Producing Clean Coal from British Columbia Coalfields Using the Water-Based Roben Jig Process: Application to an Industrial Setting

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Introduction

There are a number of coalfields in British Columbia (BC): several thermal coalfields and two major metallurgical coalfields, the Kootenay and Peace River (Figure 1). Metallurgical coals are destined mainly for use in commercial coke ovens to produce coke for use in blast furnaces in steelworks.

One of the main challenges after finding and identifying coal seams is evaluating the quality of the coal resource during the exploration stage. Understanding coal quality can be a complex process and is key to a sound economic evaluation of the resource. During the exploration phase of coal-mine development, evaluation of metallurgical-coal quality is often done using samples collected from drillcore, since the bulk of the coal deposit is generally deep underground.

Coal samples collected during exploration are prepared by screening and then lab-scale or pilot-scale washing that simulates the coal behaviour in commercial coking coal-wash plants. The coarser sized coal is processed using mixtures of organic liquids and the finer fraction is cleaned by a process called froth flotation. The quality of the coal produced by these smaller scale washing methods is critical to understand the market potential of the coal. These processes must produce the same quality coal as a commercial plant.

On the lab scale, the float-and-sink procedure (Figure 2) is used to separate coal from dirt, rock and mineral matter using a density separation, the same process used in commercial plants. The lower density solutions tend to float mainly the coal. During the float-and-sink process, the coal sample is separated at relative densities (specific gravities, sg) between roughly 1.40 and 1.80 using tanks of organic mixtures made from white spirit (1.40 sg), perchloroethylene (PCE; 1.60 sg) and methylene bromide (1.80 sg; ASTM D4371-06(2012)). This produces clean-coal samples at the target ash, sulphur and calorific content typical of what would be produced in a commercial coal-washing plant.

Commercial plants separate the coal into size fractions that are processed in equipment that separates the coal from waste (rock, dirt and minerals) using differences in density—coal being less dense than the waste. The equipment uses water-magnetite mixtures of controlled density in cyclones and

Figure 1. Location of coalfields in southeastern British Columbia from which the coal samples used in this study originated.

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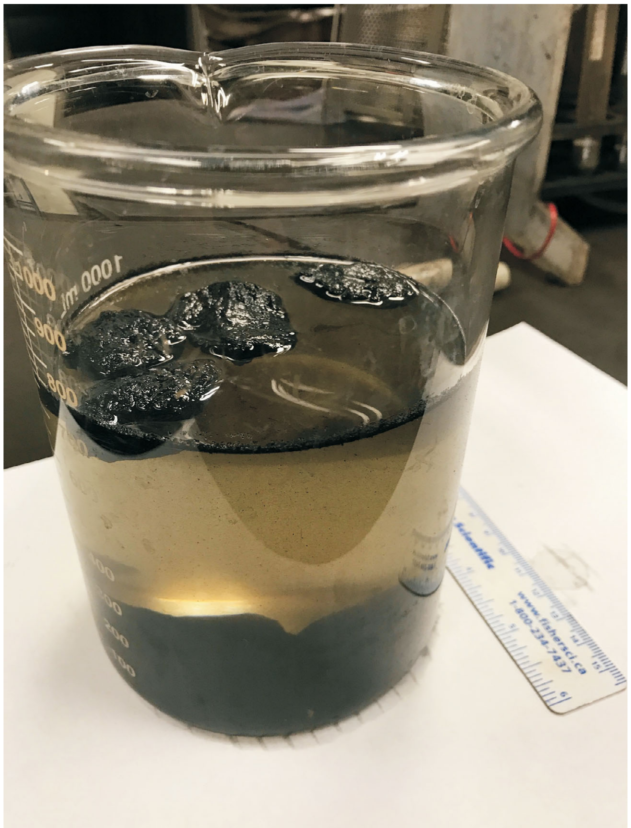

Figure 2. Coal particles floating in perchloroethylene.

baths, centrifugal force for coal-water mixtures in cyclones, and relative settling rates of the coal particles of differing densities in water to isolate/separate the 'clean' coal in jigs and settling tanks. The finest sizes are treated by water-based froth flotation, which can 'float' the coal from the waste. Exploration samples are treated/cleaned in a similar fashion.

Project economics are based on the results of the float-and-sink testing, which produces information on the yield of clean coal as well as the quality of the cleaned coal and resulting coke quality. The coking characteristics for a metallurgical coal deposit are critical in evaluating project economics (i.e., expected price for the clean coal). It is important to ensure that coal/coking properties are correctly assessed from drillcore samples to properly evaluate project economics.

Background

Historically, the major concern in the handling and use of organic liquids such as perchloroethylene (PCE) was the safety risks associated with human exposure. Perchloroethylene is a known carcinogen and poses a safety hazard for laboratory operators, so it must be handled carefully. Figure 3 shows a laboratory technician working in a specially designed fume hood wearing personal protective equipment, including a respirator mask.

Figure 3. Operator working with organic liquids in a specially designed fume hood.

In addition to the health issues, there have been increasing concerns about the impact these solvents have on the quality of coking coal. It has been the experience of the authors and their colleagues that cleaned drillcore coal samples often had lower caking/coking properties than bulk or production coal samples, an observation that goes back many decades. A number of investigations looked at how PCE and other organic solvents may impact the coking quality of coal samples, including Australian and American work (DuBroff et al., 1985; Campbell, 2010; Iveson and Galvin, 2010, 2012). These studies found that there were different impacts depending on the quality characteristics of the coal being assessed. Coals similar to the western Canadian coking coals (higher inert, lower thermal rheological coals) appeared to have been negatively impacted.

Based on these observations, the Canadian Carbonization Research Association (CCRA) undertook a preliminary program to investigate the impact of the organic solvents used in float-and-sink procedures on the coal and coke properties of a higher inert, low-fluidity, western Canadian coal sample (Holuszko et al., 2017). This study looked at the effects of PCE on coal rheology and coke quality. It was found that an 80% decrease (relative to the control sample) in Gieseler maximum fluidity occurred in the perchloroethylene-treated coal immediately following treatment. The coke resulting from the treated sample showed a 16-point decrease in coke strength after reaction (CSR) relative to the control sample. These two coal- and coke-quality parameters are key when evaluating coal resources and reserves. The ramifications of using the wrong numbers for these parameters when determining the characteristics of product for sale are severe and could result in unwarranted project abandonment or false overvaluing of the property.

After the initial study outlined above, the CCRA also completed an exploratory study that examined an alternative to organic liquids by washing coal samples in a jig. A lab-scale Roben Jig (Figures 4, 5) was used to clean several coals using only water, and the resulting quality characteristics of the clean coal and its coke were compared to those of coal that was processed using the traditional process of washing with organic chemicals. It was found that it was possible to produce a clean-coal product with quality properties very similar to those obtained using the organic liquids (Mackay et al., 2019). The Roben Jig–cleaned coals had the same/similar results for coal-quality parameters and better results for coal-rheology parameters. These findings are important because they demonstrate that the Roben Jig can be used to produce clean-coal composites similar to those obtained from traditional float-and-sink methods.

Objectives

The studies completed on the Roben Jig to date have verified the jig as a tool to help evaluate coal deposits with respect to coal and coke quality at the exploration phase. They have shown that traditional organic liquids (perchloroethylene, white spirits and methylene bromide) can negatively affect coal rheology and coke strength, resulting in an undervaluation of exploration samples (Mackay et al., 2019). Tasks completed include the development of a jig methodology; a comparison of coal and coke quality when using the jig versus organic liquids; the identification, characterization and mitigation of misplaced particles; and a comparison of jig-washed coal to an industrial process plant (using the same raw coal). Three clean-coal samples will be available for carbonization from three different washing processes: industrial wash plant, organic liquids (bulk wash) and Roben Jig (bulk jigging).

The gold standard for proving the effectiveness of the Roben Jig in cleaning coal is to compare it to an industrial setting. This was initiated in 2018 when clean coal washed through the jig was compared with coal washed through an industrial processing plant (Mackay et al., 2019). Work in 2019 has focused on creating clean-coal composites for charging in a pilot-scale coke oven (350 kg capacity). Previous work used only a small carbonization oven—the sole-heated oven (12 kg capacity). This small oven produces only enough coke to measure the CSR/CRI (coke strength after reaction / coke reactivity index). The pilot-scale carbonization oven will yield enough coke to measure up to four additional coke-strength drum indices (ASTM, JIS, Micum/Irsid) in addition to CSR/CRI.

The current research will aim to answer the following questions:

1) Since misplaced particles occur throughout the segregated coal column, how do the high-ash particles (fragments of minerals and rock) affect the coke-strength

Figure 4. Roben Jig equipment used in this study.

Figure 5. Inverted Roben Jig with coal slice to be removed.

drum indices measured on coke produced in a pilot-scale coke oven?

2) How do the coke samples made from clean coal derived from organic liquids washability, Roben Jig and industrial processing plant compare with respect to all relevant coke characteristics?
3) What is the best methodology and expected cost to do 'bulk jigging'—the process where the Roben Jig is used to create 400 kg of clean coal for charging in the pilot-scale coke oven?

The research group also aims to draft a standard operating procedure for operating the Roben Jig for the purpose of producing small-mass clean-coal samples in British Columbia.

The success of this project is beneficial to the coal industry for the following reasons:

- It eliminates the potential negative effects of perchloroethylene and other organic liquids on small-mass exploration coal- and coke-quality parameters.
- It reduces the exposure of lab technicians/operators to carcinogenic organic liquids.

Experimental Washing Methodology

The research group devised two Roben Jig methodologies that could yield products with lower ash content while minimizing misplaced coal and rock particles. These methodologies were compared to the original coal-washing methodologies from the Phase 1 research (Mackay et al., 2018). The clean coals from all processes were then compared to the product from an industrial coal-washing plant. The method for the industrial coal-washing plant is detailed in Mackay et al. (2019).

The coarse coal particles in each sample (greater than 0.50 mm) were washed during this study in several different ways:

- Raw coal was washed in an industrial coal-washing plant.
- Raw coal was segregated into one coarse fraction (12.5 × 0.5 mm) and washed in organic liquids using the float-and-sink method and following the ASTM D4371-06(2012) standard (Phase 1 Method: Float-and-Sink, One Coarse Fraction), as described in Mackay et al., 2018.
- Once initial washability was completed using organic liquids, targeting a specific ash %, one specific gravity was chosen to 'bulk wash' the remainder of the raw coal to create a clean-coal composite. This methodology is described below.
- Raw coal was segregated into one coarse fraction (12.5 × 0.5 mm) and washed in the Roben Jig (Mackay et al., 2018, Phase 1 Method: Roben Jig, One Coarse Fraction).
- A new method called 'Bulk Jigging' was developed for this phase of research and will be explained in detail below.

Common to all methodologies, the fine coal (particle sizes of less than 0.5 mm) was washed using the froth-flotation method (ASTM D5114-90(2010)). The clean coal resulting from this method was recombined with the coarser coal (greater than 0.5 mm) when creating clean-coal composite samples.

Bulk Washing in Organic Liquids

In this phase of work, the results of the 'Phase 1 Method: Float-and-Sink, One Coarse Fraction' (Mackay et al., 2018) were reviewed, a target ash % was chosen for the clean sample, and a 'cut point' (the specific gravity at which all clean coal that floated at that specific gravity and all lower specific gravities would be combined to create the clean-coal composite) was then selected. For instance, in a washability table that listed masses and ash values for the coal that floated at specific gravities of 1.30, 1.40, 1.50 and 1.60, depending on the target ash %, one may choose a cut-point of 1.50 sg. The remainder of the raw coal would then be floated in a large bath of 1.50 sg liquid instead of undergoing several flotations at specific gravities of 1.30 to 1.80.

Bulk Jigging

The intent of Bulk Jigging is similar to that of Bulk Washing in Organic Liquids. Knowing that all coal below a certain relative density will have ash % values desired for the clean-coal composite, the process of cleaning the coal can be sped up by eliminating some of the detail in the washing process (i.e., finding a 'cut point' in the jig column).

First, a trial is carried out by jigging 15 kg of raw coal and removing 12–18 slices from the jig column. The ashes are analyzed for each slice and reviewed with the corresponding apparent relative densities. The obvious rock (>1.90 ARD) and obvious clean coal (<1.35 ARD) zones are identified and measured. For instance, once the column is inverted, the rock would be located in approximately the top 15 cm of the jig column and the clean coal would be in the bottom 30 cm. Next, the higher ash coal zone is identified—this zone is always the area between the obvious rock and cleanest coal. More batches of raw coal are jigged and the thickness of the slices is increased because the boundaries between obvious clean coal, higher ash coal and rock are roughly known. For each batch, slices with similar ARD values are grouped together into buckets. Once the bulk jigging is complete, the ash % of each bucket is analyzed. A specific ash % is targeted and the buckets with ashes allowing for this ash % are chosen to be added to the clean-coal sample.

Analysis

Clean-Coal Analysis

Each clean-coal composite will be analyzed at GWIL Industries–Birtley Coal & Minerals Testing Division (Calgary, AB) for yield (percent), proximate analysis, free swelling index (FSI), specific gravity (sg), total sulphur, Hardgrove Grindability Index (HGI), calorific value (kcal/kg), mercury, ultimate analysis, mineral analyses of the ash, phosphorus in coal (calculated, percent), Gieseler maximum fluidity, Ruhr dilatation, ash fusion (oxidizing and reducing), chlorine, fluorine, alkali-extraction–light-transmittance test, Sapozhnikov X and Y indices, and caking index (G). Petrographic analysis of the coal and coke will be carried out at both CanmetENERGY (Ottawa, ON) and David E. Pearson & Associates (Victoria, BC).

Carbonization

Clean-coal samples from this study, once generated, will be sent to CanmetENERGY in Ottawa. Upon reception, coals will be air dried in open air in the laboratory for 12 hours for the sole-heated oven charges and 24 hours in the case of the larger samples that will be coked in the Carbolite oven. The coal samples will then be homogenized prior to preparing charges for coking in CanmetENERGY's 12 kg capacity sole-heated oven and its 340 kg capacity Carbolite pilot coke oven.

A description of the features and operating conditions for carbonization of coal in the sole-heated oven (ASTM D2014-97(2010)), including the preparation of coke samples from coals in this project for measurement of coke strength after reaction (CSR) and coke reactivity (CRI) following a procedure developed at CanmetENERGY (MacPhee et al., 2013), is provided in Mackay et al. (2019), as is a description of the Carbolite pilot oven.

Results

After this part of the project began on April 1, 2019, the team had the opportunity to obtain raw and clean coal from a single-seam plant run, which is a relatively rare event. Due to the timing of the single-seam plant run, the time schedule of GWIL Industries–Birtley Coal & Minerals Testing Division, and the time needed to jig a large volume of raw coal (close to 1 ton of raw coal), the project does not yet have any clean coal or carbonization results. It is expected that carbonization of the three clean-coal samples will begin prior to December 31, 2019. A final report for the project is expected to be released in early 2020.

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