidity. The development of this novel filtration system has allowed us to cease the scraping operation of the cake as well as to collect the highly condensed slurry more easily. These results clearly show that a new device may be realized for the deposition of highly condensed, fluid slurries. It is confirmed that the concentration of the condensed slurry amounted to 35 vol% while still retaining fluidity. The specifications of our new filtration system and its operation conditions for scale-up can be determined by theoretical methods. There is good potential for successfully collecting high condensation slurry more easily in a multiple filter system.

Key words: Filtration, Hydrostatic Pressure, Rotating Disk Filter, Thickening

INTRODUCTION

Filtration may be defined as the removal of the solid particles from a fluid by passing the fluid through a filtering medium, or septum, on which the solids are deposited [1]. Thus, the basic investigation of fine particle behavior in a slurry is very important in the filtration study field. Cake filtration is widely used in industry to separate solid particles from suspensions in liquids. When the cakes are used as products in the actual field, the solid-liquid separation is associated with some problems, such as a high concentration cake, contamination with flocculants, and a batch type process of filtration. Engler et al. [2] studied the particle fouling of a rotating membrane disk, and Yang et al. [3] investigated reduction of the turbulent drag in a rotating disk system. A rotating membrane disk configuration appears to be well-suited for the treatment of feed streams at high particle concentrations. Schwille et al. [4] investigated design parameters for rotating cylindrical filtration, and Jaffrin et al. [5] compared the hydrodynamics of rotating disk and vibratory dynamic filtration systems. Koch et al. [6] compared different scraper designs for cross-flow filtration with rotating disks and cake limitation by scrapers.

The importance of filtration feed characteristics in studies of filtration systems cannot be overemphasized. Bouzerar et al. [7] studied the concentrations of mineral suspensions and industrial effluents by using a rotating disk dynamic filtration module. Tsubaki et al. [8] investigated the effect of the concentration of a polymer dispersant on the apparent viscosity and sedimentation behavior of dense slurries. Tsubaki et al. [9] analyzed the sedimentation and settling process of dense alumina slurries by hydrostatic pressure measurements and proposed a new evaluation technique for slurry characterization by constant pressure filtration. In addition, we showed that the slurry characterization and the effect of the initial height on sedimentation could be successfully described by hydrostatic pressure measurements [10]. The principal weak point of traditional dead-end filtration is the increase in the resistance as the filtration proceeds. Either type can be continuous or discontinuous, but because of the difficulty of discharging the solid against a positive pressure, most pressure filters are discontinuous [1]. To prevent the resistance from increasing, flocculants are added. By adding flocculants, the packing fraction of the cake becomes lower. Loose cake contains much water, so adding flocculants lowers the efficiency of the solid-liquid separation. The other weak points are that scraping systems are necessary and that the system must be operated in a batch process. Thus, the purpose of this investigation was to examine the optimal experimental conditions for the easy collection of high concentration slurries of test materials and to further develop the cake-less continuous filtration equipment for high concentration slurries. The flowing slurry is easy to treat in this process system. The separation efficiency is improved because of the dense nature of the slurry. This system can be operated as a continuous process because a scraper is not necessary, which allows the use of a large filtration area [11,12].

THEORY

The first proposition we have taken is that, theoretically, the cake-less filtration system considered in this study may be divided into stages, where, from top to bottom, each is designated as the 1^{st}, 2^{nd}, … and n^{th} stage. These individual stages are independent of one another, where the slurry flows downward from the top and no flow reversal takes place, as is the case for the actual filtration system. The concentration of the condensate is calculated on the basis of

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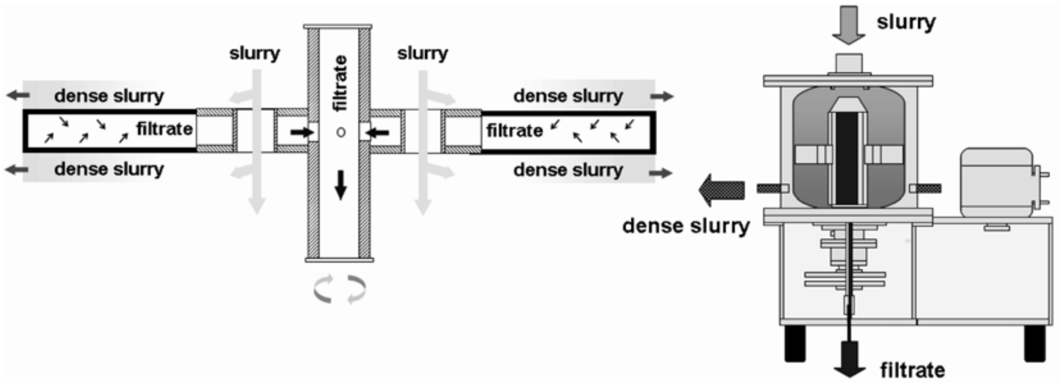

Fig. 1. The schematic diagram of a cake-less continuous filtration equipment and a filter of inner part.

the assumption that this is the volumetric concentration. Specifically, the concentration of condensate is defined as $\phi_{i,k}$ [–] and the filtration rate as $q_{i,k}$ [$m^3 \cdot min^{-1}$] in the i^{th} stage at time t_k.

Eq. (1) represents the mass balance in the i^{th} stage from time t_{k-1} to time t_k,

$$\phi_{i,k} = \phi_{i,k-1} + \frac{\phi_{i-1,k-1} v_{i,k} - \phi_{i,k-1} v_{i+1,k}}{h_i} \Delta t \quad (1)$$

where $v_{i,k}$ [$m^3 \cdot min^{-1}$] denotes the slurry feed rate from the $i-1^{th}$ stage to i^{th} stage in time t_k, and h_i [m^3] is the hold-up volume in the i^{th} stage. Δt [min] is the exchange time calculated from the expression $\Delta t = t_k - t_{k-1}$. Here, $v_{i,k}$ may be decomposed as in Eq. (2):

$$v_{i,k} = v_{i+1,k} + q_{i,k} \quad (2)$$

The slurry concentration in all of the stages prior to the start of filtration is represented by Eq. (3):

$$\phi_{i,0} = \phi_{IN} \quad (3)$$

where ϕ_{IN} is the slurry concentration to be fed. Because there is no slurry discharge when the discharge valve is closed during the condensation process, $v_{n+1,k}$ can be nullified as follows:

$$v_{n+1,k} = 0 \quad (4)$$

Hence, applying Eqs. (1)-(4) to each stage, changes in the concentrations of the condensates can be calculated. When the target concentration reaches the n^{th} stage, in order to obtain the flow rate during the steady-state continuous operation, the ultimate or outlet concentration, ϕ_{OUT}, becomes

$$\phi_{OUT} = \phi_n \quad (5)$$

In other words, ϕ_{OUT} is the final discharge or true target concentration. Then, by employing Eq. (2), the mass balance in the n^{th} stage can be expressed as follows:

$$v_n = Q_{OUT} + q_n \quad (6)$$

where Q_{OUT} [$m^3 \cdot min^{-1}$] is the discharge rate of the condensate. The mass balance in terms of the powder can be expressed by Eq. (7):

$$\phi_{n-1} = \phi_{OUT} \frac{Q_{OUT}}{v_n} \quad (7)$$

Finally, Eq. (8) can be expressed by using Eqs. (5)-(7) for each stage.

$$\frac{Q_{OUT}}{Q_{IN}} = \frac{\phi_{IN}}{\phi_{OUT}} \quad (8)$$

Here, Q_{IN} [$m^3 \cdot min^{-1}$] is the feed rate of the slurry towards the steady state. In this manner, by seeking the known values of Q_{OUT} and Q_{IN} in Eq. (8), it is possible to pursue continuous operation of the whole filtration system by maintaining constant concentration of condensates at each stage.

EXPERIMENTAL

1. Experimental Conditions

Fig. 1 shows a schematic depiction of the cake-less continuous filtration equipment used to increase the discharging rate through a centrifugal force. If we use a rotary disk filter of this type, the discharging rate and filtration rate can be individually controlled by the rotation speed and pressure, respectively. The material can be piled up on the rotary disk filter. The filter medium is sintered polyethylene with a mean pore size of 5 μm in the liquid. We used filters of this type in two sizes, a large type with outer diameter 300 mm and inner diameter 120 mm, and a small type with outer diameter 170 mm and inner diameter 65 mm.

Sericite powder (4.0 μm, SANSHINKOUKOU Co., Ltd.) and tap water were mixed to prepare test slurry. Water glass [$2SiO_2 \cdot Na_2O \cdot H_2O$, ρ=1,690 kg m^{-3}], also obtained from SANSHINKOUKOU Co. Ltd., was used as a dispersing agent. The rotation speed of the rotating filter and the filtration pressure were varied. The condensate and filtrate flowed from the respective valves. The concentration of the condensate was measured at the designated filtration time interval.

2. Filtration Tests with the New Cake-less Continuous Filtration System

Initially, it does not matter whether the condensed slurry is discharged or not. Sample slurries were prepared at 1 to 25 vol%, the feed pressure was varied from 0.1 to 0.4 MPa, and the rotation speed was controlled from 100 to 1,000 rpm. The outlet valve was closed and the filtrate valve was opened, so that the slurry in the vessel was condensed. The concentration in the vessel could be calculated from the volume of the filtrate. When the concentration exceeded 30 vol%, the outlet valve was opened; 34 vol% slurry was discharged from the outlet valve.

In the second stage, the filtration rate was measured by using the same sericite slurry. For this, the feed concentration was prepared from 0.01 to 0.03 vol%, and the filtration pressure was varied from 0.1 to 0.4 MPa. The rotation speed was controlled from 0 to 600 rpm. The outlet valve was kept closed and we measured the filtrate volume with time. When the condensed slurry concentration amounted to 35 vol%, the filtration was stopped. The slurry concentration in the vessel was increased with time. To keep the concentration constant during filtration, all experiments were performed by following the same procedure. Next, a certain amount of the concentrated slurry was fed into the vessel and the disk was rotated at a certain speed. Water was then introduced at a certain pressure. The outlet valve was closed and the filtrate did not contain any particles. The concentration in the vessel was kept constant during filtration.

RESULTS AND DISCUSSION

Fig. 2 shows the relationship between the filtration time and the concentration of the condensate. The slurry concentrate was prepared at 25 vol% and fed at 0.5 MPa. The concentration of the condensed slurry in the vessel was measured. It could be confirmed that the concentration of the condensed slurry reached 35 vol% while retaining its fluidity.

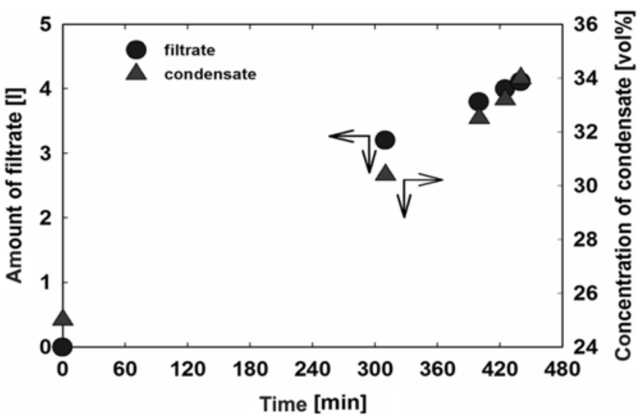

Fig. 2. The relationship between the filtration time and the concentration of condensate.

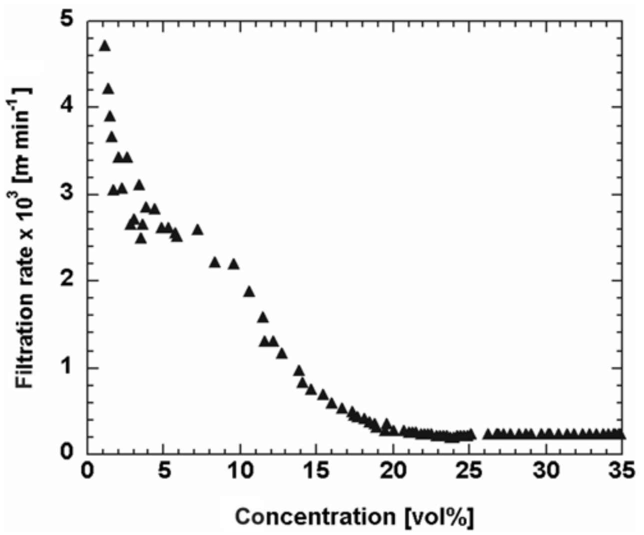

Fig. 3. The relationship between the filtration time and the filtration rate.

Fig. 3 shows the relationship between the filtration time and the filtration rate. We calculated the slurry concentration in the vessel from the population balance in this experimental result. The filtration rate is affected not only by the slurry concentration, but also by clogging of the filter, the filtration pressure, and the rotation speed of the disk.

Fig. 4 shows that the experimental value of the filtration pressure was 0.1 MPa. The rotation speed was changed from 0 to 400 rpm, where 0 rpm corresponds to dead-end filtration. In the case of 0 rpm rotation speed, the decrease in the filtration rate is due to cake formation. When the disk is rotated, the filtration rate also decreases with time. However, after about ten minutes, the filtration speed does not change further. Since cake formation was not observed,

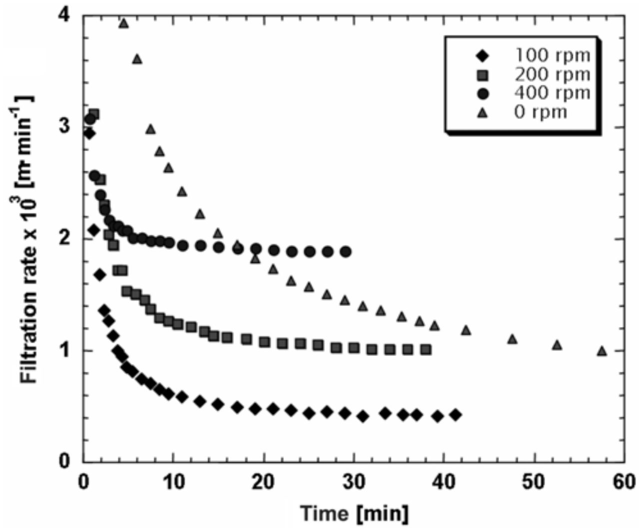

Fig. 4. The filtration under the constant slurry concentration.

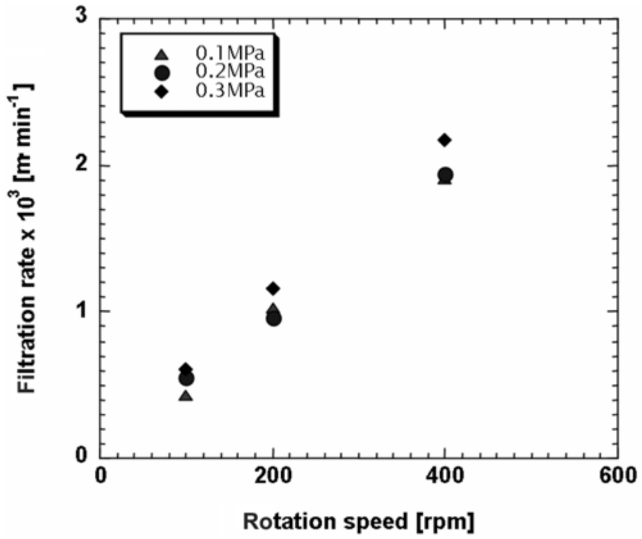

Fig. 5. The relationship between filtration rate and rotation speed of disc.

the decrease in the filtration rate must have been due to clogging. The rotation speed strongly affects the filtration rate.

At first, we thought about confinement of the filter medium. The decrease of the filtration speed (increase of filtration resistance) is seen in the thing which gave it a turn with all the pressure from a filtration start within 10 minutes. Because the formation of a cake was not confirmed after the end of the experiment, it is thought that the decrease in the filtration speed resulted from the confinement of the filter medium. However, it seems that it was not a big problem in an objective book study to run a lower filtration speed that confines the filter medium, except for the filtration in the initial stage because the filtration speed remains constant for a long time.

Fig. 5 shows a graphical overview of the relationship between the filtration rate and the rotation speed of the disk. The filtration rates increase with the rotation speed and do not depend on the filtration pressure. In the case of dead-end filtration, the filtration pressure controls the filtration rate. However, in this study, the system rotation speed seems to dominate the filtration rate. It was confirmed that the filtration speed was increased with an increase of rotation speed. When the rotation speed was increased, the centrifugal force was increased, and so a particle on the filter medium surface would have been more easily removed. It is thought that under these conditions the filtration speed would have been increased. Usually, the filtration speed becomes faster the higher the pressure of the filtration. However, in the case of sericite, which is a peculiar scale-shaped filterable material, it is thought that the removal of particles from the filter medium surface by the centrifugal force has a greater promoting effect on the filtration speed than does maintaining a high pressure.

Fig. 6 shows the experimental result which was operated in this study system in a single stage. The concentration in the vessel must be the same as the outlet concentration. The system thus has to be operated under low filtration conditions. However, in the case of a multi-stage system, filtration can be carried out at a low concentration, and so the filtration rate can be increased and hence also the throughput. The concentration at each stage can be calculated from

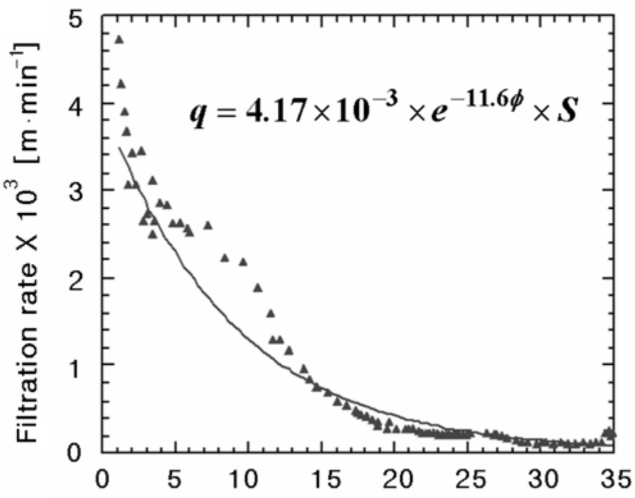

Fig. 6. The relationship between filtration rate and condensate concentration.

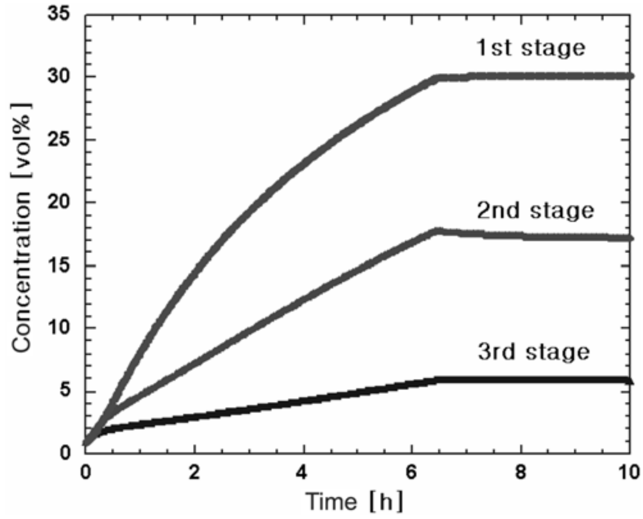

Fig. 7. The relationship between condensate concentration and filtration time by simulation.

the experimental data and mass balance model.

Fig. 7 shows an example of a three-stage system by theory consideration. The new filtration system, the specification of the system, and the operation conditions can be determined from a pre-filtration test.

CONCLUSIONS

It has been demonstrated that if particles are well dispersed, a condensed slurry obtained by filtration can be drained without the use of a scraper. We have demonstrated the development of a cake-less high concentration continuation filtration system. Moreover, we have tested the concentration of sericite slurries, a material which is known to be difficult to filter. A condensed slurry of high density yet still showing fluidity was collected. It could be confirmed that the concentration of this condensed slurry was about 35 vol%. In addition, the filtration speed in a single-step concentration experiment using the cake-less filtration system was seen to increase with an increase in the rotation speed of the disk filter. We have demonstrated that the density change of the cake-less continuous filtration system may be quantitatively predicted, and it is established that a simulation technique could be designed with a capacity and a filtration area among filters depending on the objective throughput and density. Also, the effectiveness of performing a filtration operation with a three-stage system has been demonstrated.

ACKNOWLEDGMENTS

The authors acknowledge the "Japanese Minister of Economy, Trading and Industry" and the "Regional R&D Consortium Project" for financial support of this work.

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