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EVALUATION OF HYPERBARIC FILTRATION FOR FINE COAL DEWATERING

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OBJECTIVES AND SCOPE OF WORK

The main objectives of the project are to investigate the fundamental aspects of particle-liquid interaction in fine coal dewatering, to conduct laboratory and pilot plant studies on the applicability of hyperbaric filter systems and to develop process conditions for dewatering of fine clean coal to less than 20 percent moisture.

The program consist of three phases, namely

- Phase I - Model Development
- Phase II - Laboratory Studies
- Phase III - Field Testing

The Pennsylvania State University is leading efforts in Phase I, the University of Kentucky in Phase II, and Consol Inc. in Phase III of the program. All three organizations are involved in all the three phases of the program. The Pennsylvania State University is developing a theoretical model for hyperbaric filtration systems, whereas the University of Kentucky is conducting experimental studies to investigate fundamental aspects of particle-liquid interaction and application of high pressure filter in fine coal dewatering. The optimum filtration conditions identified in phase I and II will be tested in a Consol Inc. coal preparation plant using an Andritz Ruthner portable hyperbaric filtration unit.

INTRODUCTION

Most of the coal presently used by the utility industry is cleaned at preparation plants employing wet processes. Water, while being the mainstay of coal washing, is also one of the least desirable components in the final product. Coarse coal (+3/4 inch) is easily dewatered to a 3-4 percent moisture level using conventional vibrating screens and centrifuges. However, the main problem of excess product moisture occurs in fine (minus 28 mesh) coal and refuse. Even though fines may constitute only about 20 percent of a contemporary cleaning plant feed, they account for two-thirds of the product surface moisture. This high surface moisture offsets many of the benefits of coal cleaning, and can easily undercut the ongoing programs on recovery of fine clean from refuse as well as producing an ultra-fine super clean coal fuel.

Currently, most of the coal preparation plants utilize vacuum disk or drum filter technology for dewatering of the fine coal, providing dewatered product containing about 25 percent moisture. The coal industry would prefer to have a product moisture in the range of 10 to 15 percent. Although the desired product quality can be obtained using thermal dryer, there are problems associated with this technology such as high capital costs and the greatest potential source of air pollution in a coal cleaning plant.

In the present research project, an alternative to thermal drying, hyperbaric filtration which has shown potential in lowering moisture content in fine coal to less than 20 percent level, is being investigated in detail. The project will develop fundamental information on particle-liquid interaction during hyperbaric filtration and

apply the knowledge in developing optimum conditions for the pilot plant testing of the hyperbaric filter system.

APPROACHES AND PROGRESS

Phase 1 - Model Development

Dewatering model

The development of a fundamental model for filter cake dewatering by gas displacement was presented in the last progress report (September, 1993). The theoretical treatment leads to the following relationship between dimensionless dewatering time T and the saturation $S(r)$ of pores of radius r :

$$S(r) + S_{\infty}(r) \ln \left(\frac{S(r) - S_{\infty}(r)}{S_B(r) - S_{\infty}(r)} \right) - S_B(r) = T_B - T \quad (1)$$

$S_{\infty}(r)$ is the limiting saturation for pores of size r , and is given by

$$S_{\infty}(r) = \frac{2\gamma \cos \theta}{r\Delta p_o} \quad (2)$$

$S_B(r)$ is the saturation of pores of size r at the time when gas first begins to break through the cake:

$$S_B = \sqrt{1 - \frac{r(r-r^*)}{r_m(r_m-r^*)}} \quad (3)$$

r^* is the radius for which the capillary pressure is equal to the applied pressure.

(Note: Equation 3 was incorrectly formulated in the September 1993 Report (Equation 6)). T_B is the dimensionless time corresponding to the initial gas breakthrough.

As pointed out previously, the overall cake saturation is given by integration over all pore sizes, i.e.,

$$S = \int_0^{r_m} S(r) f(r) dr \quad (4)$$

where $f(r)$ represents the pore size distribution. The cake moisture content M can then be calculated using

$$M = \frac{1}{1 + \rho_s(1-\epsilon)/\epsilon\rho_w S} \quad (5)$$

where ρ_s and ρ_w are the densities of the solid and liquid, respectively and ϵ is the fractional porosity of the cake.

Process Simulations

Equations 1-5 provide the basis for mathematical simulation of the dewatering process. However, because of the implicit form of the relationship for $S(r,t)$ given by Equation 1, the solutions must be obtained by numerical methods. The following procedure was used:

- i) Assume a maximum pore radius r_m and define the pore size distribution $f(r)$.
- ii) Calculate the fixed parameters r^* , and t_B for the specific conditions (pressure, surface tension, etc.) being considered.

- iii) Divide the pore size range into 100 equal intervals, and determine the values of S_g and S_∞ for each.
- iv) Select the appropriate time steps ($t > t_g$) and determine the corresponding values of $S(r)$ by an iterative procedure using Equation 1.
- v) Determine the overall cake saturation at each time by numerical integration of Equation 4.

Pore size distributions were assumed to conform to a truncated log-normal form such that

$$f(r) = \begin{cases} \frac{K}{r\sqrt{2\pi \ln \sigma}} \exp\left[-\frac{1}{2} \left(\frac{\ln r/r_{50}}{\ln \sigma}\right)^2\right] & \text{for } r \leq r_m \\ 0 & \text{for } r > r_m \end{cases} \quad (6)$$

where r_{50} is the median pore size, σ is the log-normal standard deviation and K is the normalization factor needed to compensate for truncation of the distribution. The value of K was determined from the normalization condition:

$$\sum_{i=1}^{100} f_i = 1 \quad (7)$$

where the f_i values are obtained from Equation 6 using

$$f_i = \frac{1}{2} (f(r_i) + f(r_{i-1})) \quad (8)$$

To ensure comparability among the simulation results, the pore size distributions were constrained with respect to the cake porosity and the specific surface area of the particles in the cake. Obviously, both the total pore volume and the pore size distribution depend on packing in the cake. Specific surface area, on

the other hand, is determined primarily by the particle characteristics and should be relatively independent of packing.

It was shown in the previous report (September 1993) that the volume specific surface area S_v is given by:

$$S_v = \frac{2\epsilon}{(1-\epsilon)} \int_0^{r_m} \frac{f(r) dr}{r} \quad (9)$$

In order to simulate the effects of packing on the dewatering of a given solid, values for the overall porosity ϵ and the pore size distribution parameters r_{50} and σ were selected so as to maintain constant surface area S_v .

The predicted effects of applied pressure on the dynamics of cake dewatering are illustrated in Figures 1 and 2 which are plots of residual saturation S and moisture content M (calculated using Equation 5), respectively. As would be expected, increased pressure leads to an increase in both the rate and extent of dewatering. Comparison with typical experimental data, suggests that the model may be overestimating both rate and extent. It should be pointed out, however, that the current model neglects tortuosity in the pore structure (which would reduce the dewatering rate) and the existence of residual water films on particle/pore surfaces (which would reduce the extent of dewatering). Modifications to the model, to account for these effects are currently being considered.

The role of particle packing in the cake is examined in Figures 3-8. Figures 3 and 4 illustrate the effects of the mean pore size and the width of the pore size distribution at fixed overall porosity. The results seem to suggest an optimum pore

Figure 1. Effect of applied pressure on the kinetics of dewatering (expressed as cake saturation S) for a 1 cm thick filter cake with a median pore radius of $4\ \mu\text{m}$, standard deviation of 1.5, specific surface area $3619\ \text{cm}^{-1}$ and porosity 0.4.

Figure 2. Effect of applied pressure on the kinetics of dewatering (expressed as residual moisture content M) for a 1 cm thick filter cake with a median pore radius of $4 \mu\text{m}$, standard deviation of 1.5, specific surface area 3619 cm^{-1} and porosity 0.4.

Figure 3. Effect of pore size distribution parameters, r_{50} and σ on the kinetics of dewatering (expressed as cake saturation S) for a 1 cm thick cake with specific surface area 3619 cm^{-1} , porosity 0.4 and applied pressure 50 psi.

Figure 4. Effect of pore size distribution parameters, r_{50} and σ on the kinetics of dewatering (expressed as residual moisture content M) for a 1 cm thick cake with specific surface area 3619 cm^{-1} , porosity 0.4 and applied pressure 50 psi.

size distribution. However, further evaluation of the effects of the somewhat arbitrary truncation of the distribution is necessary before the existence of such optima can be validated.

The effects of overall porosity ϵ are shown in Figures 5 and 6 for the case of fixed mean pore radius and in Figures 7 and 8 for pore size distributions of fixed width. Interpretation of these results in terms of the potential for controlling cake structure to aid in dewatering are currently in progress.

Phase II - Laboratory Studies

Baseline dewatering study with the Pittsburgh seam coal froth was conducted using a high pressure bench scale equipment. The main accomplishments during this period included measurements of the air consumption at various filtration conditions and investigations of the effects of filtration time, applied pressure and cake thickness on final moisture content of the filter cakes.

Measurement of Air Consumption

The original filtration/dewatering set-up was modified to measure the air throughput of dewatering experiments. Wet Test Meter was connected with a closed box which seals the filtration cell as shown in Figure 9. The air passed through the filter cake enters the Wet Test Meter resulting in an indication of amount of air consumed during the experiments as a unit of volume. The results are normalized in the following manner:

Figure 5. Effect of overall porosity on the kinetics of dewatering (expressed as cake saturation S) for a 1 cm thick cake with specific surface area 3619 cm^{-1} , a fixed mean pore radius of $4 \text{ }\mu\text{m}$ and applied pressure 50 psi.

Figure 6. Effect of overall porosity on the kinetics of dewatering (expressed as residual moisture content M) for a 1 cm thick cake with specific surface area 3619 cm^{-1} , a fixed mean pore radius of $4 \mu\text{m}$ and applied pressure 50 psi.

Figure 7. Effect of overall porosity on the kinetics of dewatering (expressed as cake saturation S) for a 1 cm thick cake with specific surface area 3619 cm^{-1} , fixed pore size standard deviation of 1.5 and applied pressure 50 psi.

Figure 8. Effect of overall porosity on the kinetics of dewatering (expressed as residual moisture content M) for a 1 cm thick cake with specific surface area 3619 cm^{-1} , fixed pore size standard deviation of 1.5 and applied pressure 50 psi.

Figure 9. Modified filtration/dewatering set-up

$$\text{Air Consumption} = \frac{\text{Air Volume}}{(\text{Filtration Area}) (\text{Time}) (\text{Dry Solid})} \left[\frac{\text{m}^3}{\text{m}^2 \cdot \text{min} \cdot \text{kg}} \right]$$

Effect of Filtration Time

The effects of filtration time on moisture content of the filter cake and air consumption are shown in Figures 10-12 using three different pressures and cake thicknesses. The filtration time was varied from 10 to 250 seconds. It was found that for any given pressure and cake thickness the residual cake moisture decreases continuously over range of filtration time from 10 to 180 seconds except for 1.0 cm thick cake. Beyond 180 seconds, moisture remained approximately constant. On the other hand, the air throughput rises with enhanced dewatering at any given pressure and cake thickness, due to the increasing gas permeability. The air consumption increases significantly beyond 90 seconds of filtration time with a cake thickness of 1.0 cm. Note, that 3 minutes filtration time with 1.5 cm thick cake at 70 psi provided a filter cake containing about 24 percent moisture and air consumption of 6 m³/(m².min.kg).

Effect of Applied Pressure

The data shown in Figures 10-12 are replotted in the form of moisture content against applied pressure for a given 3 minutes of filtration time. The results are shown in Figure 13. It was observed that increasing the pressure from 40 to 70 psi reduced moisture from 27 to 21 percent for a 1.0 cm thick cake. For higher cake thickness of 2.0 cm, moisture was reduced from 65 to 44 percent by increasing the pressure from

Figure 10. Effect of filtration time at 40 psi

Figure 11. Effect of filtration time at 70 psi

Figure 12. Effect of filtration time at 90 psi

Figure 13. Effect of applied pressure on moisture content at 3 minutes

40 to 70 psi. For the 2 cm thick cake, no further moisture reduction was observed by increasing the pressure to 90 psi.

Effect of Cake Thickness

The effect of cake thickness on moisture content of the filter cake is depicted in Figure 14 using various applied pressures. For a higher given driving force, i.e. above 40 psi, the final moisture content of the filter cake was not considerably improved over the range of 1.0 to 1.5 cm cake thickness.

Overall, it was found that a filtration time of 180 seconds, an applied pressure of 70 psi and a cake thickness of 1.5 cm provided most effective dewatering products of Pittsburgh No.8 coal sample based on cake moisture and air consumption.

Phase III - Field Testing

No activities were conducted.

FUTURE WORK

- Dewatering study with the Pittsburgh No.8 coal froth will be further advanced. The variables to be investigated will be slurry pH and concentration and filtrate viscosity (temperature).
- For flocculant-assistant filtration and dewatering studies, the following parameters will be involved; mixing speed and time, additive dosage, charge density and air consumption.

Figure 14. Effect of cake thickness on moisture content at 3 minutes

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