Washability Analysis of Coal using Water Fluidization

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ABSTRACT

With increasing concerns over the health effects of the dense liquids used to obtain coal washability data, there is growing interest in establishing an alternative approach that is safe, environmentally friendly and economic. This article outlines a novel method for obtaining washability data that relies on the use of water only as a medium for fractionating the coal and mineral matter. The focus is on relatively small (less than 4 mm) coal. It is demonstrated that through a combination of fluidization and sizing, the fractionation is sufficient to generate a realistic indication of coal preparation plant yield as a function of the particle density and cumulative ash. A consistent discrepancy evident in the vicinity of low ash values is obtained which, if required, can be removed through the application of a simple correction factor. The method is also found to be very robust and reproducible.

INTRODUCTION

Coal washability data are fundamental to the assessment of coal resources, production-phase planning, and the coal preparation plant design and operation. The washability data specify the optimum separation conditions required for different size coal in order to meet a given overall product ash. The traditional method
OSM has signed a Memorandum of Understanding with the U.S. Department of Energy, National Energy Technology Laboratory (NETL) to collaborate on CCB research and issues. OSM staff members serve on the national steering committee of the Combustion By-Products Recycling Consortium in order to assist in directing NETL CCB research efforts; and the technical program committee for the biennial International Ash Symposium conducted by the University of Kentucky (UK) Center for Applied Energy Research, which has become the combined 2005 ACAA and UK World of Coal Ash (WOCA) meeting. OSM staff members are currently working with the U.S. Environmental Protection Agency to investigate whether or not additional federal regulations are necessary to protect the public and environment when CCBs are placed at a mine site.

**BENEFICIAL USE OF CCBs AT MINES**

There are two organizations that keep track of the volume of CCBs that are being placed at mine sites. According to the American Coal Ash Association annual survey (representing 600 U.S. coal-fired power plants), the total production of these materials in 2002 was 128.7 million metric tons of non-FBC material. Of that total, 35.4% was recycled as commercial products including 1.4% being placed at mines sites. The remaining 64.6% was placed in underground impoundments or surface landfills under the control of the electric utility industry. According to the Anthracite Region Industrial Power Producer Association, 100% of its 5.1 million tons per year of fluidized bed combustion ash is used to reclaim abandoned mine lands (total of 3,400 acres reclaimed in Pennsylvania) while eliminating 88 million tons of acid coal refuse.

Based on a survey (Murarka, 2000) concerning the location of CCB placement at coal mine sites, about 1 percent, or 100 out of the approximately 9650 coal mine sites, were using CCB placement in 17 of the 26 coal-mining states. Most of the uses to date have been extensively researched and indicate that the placement of these materials on the mine site usually results in a beneficial impact to human health and the environment when it is used to mitigate other existing potential mining hazards and secondarily as non-toxic fill within the spoil area prior to grading and final reclamation. Beneficial uses at SMCRA mine sites include:

1. A seal to contain acid forming materials and prevent the formation of acid mine drainage;
2. An agricultural supplement to create productive artificial soils on abandoned mine lands where native soils are not available;
3. A flowable fill that seals and stabilizes abandoned underground mines to prevent subsidence and the production of acid mine drainage;
4. A construction material for dams or other earthlike materials where such materials are needed as a compact and durable base; and
5. A non-toxic, earthfill material for final pits and within the spoil area.

**RCRA VERSUS SMCRA**

Although the recycling of these materials into useful products has attracted a great deal of interest as a raw material for basic construction products, there has been a growing controversy from environmental groups that believe the use of these materials places an unacceptable risk on public health and environmental quality. These groups have advocated that all CCBs are potentially toxic and should be regulated as a waste in lined landfills under the Resource Conservation and Recovery Act (RCRA) when placed at SMCRA mine sites. The result would be the loss of the use of these materials for existing beneficial applications at SMCRA mine sites.

Research has shown that less than 1% of these materials have the potential to leach hazardous constituents (According to Nationwide Analysis by the U.S. Department of Energy with only 2 out of 288 sources, or 0.7 percent, of the CCBs tested demonstrating the potential to leach trace elements at levels that would be classified as hazardous). Based on U.S. EPA groundwater monitoring of over 1,000 wells at electric utility CCB disposal areas nationwide, the data has demonstrated that only 12 of those wells have produced water at levels considered hazardous and none from SMCRA mine sites. All of the SMCRA water monitoring data I am aware of to date, indicate that placement of these materials at SMCRA mine sites does not produce groundwater that has hazardous constituents and in most cases is environmentally beneficial.

SMCRA is based on performance standards rather than design standards. By using performance standards, which are minimum levels of environmental protection, SMCRA allows for each State Regulatory Authority to develop methods and techniques that are most appropriate for the climate, geology, geography, and other site conditions. It also allows the operator to design the site-specific mining and reclamation techniques that maximize the operator’s efficiency and still ensure the appropriate level of environmental protection. The result is that each state is allowed to develop a program specifically suited to its needs to protect the environment based on local conditions, while maintaining a uniform national level of environmental protection.

There is no exemption for any coal combustion by-product placed at a SMCRA mine site from any of the permitting requirements and environmental performance standards contained in SMCRA. When the use or disposal of coal combustion by-products happens at surface coal mines, state and federal coal-mining regulators are involved to the extent that SMCRA requires the mine operator to:

1. Ensure that all toxic materials are treated, buried, and compacted, or otherwise disposed of, in a manner designed to prevent contamination of the ground or surface water;
2. Ensure the proposed land use does not present any actual or probable threat of water pollution;
3. Guarantee the permit application contains a detailed description of the measures to be taken during mining and reclamation;
4. Assure the protection of the quality and quantity of surface and groundwater systems, both on and off the mine site, from adverse effects of the mining and reclamation; and
5. Assure that rights of present users of such water are protected.
The Beneficial Use of Coal Combustion By-Products, (cont.)

This result is supported by all existing scientific research and water monitoring which finds no evidence of damage to public health or the environment due to the placement of these materials at SMCRA mine sites. In most cases, ground or surface water quality actually improves. And finally, in the cases where they are used as soil amendments, there is improved plant growth on the surface.

CONCLUSION

OSM has been extensively involved with the development and distribution of technical information related to protection of public health and the environment during the beneficial placement of CCBs at coal mine sites since 1994. Because of the complexity of the issues involved and the importance of public health and environmental protection during surface coal mining and reclamation, OSM is very supportive of additional research into the potential environmental effects of CCB placement at coal mines. It is the author’s assessment of the 20+ years of research that the placement of these materials on SMCRA mine sites usually results in a beneficial impact to human health and the environment when it is used to mitigate other existing potential mining hazards or as a non-toxic fill to reduce reclamation costs. To date, the author is unaware of any scientific evidence of damage to public health or the environment due to placement of CCBs at SMCRA mine sites. Based on a side-by-side comparison of the regulatory protections provided by SMCRA in comparison to RCRA, when SMCRA is properly applied and enforced, it is adequate to protect the public health and the environment. Any additional federal regulation of CCB placement at SMCRA mine sites, should be based on sound scientific evidence that the existing regulatory framework is not adequate.

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Washability Analysis of Coal, (cont.)

for obtaining the washability data is known as the “sink-float” technique, in which the particles of a sample are permitted to either sink or float in a liquid of a given density. Those particles that sink are then transferred to a liquid of higher density where a portion once again floats or sinks. This procedure is repeated until a standard range of densities has been used.

The coal industry has been relatively fortunate in routinely obtaining washability data. Unlike much of the minerals industry, coal particles are relatively low in density and hence liquids of sufficiently-high density are readily available for the sink-float technique. For densities in the range 1.20 -1.60 RD, solutions of white spirit (RD 0.77) and perchloroethylene (RD 1.60) are mixed to produce the liquid medium. Higher relative densities in the range 1.60 – 2.40 RD are made from a mixture of perchloroethylene and tetrabromoethane (RD 2.96). Density hydrometers are used to confirm the relative density of each bath.

It has long been recognized that these heavy liquids are harmful to human health, and hence expensive extraction systems have been required in order to minimize the exposure of operators to the vapors of these liquids. In Australia studies have been conducted in order to examine the potential of alternative media such as aqueous solutions of cesium formate, zinc chloride and suspensions of hematite. These media are very viscous and hence the time required for fine-coal testing can be significant. The particles forming the media must also be washed from the coal and recovered, which also takes significant time. Although cesium formate was found to be effective, losses during the washing procedure are arguably uneconomic. Consequently, the industry in Australia has continued to use the traditional heavy-liquid approach.

Galvin and Pratten (1999) described an alternative method for obtaining washability data based on water fluidization. This article, which is full length, provides a summary of the method and the findings of the study.

EXPERIMENTAL METHOD

The equipment required in order to use water fluidization to generate washability data on fine coal nominally less than 4 mm, is relatively simple and inexpensive. A Perspex cylinder 50 mm in diameter and 2 m high was constructed with sampling points located on the vessel wall for withdrawing particle suspensions. The sampling points consisted of 10 mm diameter holes on the vessel wall, sealed by ball valves (15 mm diameter). Pressure tappings were also incorporated on the opposite
side of the column, however, these were not used in the final method. The distributor consisted of 127 1-mm diameter holes, covered by a fine mesh. Care was taken to ensure even fluidization through the base, by filling the vessel below the distributor with large spheres. Care also was taken to ensure the column was vertical. A mesh was also placed near the top of the column to prevent particle loss.

Preliminary studies were conducted using colored density-tracer particles. The particles were in the narrow size range of 1.18 to 1.40 mm, with the relative density of the yellow particles 1.3, the relative density of the light blue particles 1.5, the relative density of the green particles 1.7, the relative density of the dark blue particles 1.9, and the relative density of the white particles 2.1. An initial mixture separated sharply into different density layers. Within a period of about five minutes the separation was complete.

Two basic approaches to conducting the washability analysis of a coal feed in the range 0.5 to 2.0 mm were investigated. The initial approach (Method A) was to sieve the feed into a series of “narrow” size fractions, -2+1.4 mm, -1.4+1 mm, -1+0.7 mm, -0.7+0.5mm. Then, each fraction was fluidized separately and permitted to segregate to an equilibrium state. In general, two fluidization rates were used for a given size fraction in order to ensure a relatively low rate was used for the less dense particles. Moving from the top of the column down, the fluidized suspension above a given valve was completely removed. The valve was closed and the next lowest valve opened to withdraw the next sample. In this way denser and denser samples were obtained. The average particle density of each sample was then determined by water pycnometry and the sample was analyzed for the ash content. A cumulative yield versus density curve and a cumulative yield versus ash content curve were then produced for the specific size fraction. The method was repeated for each of the size fractions and an overall result for the full size range was generated.

The alternative approach (Method B) of placing the sample covering the full size range, -2+0.5 mm into the column was also examined. The advantage here was that less sample in total was required. Care was needed to ensure the full sample was properly segregated. The fluidization rate was varied over a broad range to free up all of the particles. The rate was then dropped, thus allowing a packed bed of larger particles to form on the base. Once the top portion reached an equilibrium segregation state, a sample was removed from above the upper valve. The fluidization rate was adjusted upwards to ensure the next portion of the particles was sufficiently suspended, thus permitting another sample to be taken. This procedure was repeated until all of the particles were removed. Each of these sub-samples was then placed on a set of sieves equivalent to those used in the first method (-2+1.4 mm, -1.4+1 mm, -1+0.7 mm, 0.7+0.5mm).

Each size fraction of each sub-sample was then analyzed for ash content. Selected sub-samples (based on the ash content) were then analyzed for density analysis using pycnometry.

Following an examination of the above two methods, a series of case studies was investigated using Method B, covering the broader size range of -4+0.25 mm. A further experiment was conducted on a flotation feed, in the size range -0.25+0.045 mm, the aim being to compare the results of the method with those from the “Tree Flotation Method” (Australian Standards, 1998).

RESULTS AND DISCUSSION

During the study it was discovered that some particles degraded in size, perhaps as a result of the breakdown of clays, though it was noted that the level was relatively small but sufficient to alter the recombined head ash. This breakdown would be similar to that which occurs during the washing operation after mining. Thus, as part of the preparation of the sample for the test, we decided to wet-split the sample at the lowest sieve size. This in turn resulted in the particle breakdown occurring prior to the washability test. This was considered a more realistic approach, and representative of what occurs in a coal preparation plant.

In a systematic study of using water fluidization to produce washability data, it was established that the final results are independent of whether the sample is first sieved into narrow size fractions and then fluidized or fluidized and the sub-samples sieved into the narrow size fractions. These findings are shown in Figure 1, with a further comparison made with data generated using heavy liquids via the sink-float method. Clearly, the results of Methods A and B are equivalent which suggests the effects of the two processes, of size separation and fluidization, are independent.

It is also evident from Figure 2 that there is generally good agreement with the results from the sink-float method, though clearly there is a discrepancy in the regime of the low ash data. This discrepancy is to be expected because some degree of dispersion (or mixing) must always
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Figure 2b shows the density distribution data obtained using the sink-float method, Figure 2c shows the washability data as a function of density, obtained using the sink-float and water fluidization methods, and Figure 2d shows the washability data as a function of density, obtained using the sink-float and water fluidization methods.

Once again, there is reasonable agreement in the results obtained using the sink-float and water fluidization methods, despite the characteristic discrepancy evident in the vicinity of low ash values. As noted earlier, the data produced using the water fluidization method is probably indicative of the best performance expected in a coal preparation plant. We have, nevertheless, proposed an algorithm to modify the water fluidization results, and in turn obtain improved agreement with the sink-float method. That is,

\[ A_{\text{new}} = A - F(A_{\text{max}} - A)/(A_{\text{max}} - A_{\text{min}}) \]  

where \( A_{\text{new}} \) is the corrected ash value, \( A \) the original ash value, \( A_{\text{max}} \) the head ash of the whole sample, and \( A_{\text{min}} \) the lowest ash value obtained. The parameter \( F \) is the correction factor, which we suggest should be about 1.3. We have observed for one coal with a higher proportion of particles in the relative density range 1.5 to 1.8, that a slightly larger correction factor is required.

In the interest of applying the water fluidization method to much finer particles, an experiment was conducted on a flotation feed in the range \(-0.25+0.045\) mm. The findings obtained using the Tree Flotation test and the water fluidization method are shown in Figure 3. It is evident that the agreement is very good between the two methods, though it is noted that both sets of data are almost certainly below that which would be produced using the sink-float method. The water fluidization method is very rapid, even at this fine-particle size, and may provide a better indication of recovery potential than the Tree Flotation curve. Certainly, the water fluidization method should provide a more reproducible set of results. A lower limit of 0.045 mm was used here as this is close to the usual lower limit of sieve analysis. In practice, the water fluidization method might require a single-stage flotation test on the \(-0.045\) mm portion in order to cover the full size range.
CONCLUDING REMARKS

We have outlined a new method for washability analysis based on water fluidization. A given sample undergoes a density-driven segregation process in a fluidized bed which, when combined with the process of size separation, produces sufficient fractionation to closely approach the results of the sink-float method. The capital and operating costs of the method are very low, and the procedure is relatively rapid. The main disadvantage of the method is the need to always examine the washability of the coal as a function of particle size and hence, in this respect, the procedure may not be as economic as the sink-float method. However, for the additional expense, additional information is obtained. Application of an ash scanner along the fluidization column may in time lead to an even faster technique.

Clearly, the new method under-predicts the yield for a given ash, in a relatively consistent fashion. While this will concern many, a change in the “mind-set” is all that is necessary for the lower yields to be acceptable, as these more realistically reflect yields that are obtained in practice under ideal conditions.

This study was limited to a top size of 4 mm, whereas in practice a significantly larger size would be required before universal acceptance was achieved. Further study using coarser particles is therefore required.

ACKNOWLEDGEMENTS

The author would like to acknowledge ACARP for funding this research.

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A.M. Callen, S.J. Pratten, N. Lambert, and B.D. Belcher also contributed to this article.