Dewatering of fine coal and refuse slurries—problems and possibilities

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Abstract

Dewatering of fine clean coal and refuse slurry is one of the most important aspects of coal cleaning scenario. It is also adds significant cost to the price of clean coal. This article summarizes the current state-of-the-art of dewatering being practiced around the world and discuses some of the upcoming novel dewatering technologies. Hyperbaric filter provides a low moisture product for fine coal slurries. For fine coal refuse slurries the Deep Cone Thickener provides dewatered product containing 50 percent solids. The article also discusses economics of dewatering, which is about $3.30/t for fine clean coal slurries.

Keywords: dewatering; drying; centrifuge; economics

1. Introduction

For the United States of America, it is forecasted that coal will constitute a principal source of energy for the next several decades. A typical coal preparation plant produces about 20 percent of the mined coal as minus 0.5 mm (28 mesh). Generally, this fine fraction is discarded due to its high cost of processing. However, with the development of advanced coal cleaning technology, such as column flotation, cleaning of fine size coal to low ash and low pyritic sulfur is feasible at high recovery. One of the biggest hurdles in utilization of fine coal cleaning technology by the coal industry is the economic dewatering of the fine clean coal product. Until an economical and practical solution to dewatering of fine clean coal is achieved, the efforts devoted to developing fine clean coal technology will be wasted.

For particles larger than 0.5 mm (28 mesh) size no particular dewatering problem is encountered, however, particles finer than 0.5 mm are the most difficult to dewater. Even though, vacuum filtration can provide a product containing 25% to 30% moisture content, most of the coal preparation plants utilize screen bowl centrifuge to dewater fine coal by combining fine coal with the coarse coal. Because of this widely used practice of dewatering of fine coal, certain amount of ultra fine clean coal is lost as screen bowl centrifuge overflow. Also, the screen bowl drain which is re-circulated contains about 20% to 25% solids which reduces plant performance and capacity. Similarly, the fine refuse containing about 2 to 3% solids is dewatered in a conventional thickener to about 30% solids and discharged in an impoundment. Maintenance of impoundment is costly and its breakage could be detrimental to environment as well as life.
1.1. Why to remove water from clean coal or refuse slurries?

Water present in clean coal is a contaminant and reduces heat content of the coal. It is estimated that every one percent moisture in clean coal is equivalent to ~4% ash. Moisture adds to the transportation cost as well as handling problems. In case of refuse slurry, a significant amount of land and water gets tied up with the slurry disposal and also a significant amount of water is lost due to seepage and evaporation. Breakage of the slurry dams creates a substantial loss of property and sometimes human lives.

2. Background

Although the term “dewatering” refers to removal of water, researchers have used different terms and descriptions to define water associated with particles. Tschamler and Ruiten (1) classified five types of water associated with coal, including interior adsorption, surface adsorption, capillary, interparticle and adhesion water. The last three types of water are termed as “free” water and are potentially removable by mechanical techniques. However, the first two types of water, known as “inherent” moisture, can only be removed by energy intensive techniques such as thermal drying. A variety of techniques are now used in contemporary practice for dewatering coal. The type and efficiency of various dewatering equipment varies as a function of particle size.

The degree of difficulty associated with mechanical dewatering increases as the surface area of the particles increases. Particles finer than 0.5 mm (28 mesh) present the greatest dewatering problem due to a large surface area of the particles. There has been a rapid increase in research and technology involving developments to improve fine-coal dewatering. Parekh et al. (2) have published a review on fine coal and refuse dewatering which also included new dewatering technologies being developed in dewatering of fine coal.

Two important aspects of dewatering fine coal are the dewatering rate and the final moisture content of the product produced; the most desirable conditions would be to have a fast dewatering or filtration rate and low product moisture. Filtrate clarity is not of primary importance in coal applications because filtrate water and any solids in it are generally re-circulated within the dewatering circuit. Theoretical treatment of the dewatering process has concluded that product moisture, or residual moisture as it is sometimes termed, is reduced while the dewatering rate is increased with increasing driving force (gravity, vacuum or pressure), permeability of the medium (filter cloth and filter cake), contact angle or hydrophobicity, filter area. The other avenue is to decrease surface tension or viscosity of the filtrate, and cake thickness.

When considering these factors, the driving force, medium permeability and filter area will be determined by the dewatering device used. The other parameters are properties of the slurry to be dewatered and can be controlled by the use of chemical additives. The interconnected voids or pores in filter cakes form irregular capillary tubes. This analogy is frequently used in soil mechanics to describe the pore structure of soils. If one considers the cake structure to simplistically be a bundle of capillary tubes, residual saturation can be related to capillary rise or the level of water within a capillary tube. The Capillary rise formula is:

\[ h = \frac{2\gamma \cos \theta}{g \rho R} \]  

Where \( h \) is the capillary rise, \( \gamma \) is the liquid/air surface tension, \( \theta \) is the liquid/solid contact angle, \( R \) is the capillary radius, \( g \) is the acceleration due to gravity, vacuum or pressure and \( \rho \) is the liquid density.

The above equation shows that maximizing the radii of the capillaries within the filter cake structure reduces the capillary rise, which can be achieved by blending coarser material. The increase in contact angle or decrease in interfacial tension can significantly reduce the capillary rise which depends on the extent surfactants can increase the hydrophobicity or reduce the surface tension. In the filtration process, for fluid flow through the medium, it is necessary that a pressure drop be applied across the medium. The driving force to achieve the pressure drop can be gravity, vacuum or pressure. Increasing the driving force will increase moisture removal from the capillary net work in the filter cake. Pressure filters provide product containing lower moisture content compared vacuum filters because of higher driving force. However, because of higher equipment and maintenance costs pressure filters are not being used in the coal industry.

Methods for improving filtration of fine coal can be divided into two groups: those involving equipment modification and those involving process modifications. Perhaps the most promising avenue to improved dewatering
of fine coal and refuse slurries lies in the category of equipment modifications. In equipment modifications, development of high ‘g’ centrifuge capable of creating forces up to 2000 times gravity has been reported to provide around 12% moisture product for the froth flotation product (3). Recently, the Virginia Polytechnic Institute (VPI) has developed a high pressure centrifuge which has shown encouraging results. Parekh (4) recently developed a novel two-stage dewatering technique, which involves using vacuum to form cake and then apply a high pressure to dewater the cake. The preliminary results showed that the two-stage process provided more than 40% reduction in moisture compared to the conventional vacuum or high pressure dewatering process alone. Other advanced dewatering processes which have shown significant reduction in filter cake moisture of fine coal are the Shoe Rotary Press (5), membrane pressure filter (6), and electro-acoustic dewatering (7) techniques.

Another avenue to improve dewatering of fine coal slurries will be through surface chemical modification which involves viscosity reduction of the slurry, flocculation and surfactants addition to improve hydrophobicity of coal. However, the surface chemical treatment has shown a limited improvement in dewatering at a significant cost and hence it is the least popular approach.

2.1. Current Practice

For fine coal (minus 150 microns) dewatering generally centrifuge and filters (vacuum and pressure) are utilized. The solid bowl and screen bowl centrifuge both are effective in dewatering of fine coal as shown in Figure 1. The screen bowl centrifuge even though more effective in providing a low moisture product, loses a significant amount of fine size coal in the effluent. Wen et al (8) reported that if the coal slurry is pre-treated with a petroleum based reagent such as “Orimulsion”, which is 70% heavy petroleum, 28% water and 2% surfactant, before it is fed to the screen bowl centrifuge, the moisture in the clean coal reduces from 35% to 25% and improves solids capture from 65% to 95%.

![Fig. 1. Screen and solid-bowl centrifuge performance data for fine coal cleaning](image)

Vacuum filter provide a filter cake containing about 35% moisture filter cake with 99% capture of solids. Addition of about 20 kg/t of an anionic/cationic flocculant combination reduces moisture to about 25%. High pressure (hyprbaric) filtration (HBF), which is being used in several countries, except USA, has been very effective in providing a clean coal filter cake with about 20% moisture. The capital and operating cost of the HBF process is much higher than the currently used conventional processes. Table 1. lists a typical performance data for fine coal dewatering processes.

Table 1. A typical performance data of various fine coal dewatering processes

<table>
<thead>
<tr>
<th>Process</th>
<th>Feed size (% &lt; 60 microns)</th>
<th>Feed solids (%)</th>
<th>Solids throughput (kg/m²/h)</th>
<th>Moisture in filter cake (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotary drum vacuum filter</td>
<td>20-60</td>
<td>~20</td>
<td>17-600</td>
<td>30-35</td>
</tr>
<tr>
<td>Hyperbaric</td>
<td>40-50</td>
<td>20-40</td>
<td>400-700</td>
<td>16-20</td>
</tr>
<tr>
<td>Ceramic filter</td>
<td>D50 = 30 µm</td>
<td>~30-40</td>
<td>180</td>
<td>15</td>
</tr>
<tr>
<td>Tube filter</td>
<td>70-80</td>
<td>45-50</td>
<td>1300-1500</td>
<td>~20</td>
</tr>
</tbody>
</table>
2.2. Economics of dewatering

Figure 2 shows the fine coal slurry dewatering cost as a function of particle size. Note, that the dewatering cost increases significantly for particle size finer than 0.5 mm. For fine size particle (minus 150 µm) the dewatering cost is approximately $3.30/t, which includes price of chemicals, which could be substantial. In case of hyperbaric filter the capital and operating cost are significantly higher than vacuum or centrifuge filter, however it provides the lowest moisture product.

3. Dewatering of fine coal refuse

Table 2 lists the performance data for fine coal refuse dewatering. Note, that Hyperbaric filter (HBF) provides the lowest moisture filter cake, However, HBF being an expensive technique and refuse being waste material, the coal company do not want to invest money in dewatering refuse. Recently, Patil et al (9) evaluated the Deep Cone Thickener (DPT) for dewatering of fine coal refuse. Their study showed that using a proper addition of anionic and cationic flocculants to the slurry before it is fed to the Deep Cone Thickener produced a dewatered paste product containing about 50% solids. Figure 3 and 4 show the Deep Cone Thickener in operation and the paste produced, respectively. The process captured more clear water for recycling and produced a material that could be stacked on a slightly slanted surface. The paste eliminates the danger of slurry spillage which has been a serious problem in West Virginia and Kentucky. Currently, a couple of coal preparation plants in the USA have installed commercial scale Deep Cone Thickeners.

Table 2. A typical performance data for fine coal refuse dewatering (Feed size minus 150 µm)

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Feed % solids</th>
<th>Cake Capacity (kg/m²/h)</th>
<th>Moisture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickener</td>
<td>~ 3-5</td>
<td>~ 70</td>
<td></td>
</tr>
<tr>
<td>Belt filter press</td>
<td>~ 30</td>
<td>~ 50</td>
<td></td>
</tr>
<tr>
<td>Hyperbaric</td>
<td>~ 30</td>
<td>250</td>
<td>~ 25</td>
</tr>
</tbody>
</table>

Fig. 2. Cost of dewatering as a function of particle size
4. Conclusions

Dewatering of fine coal slurries to less than 20 percent moisture could be achieved using the hyperbaric filter, however, the capital and operating cost will be high ~ $3.30/t. Addition of chemical show limited success. Novel approaches for fine coal slurries have been developed, however, no technique has been tested on a large scale. Dewatering of fine coal refuse to 50 percent solids could be achieved economically using the Deep Cone Thickener. The dewatered material does not required to be ponded as it is in the form of paste which could be stacked (10 pt) Here introduce the paper, and put a nomenclature if necessary, in a box with the same font size as the rest of the paper. The paragraphs continue from here and are only separated by headings, subheadings, images and formulae. The section headings are arranged by numbers, bold and 10 pt. Here follows further instructions for authors.
References