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EVALUATION OF HYPERBARIC FILTRATION FOR FINE COAL DEWATERING

DOE Grant No. DE-^{FG}PS22-92PC925⁵~~20~~

Third Quarterly Technical Progress Report
(March 1, 1993 - May 31, 1993)

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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 will lead the effort in Phase I, the University of Kentucky in Phase II, and Consol Inc. in Phase III of the program. All three organizations will be involved in all the three phases of the program. The Pennsylvania State University will develop a theoretical model for hyperbaric filtration systems, whereas the University of Kentucky will conduct experimental studies to investigate fundamental aspects of particle-liquid interaction in fine coal dewatering. Finally, the optimum filtration conditions identified through both phases 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 disk type technology for dewatering of the finecoal, 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 by using thermal dryers, there are problems associated with these equipments 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. This

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 I Model Development

The basis for a model for dewatering of filter cake by gas displacement was described in an earlier report (March 1993). The essence of the model is that water is driven out of the pores in response to the applied gas pressure until breakthrough occurs in the largest pores present.

Prior to breakthrough, it is reasonable to assume that the applied pressure differential acts entirely across the gas-liquid interface in the pores. At the same time, the applied pressure is opposed by the capillary pressure P_c in the pore. For a pore of effective radius r , the latter is given by

$$P_c = \frac{2\gamma\cos\theta}{r} \quad (1)$$

where γ is the liquid surface tension and θ is the contact angle at the solid-liquid interface. For a cake of thickness L with pressure P_1 above and P_2 below, the effective pressure gradient driving liquid out of a pore at a given instant is $(P_1 - P_2 - P_c)/(L - z)$ where z is the location of the gas-liquid interface at that particular time (see Figure 1).

The flow velocity in the pore can be estimated using Poiseuille's law, i.e.

$$v = \frac{r^2(P_1 - P_2 - P_o)}{8\mu(L-z)} \quad (2)$$

where μ is the liquid viscosity. By definition,

$$v = \frac{dz}{dt} \quad (3)$$

Combining Equations 2 and 3 and solving the resulting differential equation subject to the initial condition:

$$z = 0, \text{ when } t = 0$$

leads to

$$z(2L-z) = \frac{r^2(P_1 - P_2 - P_o)t}{4\mu} \quad (4)$$

Breakthrough occurs when $z=L$. Initial breakthrough occurs in the largest pores present ($r=r_m$) at time t_B given from Equations 1 and 4 by

$$t_B = \frac{4\mu L^2}{r_m(\Delta P_o r_m - 2\gamma \cos\theta)} \quad (5)$$

where ΔP_o is the applied pressure drop ($=P_1-P_2$). Examples of calculated breakthrough times for a 1 cm thick cake are given in Table 1.

Table 1. Breakthrough times in pressure dewatering

Applied Pressure ΔP_o (psi)	Breakthrough Time (sec) in Pore of Radius:		
	10 μ m	20 μ m	50 μ m
10	0.07	0.020	0.002
15	0.044	0.010	0.0016
30	0.020	0.005	0.0008
50	0.012	0.003	0.0005
70	0.0085	0.0021	0.0003
90	0.0066	0.0016	0.0003

Following breakthrough, it is assumed that gas flow leads to a linear pressure gradient along the empty pores which, because of interconnection among all pores, gives rise to a linear gradient across the entire bed. Thus, for the system defined in Figure 1, the pressure $P(z)$ at location z below the upper surface will be

$$P(z) = P_1 - \frac{z}{L}(P_1 - P_2) \quad (6)$$

For a pore of effective radius r which is partially filled with liquid to the level z , the driving force for further dewatering is the effective pressure drop, including the capillary pressure term, given by

$$\Delta P = \Delta P_o \left(1 - \frac{z}{L}\right) - \frac{2\gamma \cos \theta}{r} \quad (7)$$

Such a pore will be subject to continued dewatering until ΔP_e is reduced to zero, i.e., when z reaches its limiting value, z_m , given by

$$z_m = L \left(1 - \frac{2\gamma \cos \theta}{r \Delta P_o}\right) \quad (8)$$

At this point, flow of liquid from the pore ceases leaving a residual saturation in the pore

$$S(r) = 1 - \frac{z_m}{L} = \frac{2\gamma \cos \theta}{r \Delta P_o} \quad (9)$$

The overall residual saturation of the bed can then be obtained by integration over all pore sizes. Thus

$$S = \int_0^{r_m} S(r) f(r) dr \quad (10)$$

where the pore size distribution $f(r)$ is defined such that:

$f(r)dr$ = volume fraction of pores which have effective radius between r and $r+dr$.

Substitution from Equation 9 leads to

$$S = \frac{2\gamma \cos \theta}{\Delta P_o} \int_0^{r_m} \frac{f(r) dr}{r} \quad (11)$$

The residual moisture content M (expressed on a weight basis) is related to the saturation S through

$$M = \frac{\rho_e \epsilon S}{\rho_e \epsilon S + \rho_s (1 - \epsilon)} \quad (12)$$

where ρ_e and ρ_s are the respective liquid and solid densities and ϵ is the cake porosity.

Some estimates of residual (limiting) saturation and moisture content for a coal filter cake containing 35% -325 mesh material are given in Table 2. At this stage, the estimates were obtained using reasonable approximations to the pore size distribution. Further investigation of pore size relationships in filter cakes are in progress.

It is clear from Table 2 that the model presented here can provide reasonable predictions of dewatering behavior in pressure filtration. Extension of the model for analysis of dewatering rates is also in progress.

Table 2. Residual saturation and cake moisture content in pressure dewatering.

Applied Pressure ΔP_o (psi)	Residual Saturation (%)	Moisture Content (%)
10	79.8	34.7
15	53.0	26.2
30	26.6	15.1
50	16.0	9.6
70	11.4	7.1
90	8.9	5.6

PHASE II Laboratory Studies

The main accomplishments during this period include modification of the experimental set-up for preventing particle segregation during cake formation, evaluation of the pressure filter system and development of optimum process conditions for dewatering of fine clean coal.

- System Modification

Dewatering studies are being conducted on a froth floated Illinois No.6 coal sample supplied by Consol Inc.. During formation of a filter cake, significant segregation of particles in different layers of the cake was observed due to presence of a large amount (about 45 weight percent) of +100 mesh particles. Smaller particles were found near the top of the cake and larger particles were found at the bottom of the cake. The effect of segregation of particles will result in a cake of non-uniform structure with a wide variation of filtration properties from one layer to another. In general, the cake with non-uniform structure exhibits a lower filtration rate than the cake with uniform structure due to smaller pore size in the top layer of the cake.

A novel modified pressure filtration technique was developed which provided agitation during cake formation to avoid segregation of large and small particles and to simulate actual plant conditions encountered during pressure filtration of the slurry. The modified pressure cell as well as schematic diagram of the instrumented filtration/dewatering apparatus are shown in Figure 2. Morphology of the cake structure was studied using image analysis of the in-situ formed consolidated filter cakes. A mixture of epoxy system consisting of a resin (No. 20-8130) and a hardener (No. 20-8132), both supplied by Buehler Inc., and acetone with volume ratio of 3:1:4 was used as a consolidating agent. After consolidation, the filter cakes were sectioned and polished for the image analysis. Pictures of the filter cakes formed with and without agitation of the slurry are shown in Figure 3. The size analysis of three different layers, i.e., top, middle and bottom layers, is given in

Figure 4. It is seen that the cake obtained using agitation during cake formation produced a more uniform cake structure.

● System Evaluation

For the purpose of system evaluation, experiments were conducted with and without agitation during filtration as functions of filtration time, cake thickness and applied pressure. Figure 5 shows effect of filtration time on cake moisture with and without agitation. For the period of cake formation time the filtration without agitation leads to faster rate and shorter cake formation time than that with agitation. Also, agitating slurry provides a lower moisture cake. Note, at the time of cake formation the cake formed by agitation contains somewhat lower moisture than that of unagitated cake. This is due to the fact that an uniformly distributed particles led to more compact packing in cake structure resulting in less porosity of cake. It was seen that the filtration with agitation was more effective during dewatering cycle of the filtration/dewatering process.

Effect of cake thickness on moisture content with and without agitation is given in Figure 6. With a cake thickness of 0.8 cm, the filter cake moisture was reduced by about 4 percent by weight over that observed in the absence of agitation. Moisture was reduced from 26.7 to 25.2 percent with agitation at a cake thickness of 2.8 cm.

Figure 7 depicts the effect of applied pressure on residual moisture content of the filter cake with and without agitation. It was observed that moisture of the filter cake formed by agitation was decreased from 3 to 6

percent compared to that obtained using unagitated filter cake, over the pressure range of 20 to 100 psig.

Overall, it was found that the cake formed using the new modified equipment set-up provided uniform structure which prevented segregation of particles and thus improved filtration and dewatering properties of the cake. The improvements in filtration and dewatering properties are reflected in lower final moisture content of the filter cake.

- Development Optimum Process Conditions

For the investigation of optimum process conditions for dewatering of the fine clean coal, filtration experiments were carried out using the new improved filtration set-up. The filtration variables studied included filtration time, applied pressure and cake thickness. The filtration time was varied from 10 to 180 seconds; the driving force was altered from 40 to 80 psig; and the cake thickness was changed from 0.8 to 2.8 cm.

The effect of filtration time on moisture content of the filter cake is shown in Figure 8 using three different pressures and cake thicknesses. 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 120 seconds except a 0.8 cm thick cake at 40 psig. Beyond 120 seconds, moisture remained approximately constant. The data shown in Figure 8 are replotted in the form of cake moisture against applied pressure and cake thickness for a given 120 seconds of filtration time in Figures 9 and 10, respectively. When the pressure was increased from 60 to 80 psig the reduction of the cake moisture was found to be insignificant for different constant cake thickness.

The final moisture content of the filter cake was not considerably improved over the range of 0.8 to 2.0 cm cake thickness for applied pressure of both 60 and 80 psig. Overall, it was found that a filtration time of 120 seconds, an applied pressure of 60 psig and a cake thickness of 2.0 cm provided most effective dewatering of Illinois No.6 coal sample.

PHASE III Field Testing

No activities were conducted.

FUTURE WORK

- Three different types of flocculants with the same molecular weight and ionic charge density obtained from American Cyanamid Co. will be used in flocculant-assisted filtration studies.
- For additive-assisted filtration and dewatering investigations the following variables will be involved; mixing condition, surface tension, contact angle and additive dosage.
- Statistical experimental design on filtration will be employed to identify significant variables and the interactive effect of these variables in order to reduce the large number of experiments required.

Before Breakthrough **Following Breakthrough**

Figure 1. Pressure distributions during dewatering of filter cake

Figure 2. Filtration/dewatering apparatus

Without Agitation

Top

Middle

Bottom

With Agitation

Figure 3. Photomicrographic analysis of -28 mesh coal filter cake

Figure 4. Mesh size analysis of -28 mesh coal filter cake

Figure 5. Effect of filtration time on cake moisture with and without agitation

Figure 6. Effect of cake thickness on cake moisture with and without agitation

Figure 7. Effect of applied pressure on cake moisture with and without agitation

Figure 8. Determination of optimum process condition for filtration time

Figure 9. Determination of optimum process condition for applied pressure

Figure 10. Determination of optimum process condition for cake thickness

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