Canadian Carbonization Research Association

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Producing Clean Coal from Western Canadian Coal Fields using the Water-based Roben Jig: Refining the Process

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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.

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

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. Although many coal seams outcrop, the bulk of the coal deposit is generally deep underground. Coal near the surface can be sampled using test pits or adits, but drilling is the method most often used to obtain representative coal-seam samples. During the feasibility stage of an exploration property, a bulk sample of more than a tonne is required for testing the coal in a pilot-scale coke oven to fully understand the coking potential of the coal. Sufficient sample can be obtained using several 6-inch drill-program cores, although this is costly, particularly for thinner seams.

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.

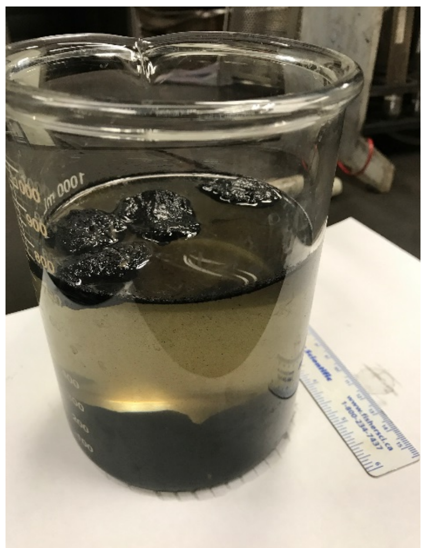

Figure 2. Coal particles floating in perchloroethylene.

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 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, in particular, 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

For years, a 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 are increasing concerns about whether the solvents impact the quality of coking coal. Many Canadian geologists have found 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 perchloroethylene 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) when compared 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.

Figure 4. Roben Jig equipment used in this study.

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

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. 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 objective of this project was to revise the existing operating methodology for the Roben Jig in order to minimize misplaced material (Mackay et al., 2018). Another goal was to answer the following questions:

- At what apparent relative density is misplacement of coal particles occurring?
- What are the characteristics of the misplaced coal particles?
- What is the preferred method of operating the Roben Jig?
- How does the Roben Jig compare to an industrial processing plant?
- How many coal types need to be tested so that results are statistically significant?

- How is the perchloroethylene interacting and affecting the coal chemistry to cause a reduction in rheology and an increase in Hardgrove Grindability Index?

If successful, this project would benefit the coal industry by eliminating of use of PCEs and other organic liquids in the production of small-mass exploration samples for the determination of coal- and coke-quality parameters and reduce the exposure of lab technicians/operators to carcinogenic organic liquids. Results from most aspects of this project are also presented in Mackay et al. (2019).

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 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 standard (Phase 1 Method: Float-and-Sink, One Coarse Fraction)
- Raw coal was segregated into one coarse fraction (12.5 × 0.5 mm) and washed in the Roben Jig (Phase 1 Method: Roben Jig, One Coarse Fraction)
- Clean coal resulting from the jigging of one coarse fraction was then rejigged (New Method A: Re-Jigging).
- Raw coal was segregated into two coarse fractions (12.5 × 2 mm and 2 × 0.5 mm) and washed in organic liquids using the float-and-sink method and following the ASTM D4371 standard (New Method B: Float-and-Sink, Two Coarse Fractions).
- Raw coal was segregated into two coarse fractions (12.5 × 2 mm and 2 × 0.5 mm) and washed using the Roben Jig (New Method C: Roben Jig, Two Coarse Fractions).

Common to all methodologies, the fine coal (particle sizes of less than 0.5mm) 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.

Industrial Coal-Washing Plant Method

This research project had a unique opportunity to piggyback on a single-seam run at an operating industrial-processing plant at a mine in southeastern BC. Mine operations seldom schedule 'single-seam' runs unless it is part of the natural release of coal from the mine plan; it is more usual to see many seams being processed through the plant together. The ability to be able to compare laboratory-washed coal to that cleaned in an industrial-sized wash plant is considered the gold standard in validating a laboratory method for washing coal. As much as possible, companies want to be able to predict the actual clean-coal product that will be delivered from a mine's washing plant. As the single seam was being run through the plant, raw coal was collected from the 'feed' side of the plant. This coal was used in the laboratory processing by organic liquids and the Roben Jig. Clean coal was also collected from the plant and analyzed for clean-coal quality and coke quality. Industrial-sized processing plants do not achieve perfect separation, and material is misplaced. A simple float-and-sink using organic liquids was also done to determine where the misplaced particles originated.

Phase 1 Method: Float-and-Sink, One Coarse Fraction

The specific gravity of a coal particle is dependent on mineral-matter content and maceral composition. Coal particles containing the lowest amount of mineral matter will float when separated in a 1.30 sg liquid, whereas those with the highest mineral-matter content are separated at 1.80 sg.

The float-and-sink method (ASTM D4371-06, 2012) was used in this project. This technique fractionates coal and mineral-matter particles based on particle density by allowing particles to settle in organic-liquid mixtures with known specific gravities. Mixtures of white spirits, perchloroethylene and methylene bromide are used to produce media densities ranging from 1.30 sg to 1.80 sg.

Phase 1 Method: Roben Jig, One Coarse Fraction

The Roben Jig is a device that enables the sorting of coal particles based on density to occur as the coal is jigged up and down in a column of water. Although no published standard (ASTM, ISO or Australian) exists for the use of the Roben Jig, the following procedure was developed by the inventor. Approximately 15 kg of 12.5 mm × 0.25 mm coal and tracers (glass marbles) of a known specific gravity (2.70) were added to the jig tube with a 0.25 mm screen at the bottom. This mesh base allowed water to enter during the jig downstroke and particles to be sorted during the jig upstroke. This tube, with coal added, was gently lowered into the jig vessel. Water level was adjusted so that it was approximately 100 mm above the level of the coal. The jig tube was attached to the pneumatic jigging mechanism. Once turned on, this mechanism moved the jig tube up and down. The down stroke was rapid to suspend particles individually, the upstroke was slower to allow the particles to sort according to density. The jigging time was 15 minutes. When the jig cycle was complete, the coal sample was presumed to have been sorted into a density continuum column, heaviest material (discard) at the bottom grading to lightest (best) coal at the top.

After jigging was completed, the jigging tube was lifted from the jig vessel, allowing the water to drain from the coal. A sample pusher was inserted in the jig tube and pressed to allow more water to drain. The entire tube was then inverted to allow the coal to be pushed upward. Once the jig tube was inverted, and the screen removed, the marbles were visible, as they had the highest specific gravity; this was evidence that the jigging was successful. A tray was attached to the top of the tube and the sample pusher was rotated, causing the coal to be pushed above the jig tube and allowing the operator to scrape off the layer. The layer was then carefully scraped into the apparent relative density (ARD) basket. Note that, because the jig tube was inverted after jigging, the first fraction collected was the highest density (heaviest or highest ash content). The thickness of the layers was dictated by the particle-size distribution of the coal and by how many fractions one expected to remove from the sorted column. Since the wet ARDs were calculated immediately, the depth of the layers could be increased or decreased to obtain a range of ARDs and subsequent range of ash contents.

Each wet coal layer was weighed and air dried, and a dry ARD calculated. Samples were then prepped for laboratory testing. Similar ARDs were added together before prepping or tested first to confirm ash results. The calculated ARD is an average for that layer.

New Method A: Re-Jigging

In this method, the clean coal from the coarse size fraction was re-jigged to see if it was possible to further segregate the particles based on density. First, a slice was taken that had an average ARD of 1.29 and an ash value of 10.20%. The slice was added back into the Roben Jig and processed. Through this 're-jigging' action, it was possible to further clean the coal by removing 158 g of a higher ash (22.77%), higher ARD (1.39) coal; this allowed for a selection of a lower ash product <7%) compared to the starting value of 10.20%. This method showed promise for being effective at cleaning coal to lower ash cut points. In this study, the clean coal resulting from jigging the coarse fraction (12.5 × 0.5 mm) was added back into the empty jig and re-jigged.

New Method B: Float-and-Sink, Two Size Fractions

The coarse coal was first divided into two size fractions (12.5 × 5 mm and 2 × 0.5 mm) instead of one (12.5 × 0.5 mm) before being washed using the float-sink method (ASTM D4371-06, 2012). It is common in the coal industry to wash different coarse fractions separately in organic liquids.

New Method C: Roben Jig, Two Size Fractions

Pielot (2010) studied the results of various widths of grain-size classes being fed to jigs and found that the narrower the grain-size classes of the coal feed, the more precise was the jigging. To test Pielot's theory, this method separated the coarse coal into size classes, each of which was jigged on its own.

Analysis

Clean-Coal Analysis

Each clean-coal composite was analyzed for various quality characteristics and was coked in the sole-heated oven (12 kg capacity) at CanmetENERGY in Ottawa, with coke characteristics subsequently being quantified. The clean coal resulting from the industrial-scale coal-washing plant was carbonized in the Carbolite pilot coke oven. The clean-coal composites were analyzed at GWIL Industries–Birtley Coal & Minerals Testing Laboratory 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 was carried out at both CanmetENERGY (Ottawa, ON) and David E. Pearson & Associates (Victoria, BC).

Carbonization

Coal samples (~20 kg each) from the float-and-sink washing with organic liquids and the Roben Jig washing with water were received at CanmetENERGY in Ottawa on August 7 and 10, 2018. In the case of 100% Plant Clean #183147, a significantly larger quantity of approximately 450 kg (three 45-gallon drums full) was received for carbonization tests in both the small-scale sole-heated oven (12 kg) and the pilot-scale coke oven (340 kg).

Upon reception, coals were air dried in open air in the laboratory for 12 hours (24 hours in the case of the larger sample of 100% Plant Clean) and 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.

This section provides a description of the features and operating conditions for carbonization of coal in the sole-heated oven, including the preparation of coke samples from coals in this project for measurement of coke strength after reaction (CSR) and coke reactivity index (CRI) following a procedure developed at CanmetENERGY (MacPhee et al., 2013). It also provides a description of the Carbolite pilot oven used to carbonize a larger amount of the sample of 100% Plant Clean and assess its resulting coke quality.

Sole-Heated Oven (ASTM D2014-97(2010))

A 12 kg sample of coal (70–80% –3.35 mm or –6 mesh) was divided equally and each half charged into one chamber (approximately 280 mm in width, length and depth) of a double-chambered oven. A weighted piston applied a constant force corresponding to a pressure of 15.2 kPa (2.2 psi) to the top of the coal bed (thickness in the 76–90 mm range), which was heated from below according to a prescribed temperature program. The sole temperature was raised from 554°C to 950°C at a heating rate of 0.9–1°C/min during the test. The movement of the load was continuously monitored during the test, which was complete when the temperature at the top of the coal bed reached 500°C (normally reached after a period of 6–7 hours). The measured expansion or contraction of the sample was converted to a reference base of 833 kg/m^3 (52 lbs./cu. ft.) and 2% moisture.

After carbonization, the semi-coke was removed from the sole-heated oven and reheated in a stainless-steel holding box (229 mm wide, 292 mm long and 305 mm deep) that is hermetically sealed on top with a 3 mm thick section of stainless steel and lined with a 3 mm thick layer of ceramic-fibre insulation. The steel has an exit hole 1 cm in diameter in the centre for venting the hot coke gases. Also, the holding box is fitted on the bottom with a stainless-steel inlet tube (150 mm long and 6 mm inside diameter) connected to a cylinder of nitrogen gas, which allows for continuous flushing of the coke with the gas (5–10 L/min flow rate) to prevent its combustion. This treatment heated the semi-coke to 1100°C to complete the annealing of the coke.

A schematic of a sole-heated oven is presented in Figure 6 and a photo of the sole-heated oven used in this project is shown in Figure 7.

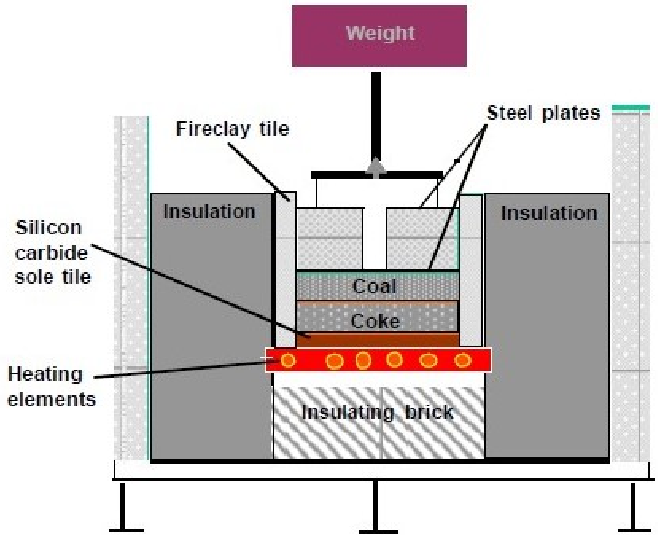

Figure 6. Schematic diagram of the CanmetENERGY sole-heated oven.

Figure 7. CanmetENERGY sole-heated oven (12 kg capacity) used in this study.

Cokes from the sole-heated oven were assessed for apparent specific gravity (ASG) and hot-strength properties, including CSR and CRI (following the ASTM D5341M-14 standard), and were analyzed for proximate (moisture, ash, volatile matter and fixed carbon), sulphur and carbon forms/textures using an optical microscope.

The ASG of coke is defined as the ratio of the mass of a volume of dry coke to the mass of an equal volume of water. Coke ASG varies with the rank and ash content of the coal carbonized, the bulk density of the coal charge in the oven, the carbonization temperature and the coking time (Price and Gransden, 1987). In this project, the ASG of cokes was determined following a method developed at CanmetENERGY and related to the ASTM D167-93 (2004) and ISO 1014:1985 standards.

According to ASTM D5341-14, the CRI is the percentage weight loss of the coke sample after reaction in CO_2 at 1100°C for 2 hours. The cooled, reacted coke is then tumbled in an I-drum for 600 revolutions at 20 rpm. The cumulative percentage of +9.5 mm coke after tumbling is denoted as the CSR.

Microscopic analysis of the textures was also performed on the sole-heated cokes to measure the carbon forms. This technique is extremely useful for understanding the behaviour of coal during coking and for interpreting pressure generation and coke-quality results.

Carbon-form analysis in cokes in this project was carried out using a combination of the US Steel method (Gray and DeVanney, 1986) and the CanmetENERGY method, which is based on work carried out by Marsh in 1978–1981 and published in the book *Introduction to Carbon Science* (Edwards et al., 1989). A single point count is made for each measured field of view. For each field, the stage is rotated in order to determine the possible highest rank carbon form. Normally, 500-point counts are performed on a sample. Each carbon form is derived from an assumed parent-coal vitrinite type. From the coke-texture analysis, one can determine the effective coal reflectance (%Ro).

Carbolite Pilot Oven

Specifications of the Carbolite pilot-scale movable-wall coke oven (Carbolite Gero Ltd., Sheffield, United Kingdom) are listed in Table 1 and the oven is shown in Figure 8.

Table 1. Specifications of the CanmetENERGY Carbolite pilot movable-wall coke oven.

Coke Oven Specifications	Carbolite Pilot Movable Wall Coke Oven
Chamber Width (mm)	460
Chamber Volume (m^3)	0.401
Charge Weight (kg)	~340 - 350
Coal Size % passing 3.35 (mm)	80-85
Charge Density in Oven (dry) (kg/m^3)	809 - 825
ASTM Bulk Density (wet) (kg/m3)	773 - 783
Charge Moisture (%)	2.5 - 3.2
Heating Control (Flue Temperature) (°C)	875 deg C start increase 15 deg °C/h to 1130 °C
Pushing Time (hrs)	3 hrs after CT = 950 °C (usually around 18h)
Quench	Water (wet) normally: N_2 gas (Dry) is also possible
Coke Treatment (Conditioning)	Client specified (usually 1 or 3 drops from 3 m height)

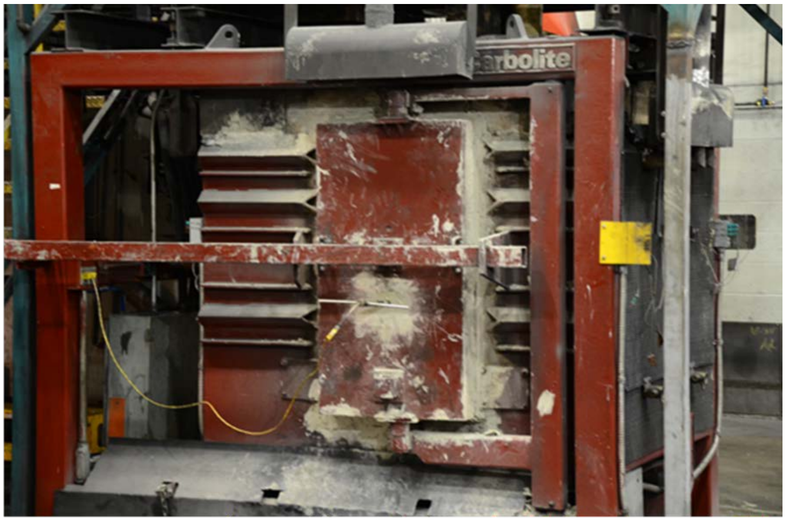

Figure 8. CanmetENERGY Carbolite pilot-scale coke oven (340 kg capacity) used in this study.

To simulate industrial coking, the temperature of the oven is kept low (875°C) at the beginning of the carbonization cycle, to limit the heat input to the coal, and then gradually raised (15°C/h) until the flue temperature reaches 1130°C. The oven is normally charged with coal 85 ±5% of which is less than 3 mm, and the coal moisture is adjusted so as to achieve a dry-coal bulk density in the oven in the range 810–825 kg/m^3. The oven is discharged 3 hours after the centre temperature of the coke reaches 950°C. The coke is water quenched and dropped 3 m onto a concrete floor in order to condition or stabilize it. This process is carried out in preparation for the drum testing, followed by measurement of the resultant coke properties.

The coke discharged from the Carbolite oven is assessed for size distribution, proximate analysis, sulphur, coke stability and hardness using the ASTM tumbler method, the cold strength drum index (DI) test of the Japanese Industrial Standard (JIS), CSR/CRI, ASG and texture.

Fundamentals of Coal Science

A small budget was set aside to further investigate the science behind the chemical reaction between perchloroethylene and coal macerals. The intent was to carry out the investigation using the micro-FTIR machine, but the work could not be completed during 2018. Therefore, the applicability of a family of liquids called Novec 7000 series in washing coal was tested, in collaboration with a research scientist at 3M.

Novec 7000, also known as 1-methoxyheptafluoropropane, is an engineered liquid developed by 3M. It has a low toxicity, is not known or suspected to cause cancer, and is nonflammable and noncorrosive. It has a specific gravity of 1.40. Novec 7700, also known as Furan (2,3,3,4,4-pentafluorotetrahydro-5-methoxy-2,5-bis[1,2,2,2-tetrafluoro-1-(trifluoromethyl)ethyl), was also engineered by 3M. This liquid has the same benign characteristics as Novec 7000; in fact, it is suggested that it can be ingested without any medical concerns. The specific gravity of Novec 7700 is 1.797. The two liquids are miscible and can be used to create a range of liquids from 1.40 to 1.80 sg.

To complete detailed washability studies with coal, customers often require float densities over that range. This Novec fluid is a potential candidate for the replacement of harmful organic liquids in the float/sink procedure. Since 3M was prepared to donate the liquids for use in this research, it was thought that this was the opportune time to carry out the research. Novec 7000 and 7700 liquids were mixed in varying proportions to create heavy liquid baths with the following specific gravities: 1.40, 1.50, 1.60, 1.70 and 1.80. Raw coal underwent float-and-sink analysis according to ASTM D4371 in both traditional organic liquids (perchloroethylene, white spirits and methylene bromide) and the Novec solutions. The float-and-sink data were then compared for yield and quality characteristics. Clean coals resulting from both studies were also compared for a range of quality parameters. Results are not finalized as yet.

Results

Clean Coal Quality

This research project had the opportunity to obtain raw and clean coal from a single-seam plant run. Because of this, clean-coal samples derived from a number of methodologies were compared. As mentioned, the ability to compare laboratory-washed coal to that cleaned in an industrial-sized wash plant is considered the gold standard in validating a laboratory method for washing coal. Table 2 shows how these clean-coal samples compared.

On an ash basis, the clean coal derived from the float-and-sink process was a cleaner product. with ash less than 7%. The float/sink process in organic liquids provides ‘perfect separation’ between coal and rock. Care was taken not to create a clean-coal product that would be impossible to create in an industrial plant. Therefore, the specific gravity cut point remained less than 1.70, which is the cut-off achievable for a processing plant. The two factors, limiting the specific gravity cut point and the organic liquids achieving perfect separation (with no misplaced particles), resulted in the ash of the clean coal being lower than those from the Roben Jig or the industrial plant.

Other coal-quality parameters remained similar between the samples washed with organic liquids and those washed in the jig, even when changing the coarse size fractions. Re-jigging the clean coal that resulted from the traditional jigging method resulted in a lowering of the ash content from 7.80 to 6.68%. The petrography for these samples is still outstanding.

The free-swelling index of the six clean-coal composites ranged from 8.0 to 8.5, with only two of the composites obtaining the 8.5 value. The chlorine content was higher in the clean-coal composites washed in the perchloroethylene float-and-sink process. This was expected due to the chlorine content of the liquids. The Hardgrove Grindability Index, fluorine, % phosphorus in coal, and mineral analysis of ash were similar for all six composites.

The Gieseler maximum fluidity was measured on all composites within a two-day period, the values ranging from 212 to 322 dial divisions per minute (ddpm). Although small differences were observed, the fluidity of this coal did not appear to be significantly decreased due to the treatment with perchloroethylene. The timeline for the dilatation testing was not kept as tight for all six samples. Therefore, the difference between the plant dilatation value of 149% and those of the other samples (107 to 125%) could have be partially due to aging.

Table 2. Clean-coal quality parameters (air-dried basis). Abbreviations: CCC, clean-coal composite; db, dry basis; ddpm, dial divisions per minute; FS, float-and-sink; REJIG, re-jigging; RJ, Roben Jig; SD 2.5, dilatation based on a 60 mm pencil per gram of air-dried coal in the test sample, multiplied by a constant of 2.5.

Clean Coal Quality (air-dried basis)	**2018**					
	FS CCC sizes	**JIG CCC sizes**	**FS CCC 12.5x0.5**	**JIG CCC 12.5x0.5**	**REJIG CCC 12.5x0.5**	**Plant Product**
Moisture%	1.29	1.21	1.20	1.38	1.22	1.00
Ash%	6.81	7.51	6.74	7.80	6.68	8.01
Volatile Matter%	29.32	30.15	29.59	29.15	29.36	28.42
Fixed Carbon%	62.58	61.13	62.47	61.67	62.74	62.57
Sulfur%	0.54	0.54	0.54	0.54	0.55	0.53
Free Swelling Index	8.5	8.0	8.0	8.0	8.0	8.5
Chlorine ppm	2280	365	2570	432	321	-
Flourine ppm	171	172	158	162	163	143
Hardgrove Grindability Index	79	78	78	79	80	-
Specific Gravity	1.37	1.37	1.31	1.35	1.36	-
% Phosphorus in coal (db)	0.040	0.042	0.043	0.045	0.044	0.045
Max Fluidity (ddpm)	290	274	281	298	322	212
Ruhr Dilatation						
% Contraction	25	25	28	25	26	28
% Dilatation	107	121	112	118	125	149
% Total Dilatation	132	146	140	143	151	177
% SD 2.5	108	120	118	127	133	150
Mineral Analysis of Ash						
SiO_2 (%)	58.50	59.76	57.56	59.57	58.27	58.86
Al_2O_3 (%)	31.44	29.60	32.79	29.61	31.16	29.78
TiO_2 (%)	1.57	1.47	1.56	1.41	1.52	1.53
CaO (%)	1.43	1.46	1.97	1.26	1.83	1.48
BaO (%)	0.28	0.31	0.31	0.32	0.29	0.28
SrO (%)	0.15	0.14	0.14	0.14	0.17	0.12
Fe_2O_3 (%)	1.46	1.59	1.50	1.62	1.60	3.17
MgO (%)	0.48	0.58	0.53	0.56	0.51	0.48
Na_2O (%)	0.08	0.08	0.05	0.07	0.07	0.09
K_2O (%)	1.16	1.51	1.22	1.66	1.41	1.22
P_2O_5 (%)	1.32	1.26	1.46	1.30	1.49	1.28
SO_3 (%)	0.27	0.27	0.30	0.23	0.23	0.21
Undetermined (%)	1.86	1.97	0.61	2.25	1.45	1.50

Petrography

Table 3 lists complete petrography data on 100% Plant Clean, Float/Sink and Roben Jig clean coal samples analysed by Pearson Coal Petrography. Petrography data is comprised of the following elements:

i. Vitrinite mean maximum reflectance (Romax) - a measure of coal rank or maturity
ii. Vitrinite types - used to tabulate vitrinite reflectance data in the form of frequency distributions, where the individual reflectance values are usually classified into groups of 0.1% reflectance
iii. Reactives - constituents in coal which undergo transformation (softening, melting, fusion, agglomeration) during heating process. Vitrinite is the most abundant reactive maceral (organic component) in bituminous coals
iv. Inerts - constituents in coal which remain unchanged during heating process

Figure 9 presents vitrinite mean maximum reflectance (Romax) for 100% Plant Clean, Float/Sink and Roben Jig clean coal samples. Data indicates very similar Romax for all samples, RoMax = 1.01 ± 0.01.

Figure 10 shows total reactives, total inerts and vitrinite in 100% Plant Clean, Float/Sink and Jig clean coal samples. As for Romax, data reveals similar correspondence for all samples except 100% Plant Clean, which is lower in vitrinite, 68%, with respect to vitrinite in Float/Sink and Jig clean coal samples, 74%, on average.

Table 3. Petrographic analysis of clean coal samples.

Project	CCRA 90 - Roben Jig Phase 2	CCRA 90 - Roben Jig Phase 2	CCRA 90 - Roben Jig Phase 2	CCRA 90 - Roben Jig Phase 2	CCRA 90 - Roben Jig Phase 2	CCRA 90 - Roben Jig Phase 2
Pearson Coal Index	38858	38859	38857	38856	38860	38855
Description	100% 12.5X0.5mm REJIG #183148	100% SIZES FLOAT SINK #183148	100% 12.5X0.5mm JIG #183148	100% 12.5X0.5mm FLOAT SINK #183148	100% SIZES JIG #183148	100% PLANT CLEAN #183147
Vitrinite Reflectance						
Vitrinite Mean Max Reflectance, %	1.00	0.99	1.01	1.01	0.99	1.02
Vitrinite V-Types (vol %)						
V08	0.8	1.5	1.5	0.7	4.4	0.7
V09	34.6	38.3	30.7	29.4	38.1	26.6
V10	36.1	32.5	38.1	41.5	29.3	36.8
V11	2.2	1.5	2.9	3.8	1.5	4.1
Total Vitrinite, %	73.7	73.8	73.2	75.4	73.3	68.2
Maceral Analysis						
Reactives, %						
Vitrinite	73.7	73.8	73.2	75.4	73.3	68.2
Liptinite	3.1	2.9	2.9	1.3	2.7	2.3
Semifusinite	7.1	7.3	7.8	8.1	7.3	9.4
Total Reactives, %	83.9	84.0	83.9	84.8	83.3	79.9
Inerts, %						
Semifusinite	7.1	7.3	7.8	8.1	7.3	9.4
Fusinite	4.4	3.7	3.2	2.5	4.0	4.0
Inertodetrinite	0.6	1.2	0.6	0.8	1.1	2.1
Macrinite	0.2					0.2
Mineral Matter	3.8	3.8	4.5	3.8	4.3	4.4
Total Inerts, %	16.1	16.0	16.1	15.2	16.7	20.1

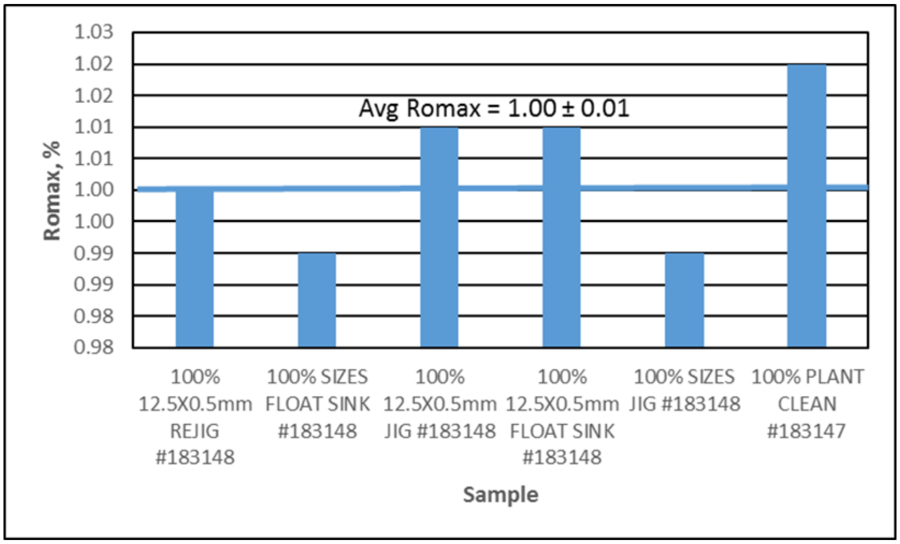

Figure 9. Vitrinite Mean Maximum Reflectance (Romax) in samples.

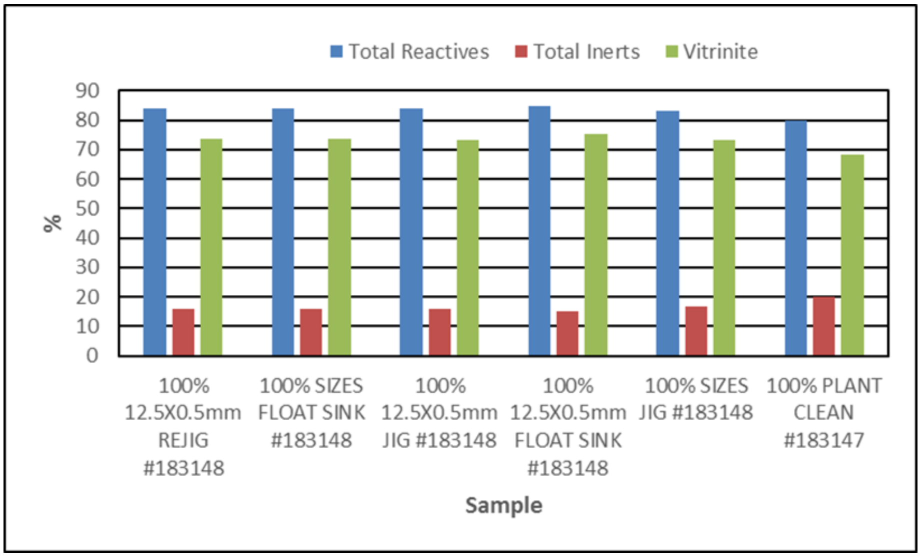

Figure 10. Total reactives, total inerts and vitrinite in 100% Plant Clean, Float/Sink and Jig clean coal samples. As for Romax, data reveals similar correspondence for all samples except 100% Plant Clean, which is lower in vitrinite, 68%, with respect to vitrinite in Float/Sink and Jig clean coal samples, 74%, on average. Vitrinite Mean Maximum Reflectance (Romax) in samples.

Phase 1 Method: Float-and-Sink and Roben Jig, One Coarse Fraction

As was found with the work completed in 2017, the Roben Jig was able to create a clean-coal composite similar to that created using organic liquids except that, in the work reported here, the ash in the clean coal from the jig was higher. This was because the specific gravity cut-point was limited to what the processing plant could achieve at the mine. It is known that organic liquids provide a perfect separation and there is usually a 'plant factor' added to yield information coming from studies such as these to account for the imperfection of a processing plant. If the limitation was not imposed on the cut point, it would have been possible to make the ashes the same.

Also, of note is that the Gieseler maximum fluidity values were comparable between the water-based method and the organic liquids. This could be due to there being less fusinite and semifusinite macerals in the coal. The petrography results will confirm this.

Misplaced Material

One of the objectives of this project was to identify and quantify the misplaced material that occurs in the column during the jigging process. A few clean slices were taken from the jigged clean coal and washed in organic liquids. Figure 11 illustrates the specific gravities of the particles that made up slice #13, one of the cleaner slices, which had an average relative density of 1.18. Washing the slice by float-and-sink showed that most of the particles fell at or below the 1.30 sg, but there were also particles from the 1.40, 1.60 and +1.90 specific gravities.

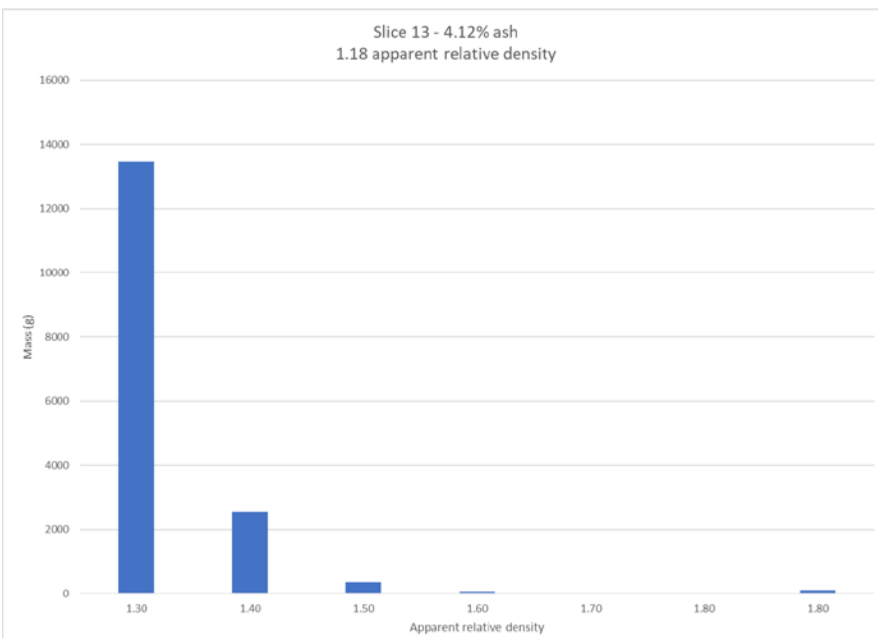

Figure 11. Particle-density distribution, expressed as proportions by mass, of low-density jig slice.

Figure 12 shows slice #1 from the Roben Jig. This was the slice with the highest ash content and had an average apparent relative density of 2.28. The float-and-sink process separated the coal particles into the correct specific gravity baths. Most of the particles fell into the +1.90 sg class, which is what one would expect to see as the highest ash 'sink'. This would be where one would find the rock. Particles contained in slice #1 also fell into the –1.30, 1.30, 1.40, 1.50, 1.60, 1.70 1.80 classes.

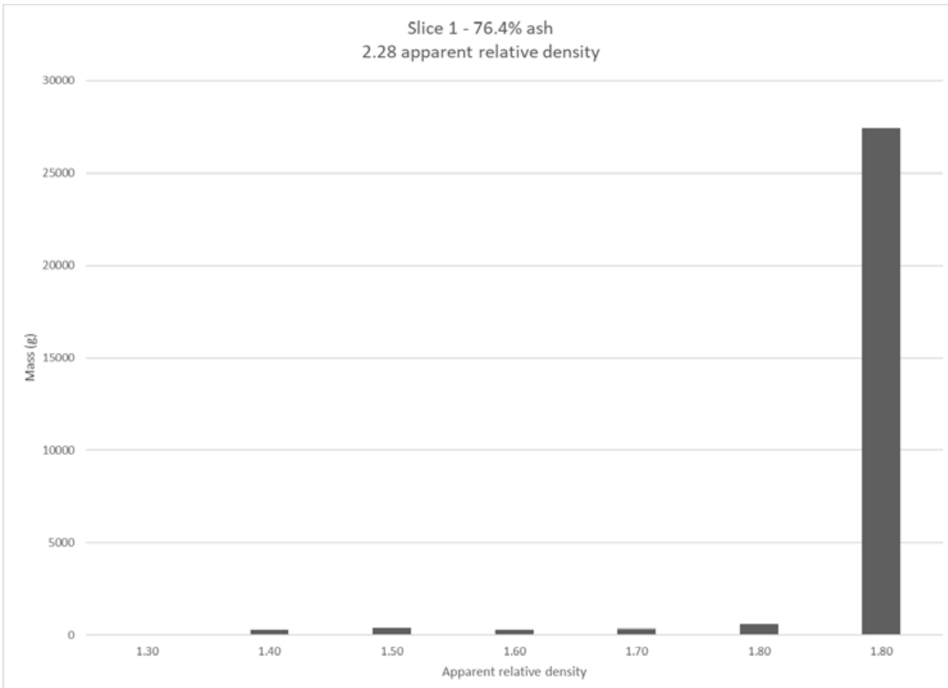

Figure 12. Particle-density distribution, expressed as proportions by mass, of high-density jig slice.

A further step was to take the clean-coal composite, as compiled from the Roben Jig method, and wash it in organic liquids to determine the density of the particles. The cut-point of the clean-coal composite had an ARD of 1.54. Table 4 shows the mass percentage falling into each specific-gravity class. Approximately 94% of the particles fell below the 1.54 sg. Five percent of the particles forming the clean-coal composite was misplaced from higher specific gravities, including 1.3% from the rock particle (+1.80 sg) sink. Although these misplaced particles exist, they do not seem to negatively impact the clean-coal quality parameters.

New Method A: Re-Jigging

The clean coal resulting from the Roben Jig traditional method was re-jigged to determine if a second cleaning action could remove misplaced particles. After re-jigging, the clean coal created during the second jigging process underwent float-and-sink analysis in organic liquids. Table 4 shows the percentage of particles falling into each specific gravity range. After re-jigging, only 2.9% of the particles in the

Table 4. Float-and-sink mass percentages falling within specific-gravity ranges of a clean coal produced by the Roben Jig. Abbreviations: FLT, float; SNK, sink.

SG	Mass %
1.30 FLT	67.4
1.30 - 1.40	22.6
1.40 - 1.50	4.1
1.50 - 1.60	1.4
1.60 - 1.70	0.9
1.70 - 1.80	0.7
1.80 SNK	3.0

Table 5. Float–and-sink mass percentages falling within specific-gravity ranges of a rewashed clean coal produced by re-jigging. Abbreviations: FLT, float; SNK, sink.

SG	Mass %
1.30 FLT	69.9
1.30 - 1.40	23.8
1.40 - 1.50	3.5
1.50 - 1.60	1.0
1.60 - 1.70	0.6
1.70 - 1.80	0.4
1.80 SNK	0.9

clean-coal composite were misplaced from other higher specific gravity ranges. Re-jigging was confirmed to be a useful method of reducing the amount of misplaced material.

New Methods B and C: Float-and-Sink and Roben Jig, Two Size Fractions

Changing the size range of the coarse particles that undergo float-and-sink washing is a standard practice in the laboratory washing of coal. It was because of this, and some information from Pielot (2010), that it was proposed to investigate washing different coarse fractions separately in the Roben Jig. Pielot thought that narrowing the size fraction resulted in more precise jigging. In this study, no difficulties were encountered while jigging the 12.5 × 2 mm fraction. However, jigging the finer 2 × 0.5 mm fraction proved difficult: it was found that there were inconsistencies between slices. Usually, the relative density of slices behaves predictably: the highest relative density occurs at the bottom of the column, with lower relative densities occurring in a stepwise fashion moving to the top of the column. The inconsistencies between slices of the finer fraction suggested that there was misplaced material. When the clean coal from this fraction was washed by float-and-sink, it was found that there were 9% misplaced particles. Table 6 shows the specific-gravity distribution of the coal particles at the 1.40 sg cut point.

From an operational standpoint, jigging the finer size fraction was also more time consuming, as the operator had to continually check the work that was done. This method of misplaced-material mitigation did not prove to be the best method.

Table 6. Float–and-sink mass percentages falling within specific-gravity ranges of a washed clean coal produced by jigging the 2 x 0.5 mm size fraction. Abbreviations: FLT, float; SNK, sink.

SG	Mass %
1.30 FLT	72.2
1.30 - 1.40	18.8
1.40 - 1.50	3.7
1.50 - 1.60	1.8
1.60 - 1.70	0.8
1.70 - 1.80	0.5
1.80 SNK	2.2

Clean-Coal Carbonization

Table 7 presents analytical data for cokes made in the sole-heated oven from coals studied in this project.

Contraction levels range from –15% for 100% plant clean product crushed to 12.5 mm to –9% for 100% JIG CCC 12.5 × 0.5 and 100% REJIG 12.5 × 0.5. The type of washing medium, namely organic liquids for float-and-sink and water for Roben Jig, had a minor effect on the level of sole-heated oven contraction observed, –11% and –10%, respectively. The low amount of volatile matter remaining in the cokes (<1%) provides clear evidence that the coals were essentially fully carbonized by a combination of coking in the sole-heated oven and heat treatment of the resulting semi-coke to 1100°C under nitrogen to complete the annealing of the coke.

The apparent specific gravity (ASG) of coke ranged between 0.96 (100% REJIG 12.5 × 0.5) and 1.01 (100% plant clean product crushed to 12.5 mm). As stated earlier, the rank and ash content of the carbonized coal dictates the coke ASG. The low ash content of 6.8% (db) in 100% REJIG 12.5 × 0.5 results in the lowest ASG coke, whereas the high ash content of 8.2% (db) in 100% plant clean product crushed to 12.5 mm results in the highest ASG coke.

Coke textures/carbon forms (C forms) data listed in Table 7 indicate that the washing media had only a minor influence on the development of textures during coal to coke transformation. The only apparent difference observed is in the proportions of inert fusinite and semi-fusinite in the cokes produced from washing coal with organic liquid and water. Organic liquid washing (float/sink) produced cokes with respectively higher percentage of fusinite, 35 ± 2%, and lower percentage of semi-fusinite, 61 ± 1% than measured in cokes issued from washing coal with water, fusinite, 18 ± 4%, and semi-fusinite, 79 ± 3%.

The fractions of reactive and inert textures in the cokes are found to be similar by washing coals using traditional float and sink method with organic liquids and by the Roben jig using water. This is also supported by the fact that the ‘effective’ coking rank (Roeff) for the individual coals washed in the different media are identical, Roeff = 1.01. The most common classification of coal is based on rank, referring to the degree of coalification that has occurred. The rank of a coal is determined primarily by the depth of burial and temperature to which the coal was subjected over time. Examination of carbon forms in coke, after a coal is transformed into a coke, provide a true measure of the degree of coalification or rank of coal, which is its effective coking rank or Roeff. It is revealing and interesting to point out that coking rank based on carbon forms measured in the cokes are almost identical to the rank determined from coal petrography. In fact, Roeff = 1.01 and Ro = 1.00. This indicates that Plant Clean coal produces carbon forms expected based on coal petrography vitrinite-type measurements.

Table 7. Quality of coke samples obtained from sole-heated oven tests. Abbreviations: CCC, clean-coal composite; FS, float-and-sink; JIG, Roben Jig; REJIG, re-jigging.

Date Received		AUG/10/18	AUG/10/18	AUG/10/18	AUG/10/18	AUG/10/18	AUG/7/18	AUG/7/18
Weight Received		1-PAIL	1-PAIL	1-PAIL	1-PAIL	1-PAIL	1-PAIL	3-DRUMS
Project		CCRA 90 - Roben Jig Phase 2	CCRA 90 - Roben Jig Phase 2	CCRA 90 - Roben Jig Phase 2	CCRA 90 - Roben Jig Phase 2	CCRA 90 - Roben Jig Phase 2	CCRA 90 - Roben Jig Phase 2	CCRA 90 - Roben Jig Phase 2
Coal Index		26774	26775	26776	26777	26778	26798	26800
Description		100% 12.5X0.5mm REJIG #183148 Sole-Heated Oven	100% SIZES FLOAT SINK #183148 Sole-Heated Oven	100% 12.5X0.5mm JIG #183148 Sole-Heated Oven	100% 12.5X0.5mm FLOAT SINK #183148 Sole-Heated Oven	100% SIZES JIG #183148 Sole-Heated Oven	100% PLANT CLEAN CRUSHED TO 12.5mm Sole-Heated Oven	100% PLANT CLEAN #183147 Sole-Heated Oven
Expansion/Contraction	%	-9.4	-11.8	-9.2	-11.0	-11.0	-14.5	-11.6
Moisture	%	0.12	0.16	<0.1	0.14	<0.1	<0.1	<0.1
Ash	%	8.89	8.64	10.74	9.29	10.18	10.71	11.0
Volatile Matter	%	0.64	0.67	0.92	0.38	0.71	0.49	0.5
Fixed Carbon	%	90.47	90.69	88.34	90.33	89.11	88.80	88.4
Sulphur	%	0.45	0.42	0.44	0.45	0.45	0.46	0.5
CSR		65.0	65.5	64.3	68.3	70.5	64.2	61.5
CRI		20.6	21.3	19.2	18.5	17.2	23.0	25.2
ASG		0.963	0.970	0.989	0.988	0.995	1.012	1.004
Isotropic	%	2.2	1.3	1.8	2.0	1.6	1.5	2.8
Very Fine Mosaic	%	12.3	11.6	16.1	5.9	9.5	8.8	11.4
Fine Mosaic	%	47.6	52.8	46.7	33.1	28.9	36.7	20.0
Medium Mosaic	%	23.7	19.1	18.7	45.1	43.8	33.3	48.3
Coarse Mosaic	%	1.1	1.8	1.5	2.5	3.1	2.1	4.2
Total Mosaic	%	84.7	85.3	83.0	86.6	85.3	80.9	83.9
Elongated Fine Flow	%	3.1	0.9	4.6	2.7	1.9	4.8	3.3
Rlongated Medium Flow	%	0.3	0.1	0.6	0.8	0.4	0.3	1.0
Elongated Coarse Flow	%	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Total Flow	%	3.4	1.0	5.4	3.5	2.3	5.1	4.3
Domain Flat Flow	%	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Domain Undulating	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Domain Ribbon	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Domain	%	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Fusinite	%	2,3	4.1	2.2	2.9	1.4	2.5	1.9
Semifusinite	%	6.6	7.7	7.4	4.7	8.8	8.9	6.1
Unidentifed Inerts	%	0.8	0.6	0.2	0.3	0.6	1.1	0.9
Altered Vitrinite	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Inert	%	9.7	12.4	9.8	7.9	10.8	12.5	8.9
Coal Ro Calculated		0.99	0.97	0.98	1.05	1.04	1.03	1.05
Coke Mosaic Index		1.91	1.90	1.90	2.00	1.95	1.98	1.97

The Coke Mosaic Size Index (CMSI) for the Plant Clean coal washed in the different media is also very similar, namely 1.95 ± 0.05 for cokes from float/sink washing and 1.93 ± 0.02 for cokes from Roben Jig washing. CMSI is a mathematical method to summarize the carbon form analysis (Coin). The higher the CMSI, the higher the rank based on carbon forms measured. In the present study, the CMSI of the various cokes is very similar, CMSI in range 1.90 – 2.00.

The coke strength after reaction (CSR) of the clean coal resulting from all washing methods was compared. Comparison of New Methods B (FS CCC sizes) and C (JIG CCC sizes) revealed that Method C (Roben Jig) washing improved the CSR by 5 points relative to Method B (float-and-sink). Method C (JIG CCC sizes) also resulted in a 6-point increase in CSR when compared to the Phase 1 Method (JIG CCC 12.5 × 0.5). Washing the coal using New Method B (FS CCC sizes) resulted in a 3-point decrease in the CSR compared to the Phase 1 Method (FS CCC 12.5 × 0.5).

A comparison of the CSRs resulting from coal washed using the Phase 1 methods of jigging and float-and-sink (one coarse fraction of 12.5 x 0.5 mm) shows that Roben Jig washing led to a CSR 4 points lower than float-and-sink washing. Re-jigging of this coal led to a negligible change/improvement in CSR.

The CSR of the plant-washed coal (plant product) was 61.5. After crushing the plant-washed coal to pass 12.5 mm, the CSR increased to 64.2. Crushing of the product to 12.5 mm led to a 3-point improvement in CSR relative to the complete size range. It should be noted that the repeatability of this test is 3.3. This would indicate that the CSRs are actually quite similar.

Table 8 presents analytical data for coke made in the Carbolite oven from 100% plant clean product (sample #183147).

Assessment of the quality of cokes made in the sole-heated oven and the Carbolite pilot oven from 100% plant clean product found ASTM stability and hardness of 56 and 66, respectively; JIS DI30/15 and DI150/15 of 94 and 85, respectively; and CSR and CRI of 58 and 27, respectively. The CSR and CRI from the larger pilot-scale coke oven (340 kg) are found to be inferior to those from the smaller sole-heated oven (12 kg), which are 62 and 25, respectively (Figure 13).

The superior CSR and CRI of coke produced in the smaller sole-heated oven is expected, since the carbonization process took place under a significantly higher load/pressure (15.2 kPa) than that in the larger pilot oven (4–8 kPa). This led to the formation of a coke with higher apparent density (ASG of 1.00), and thus lower porosity, from the sole-heated oven compared to that from the larger pilot oven (ASG of 0.92).

Table 8. Quality of coke samples obtained from Carbolite pilot oven tests on 100% plant clean #183147.

	Date Received		AUG/7/18
	Weight Received		3-DRUMS
	Project		CCRA 90 - Roben Jig Phase 2
	Coal Index		26799
	Description		100% PLANT CLEAN #183147 C-2733
Sole-Heated Oven Test	Expansion/Contraction	%	-11.6
Coke Moisture	Moisture	%	<0.1
Coke Proximate (db)	Ash	%	10.88
	Volatile Matter	%	0.46
	Fixed Carbon	%	88.66
	Sulphur	%	0.46
Carbonization Results	Oven Test Number		C-2733
	Test Date		SEP/7/18
	Moisture in Charge	%	3.0
	Net dry charge weight	kg	336.8
	ASTM BD	kg/m3	773.7
	Oven dry BD	kg/m3	815.6
	Coking time	h:min	18:14
	Final Center Temp	oC	1074
	Time to 900 °C	h:min	14:48
	Time to 950 °C	h:min	15:14
	Time to 1000 °C	h:min	15:51
	Time to Max Wall Pressure	h:min	2:45
	Max wall pressure	kPa	4.1
	Max gas pressure	kPa	6.7
	Coke Yield	%	72.4
Sieve Analysis of Coke, cumulative	100 mm sieve	%	0.4
	75 mm sieve	%	7.6
	50 mm sieve	%	51.3
	37.5 mm sieve	%	83.6
	25.0 mm sieve	%	94.3
	19.0 mm sieve	%	95.3
	12.5 mm sieve	%	96.1
	Passing 12.5 mm sieve	%	3.9
	Mean coke size	mm	53.0

ASTM Coke Tumbler Test	Stability		56.3
	Hardness		66.3
JIS Coke Tumbler Test	50 mm sieve 30 rev		21.2
	25 mm sieve 30 rev		90.6
	15 mm sieve 30 rev		93.6
	50 mm sieve 150 rev		8.0
	25 mm sieve 150 rev		79.4
	15 mm sieve 150 rev		85.1
	CSR		58.3
	CRI		27.2
	ASG		0.920
Coke Texture	Isotropic	%	2.7
	Very Fine Mosaic	%	7.4
	Fine Mosaic	%	34.9
	Medium Mosaic	%	32.3
	Coarse Mosaic	%	3.8
	Total Mosaic	%	78.4
	Elongated Fine Flow	%	4.2
	Rlongated Medium Flow	%	0.9
	Elongated Coarse Flow	%	0.0
	Total Flow	%	5.1
	Domain Flat Flow	%	0.0
	Domain Undulating	%	0.0
	Domain Ribbon	%	0.0
	Total Domain	%	0.0
	Fusinite	%	3.5
	Semifusinite	%	9.5
	Unidentifed Inerts	%	0.8
	Altered Vitrinite	%	0.0
	Total Inert	%	13.8
	Coal Ro Calculated		1.04
	Coke Mosaic Index		2.02

(Table 8 continued)

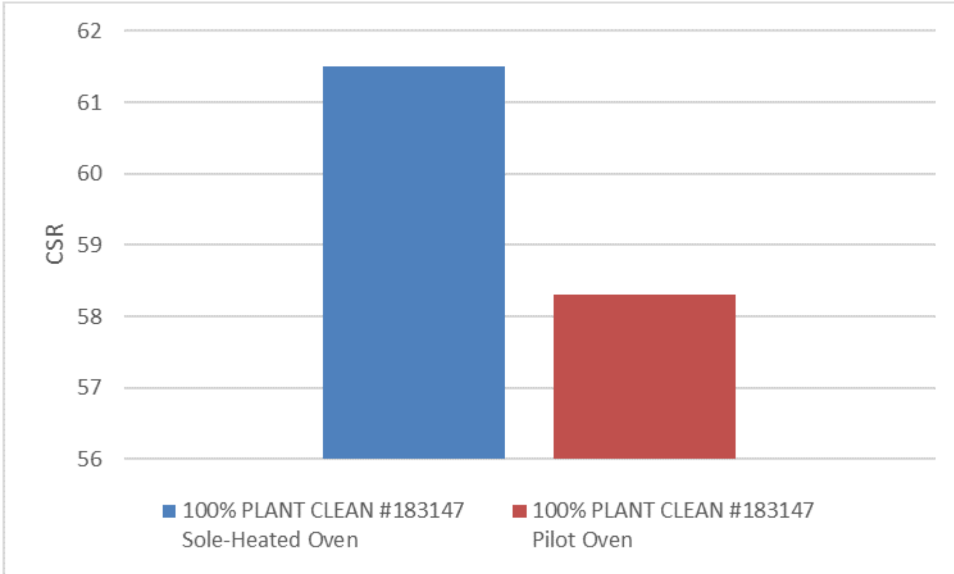

Figure 13. CSR comparison of cokes made in the sole-heated oven and Carbolite pilot-scale oven from 100% plant clean product (sample #183147).

Fundamentals of Coal Science

The original proposal outlined research work involving micro-FTIR technology for use in evaluating the chemical reaction between the coal surface and organic liquids. This work was to be a continuation of some preliminary studies completed in 2017. This work was being peer reviewed during 2018 and we were unable to move forward with this line of study.

Researching alternative liquids has always been on our research road map. The Roben Jig allows us to create clean coal composites quickly and effectively for charging into a small-scale coke oven, however it does not fully deliver detailed, precise washability tables due to the misplaced material that occurs. At this time, organic liquids (PCE, naptha and methylene bromide) is still the only proven way to provide these detailed wash studies.

Our research group had several meetings with a research chemist from 3M Canada. They were provided with a proposal that outlined a potential business case (appendix) and were fully briefed on our research activities and goals. They offered to donate approximately $1000 in fluids – Novec 7000 and Novec 7700 for some preliminary studies. We decided to use the budget for "Fundamentals of Science" to do a test washability using the Novec fluids.

Novec fluids are engineered to be used for the cooling and cleansing of electronic devices. They are not harmful to humans. In fact, the MSDS sheet indicates that if these fluids are swallowed, no medical intervention is required. The Novec 7000 fluid has a specific gravity of 1.42 and the Novec 7700 has a specific gravity of 1.805. This allowed us to create baths with specific gravities 1.42, 1.50, 1.60, 1.70, 1.805.

The same coal that was used in evaluating the Jig was used to test the Novec fluids. A new subsample was taken from the raw coal. Half of this sample was washed in the Novec fluids and the other half was washed using the tradition organic liquids – PCE, Naptha and Methylene Bromide. Results of these float/sink tests are listed in Table 9 below. In terms of delivering washability data – wt. (g) and wt. (%) that floated at each specific gravity, the Novec fluids worked just as well as the traditional organic liquids. Even the coal quality of each float compared very closely. The results in Table 9 suggest that the Novec fluids can be substituted for traditional organic liquids in the float/sink procedure and yield correct results.

Table 9. Washability tables resulting from the float/sink procedure using Novec fluids and traditional organic liquids.

NOVEC - FLOAT SINK ANALYSIS (12.5mmx0.5mm), air dried basis (ASTM D4371)														
								CUMUALATIVE						
S.G.	WT(g)	WT%	MOIST%	ASH %	VM %	FC %	FSI	WT%	MOIST%	ASH %	VM %	FC %	FSI
1.42 FLT	3488	66.82	0.77	5.44	29.07	64.72	8.0	66.82	0.77	5.44	29.07	64.72	8.0
1.42 - 1.50	117	2.24	0.72	22.16	23.72	53.40	3.5	69.06	0.77	5.98	28.90	64.35	7.9
1.50 - 1.60	73	1.40	0.66	33.01	21.97	44.36	3.0	70.46	0.77	6.52	28.76	63.96	7.8
1.60 - 1.70	66	1.26	0.70	42.46	19.92	36.92	2.5	71.72	0.77	7.15	28.60	63.48	7.7
1.70 - 1.805	99	1.90	0.78	51.87	17.68	29.67	1.5	73.62	0.77	8.30	28.32	62.61	7.5
1.805 SNK	1377	26.38	0.81	78.70	11.57	8.92	0.0	100.00	0.78	26.87	23.90	48.45	5.5
	5220	**5269**	**49**	**grams loss**									

PERC - FLOAT SINK ANALYSIS (12.5mmx0.5mm), air dried basis (ASTM D4371)													
								CUMUALATIVE					
S.G.	WT(g)	WT%	MOIST%	ASH %	VM %	FC %	FSI	WT%	MOIST%	ASH %	VM %	FC %	FSI
1.40 FLT	3414	65.50	1.08	5.40	29.27	64.25	8.0	65.50	1.08	5.40	29.27	64.25	8.0
1.40 - 1.50	179	3.43	1.00	20.53	23.34	55.13	3.5	68.94	1.08	6.15	28.97	63.80	7.8
1.50 - 1.60	78	1.50	0.90	31.65	22.03	45.42	3.0	70.43	1.07	6.70	28.83	63.41	7.7
1.60 - 1.70	78	1.50	1.10	41.90	19.57	37.43	2.5	71.93	1.07	7.43	28.63	62.86	7.6
1.70 - 1.80	68	1.30	0.92	50.72	17.90	30.46	1.5	73.23	1.07	8.20	28.44	62.29	7.5
1.80 SNK	1395	26.77	0.97	78.60	11.37	9.06	0.0	100.00	1.04	27.04	23.87	48.04	5.5
	5212	**5241**	**29**	**grams loss**									

Two separate clean coal composites were made using all floats including and below 1.60 sg. Table 10 compares some key clean coal quality characteristics. Clean coal separated using both liquids had essentially the same ash, volatile matter, fixed carbon, Hardgrove grindability index, sulfur and FSI. The light transmittance and percent phosphorous in coal were also the same. Because perchloroethylene contains chlorine and is known to remain as a film on the coal surface after the washing process, it is not a surprise that the PCE washed coal had a higher chlorine content than the Novec washed coal. The fluorine was slightly higher in the Novec washed coal which could be attributable to the fact that the Novec liquids both contain fluorine. The Gieseler fluidity was lower in the PCE treated coal. Perchloroethylene is known to result in lower fluidity numbers (Holuszko et al., 2017). Dilatation was only slightly higher in the Novec washed coal.

Due to the boiling point of Novec 7000 being 34 degrees Celsius, it was expected that the fluid would evaporate readily. Novec 7000 was added to a 150 ml beaker and left out for 24 hours. The fluid did evaporate readily and after 24 hours the 150 ml beaker was empty. Figure 14 shows how the Novec 7000, Novec 7700 and mixtures of the two (at varying specific gravities) evaporated over time.

The Novec 7700 fluid only lost 2 ml of fluid due to evaporation over a 24-hour period. The solutions of the two Novec fluids, varying in specific gravity, lost fluid to evaporation due to the content of Novec 7000 in the solution. It should be noted that the laboratory technicians did not see changes in the specific gravities of the liquid baths as the float/sink process was underway. For the time period spent floating the coal in the liquids, the evaporation of the Novec 7000 must have been minimal otherwise the specific gravity of the bath would have changed.

Table 10. Coal quality of clean coal arising from washing in Perchloroethylene based liquids and Novec series liquids.

Air-dried basis Unless Stated	**NOVEC**	**PERC**
Moisture%	0.91	1.13
Ash%	6.46	6.55
Volatile Matter (%)	29.9	29.9
Fixed Carbon (%)	62.7	62.4
S%	0.54	0.54
FSI	8.0	8.0
Chlorine ppm	110	2200
Flourine ppm	163	156
Hardgrove Grindability Index	79	78
Light Transmittance	94.5	94.5
%Phophorous in coal (dry basis)	0.047	0.042
Gieseler Fluidity (ddpm)	336	275
Rhur Dilatation	113	100

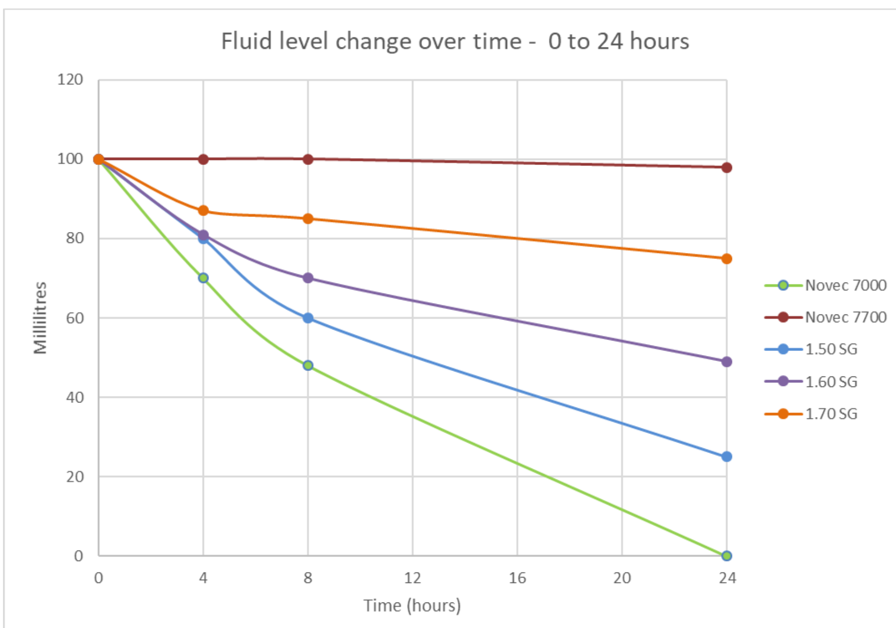

Figure 14. Novec 7000, Novec 7700 and three solutions of the two fluids at 1.50, 1.60 and 1.70 sg – comparison of fluid levels in a 150 ml beaker at 0, 4, 8, 24 hours.

Because the Novec fluids are more expensive than perchloroethylene, and the Novec 7000 fluid readily evaporates, it will be important for laboratories to install a capturing system where the Novec 7000 gas is captured and condensed for reuse. This capture and reuse method will be a consideration to look at in future phases of study.

Conclusions

The Canadian coal industry needs a reliable method of washing small metallurgical-coal samples whereby the exposure of both the coal sample and the laboratory technicians to perchloroethylene and other toxic organic liquids can be eliminated. This study evaluated the use of the Roben Jig and varying methodologies, as well as two engineered liquids (Novec 7000 and 7700), in satisfying these requirements.

When comparing the quality characteristics of clean coal samples, it is apparent that the Roben Jig was able to produce a clean-coal sample similar to that from the industrial coal-washing plant that uses the float-and-sink method with organic liquids. The ash value of the clean coal from the jig was higher than that from the float-and-sink method, but only because of limitations on cut-points imposed by the methodology. Misplaced material was found in clean-coal composites created in the jig, but in small enough proportions that it did not have a negative effect the clean-coal quality. A re-jigging action was found to be the most useful in reducing the percentage of misplaced particles. Narrowing the size range of particles during jigging proved to be operationally difficult for the finer size fraction (2 × 0.5 mm).

With respect to carbonization, evaluation of the cokes produced from the plant clean-coal product after washing of the complete size range of coal particles in the two types of media showed that the Roben Jig (New Method C) had a CSR of 70 compared to values of 65.5 and 68.3 for the float-sink methods (Phase 1 Method and New Method B). The New Method C of washing two coarse size fractions separately in the Roben Jig led to a 6-point improvement in CSR relative to washing only the 12.5 × 0.5 mm size fraction. Re-jigging the coal (New Method A) led to a negligible change/improvement in CSR.

The Novec fluids were as successful as perchloroethylene-based fluids at delivering a washability table and clean coal quality characteristics except that the rheology and chlorine content of the coal were not negatively impacted. The evaporation of the Novec 7000 fluid must be mitigated in laboratories in order to prevent loss of this fluid.

Acknowledgments

The project members thank the peer reviewer, E. Gravel (P.Geo.), Independent Consultant. Thanks also go to Geoscience BC, the Canadian Carbonization Research Association, Teck Resources Ltd., 3M Canada and GWIL Industries–Birtley Coal & Minerals Testing Division for their financial and in-kind contributions that made this project possible.

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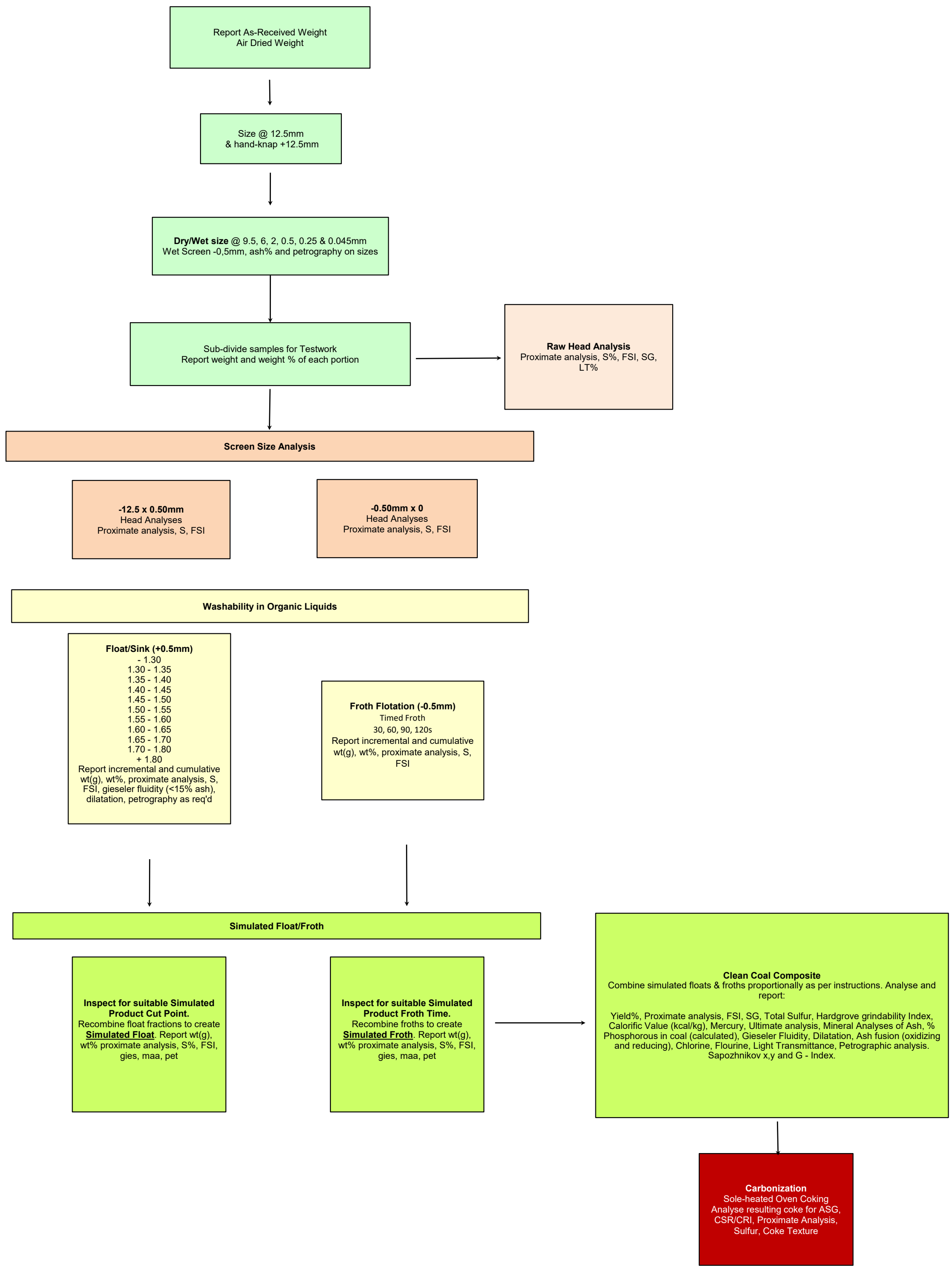
Appendix A: Analytical Standards

LABORATORY STANDARDS USED IN ROBEN JIG PROJECT

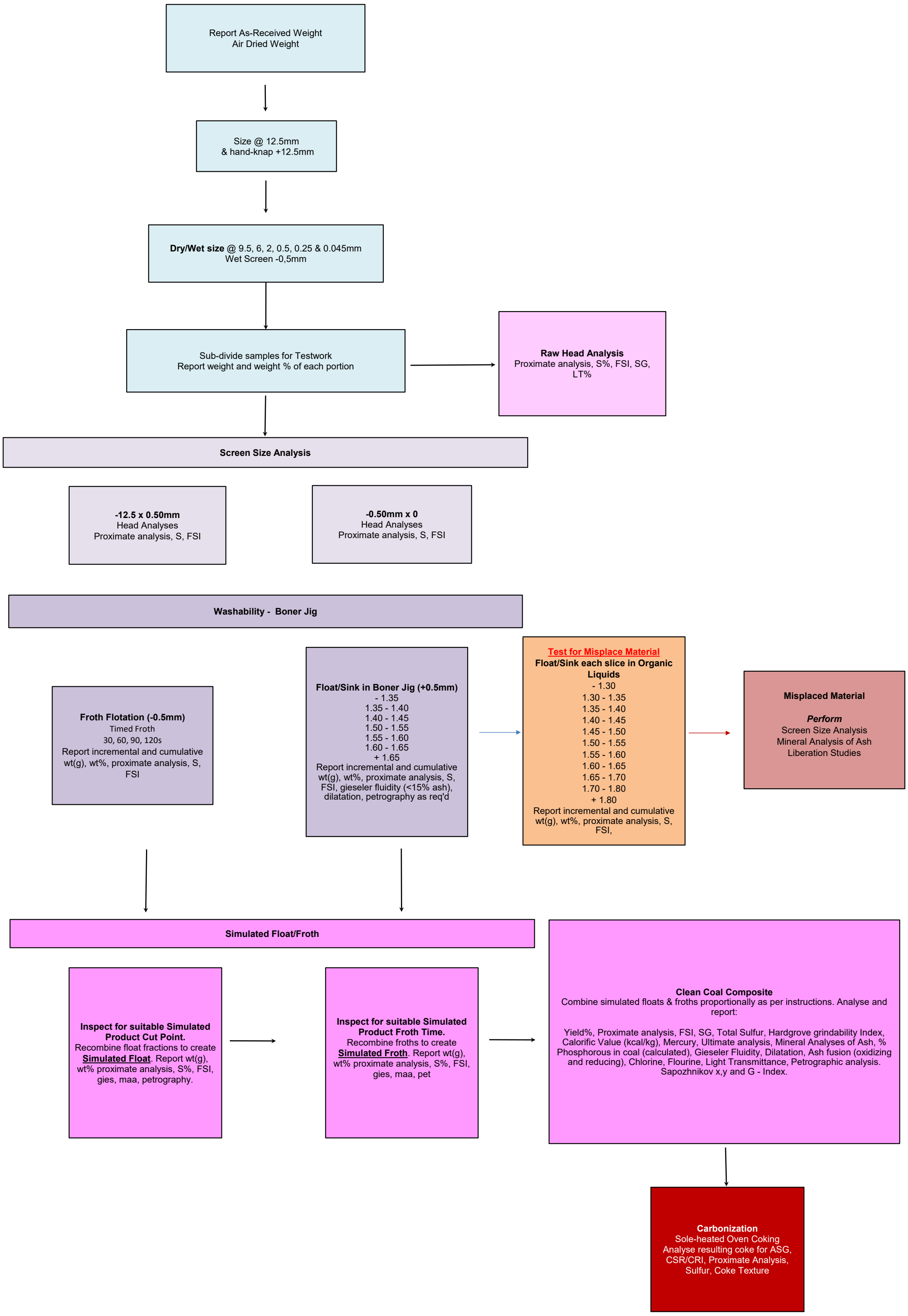
LABORATORY ANALYSIS	Procedure
APPARENT RELATIVE DENSITY (+2mm)	AS 1038 part 21.2
ASH	ASTM D3174
ASH FUSION ANALYSIS (Ox. and Red.)	ASTM D1857
CALORIFIC VALUE	ASTM D5865
CARBON or HYDROGEN or NITROGEN - COAL	ASTM 5373
CARBON and HYDROGEN and NITROGEN - COAL	ASTM 5373
CHLORINE	ASTM D4208
DILATATION TEST (RUHR-ISO 8264)	ASTM D5515
FLOAT-SINK ANALYSIS (dependent on size fraction and bulk of sample)*	ASTM D4371
FLUORINE	ASTM D3761
FREE SWELLING INDEX	ASTM D720
FROTH FLOTATION (2-Stage Standard Bench Scale Test)	ASTM D5114
GIESELER PLASTOMETER TEST	ASTM D2639
HARDGROVE GRINDABILITY TEST	ASTM D409
LIGHT TRANSMITTANCE FOR OXIDIZED COAL	ASTM D5263
MERCURY	ASTM D6722
MINERAL ANALYSIS OF ASH	ASTM D3682
MINERAL ANALYSIS OF PHOSPHOROUS	ASTM D2795
MOISTURE	
AIR DRIED - ASTM	ASTM D3302
RESIDUAL - ASTM	ASTM D3173
EQUILIBRIUM (INHERENT)	ASTM D1412
PROXIMATE ANALYSIS (Residual Moisture, Ash, Volatile, Fixed Carbon)	ASTM D3172
SCREEN ANALYSIS (dependent on size separation and bulk for sample)	ASTM D4749
SPECIFIC GRAVITY (bottle method)	ISO 1014 (MODIFIED)
SULFUR (Eschka Method)	ASTM D3177
SULFUR (LECO S-632)	ASTM D4239
SULFUR FORMS (includes total, pyritic, sulfate and organic)	ASTM D2492
ULTIMATE ANALYSIS (H2O, C, H, N, S, Ash, O)	ASTM D5373
VOLATILE MATTER	ASTM D3175
MACERAL ANALYSIS	ASTM D2799
VITRINITE REFLECTANCE	ASTM 2798, ISO7404
COKE ASG	CanmetENERGY standard based on ISO1014:1985
CSR/CRI	ASTM D5341-14
PROXIMATE ANALYSIS COKE	ASTMD7582 and ISO562
COKE TEXTURE	CanmetENERGY procedure based on Marsh, Harry; U. Newcastle, UK 1978-1981

Appendix B: Analytical Flowsheets

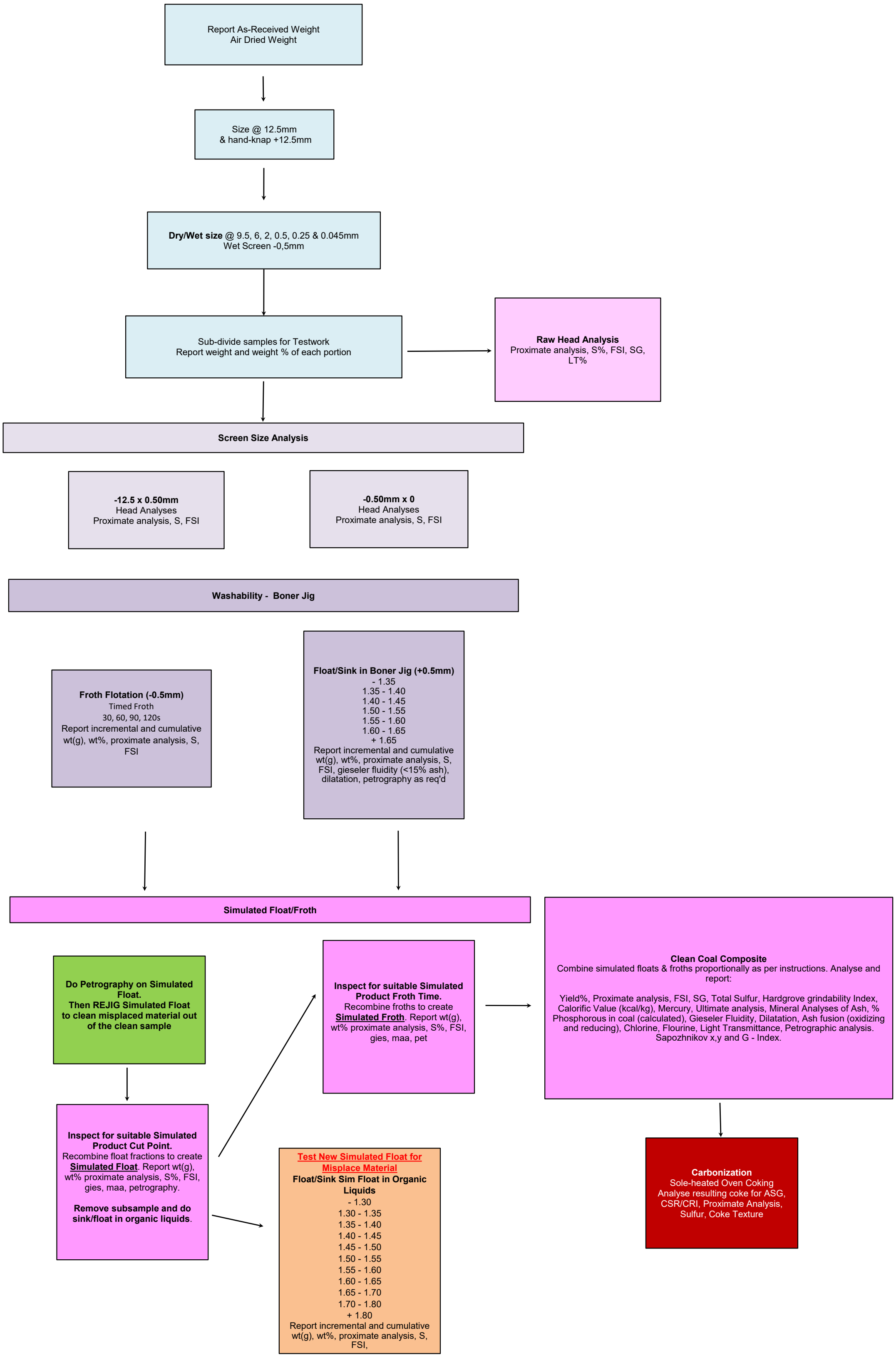
Roben Jig Project Phase 2
Float/Sink Analytical Flowsheet
Flowsheet OLFlow



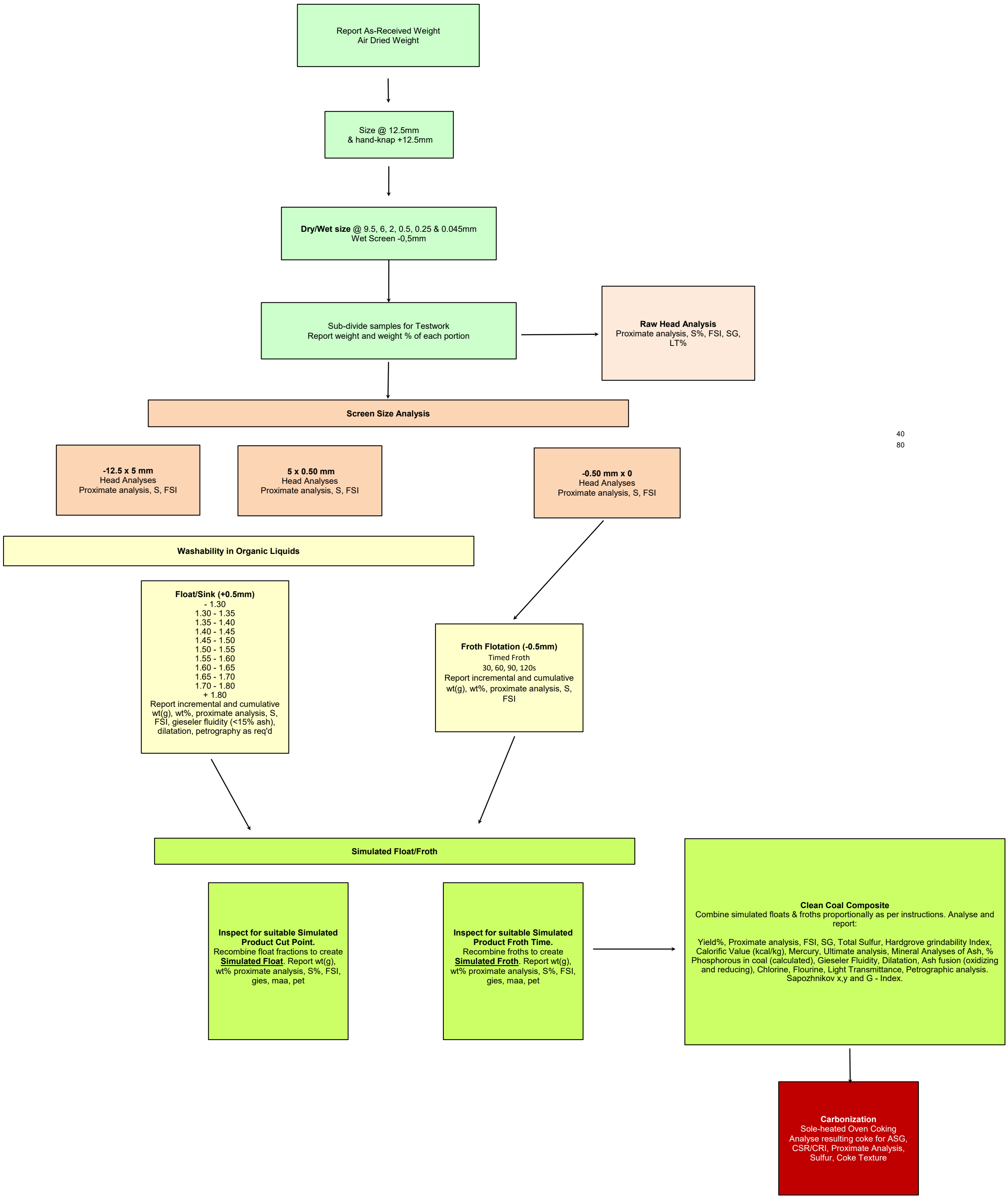
Roben Jig Project Phase 2
Original Roben Jig Method Analytical Flowsheet
Flowsheet Jig flow



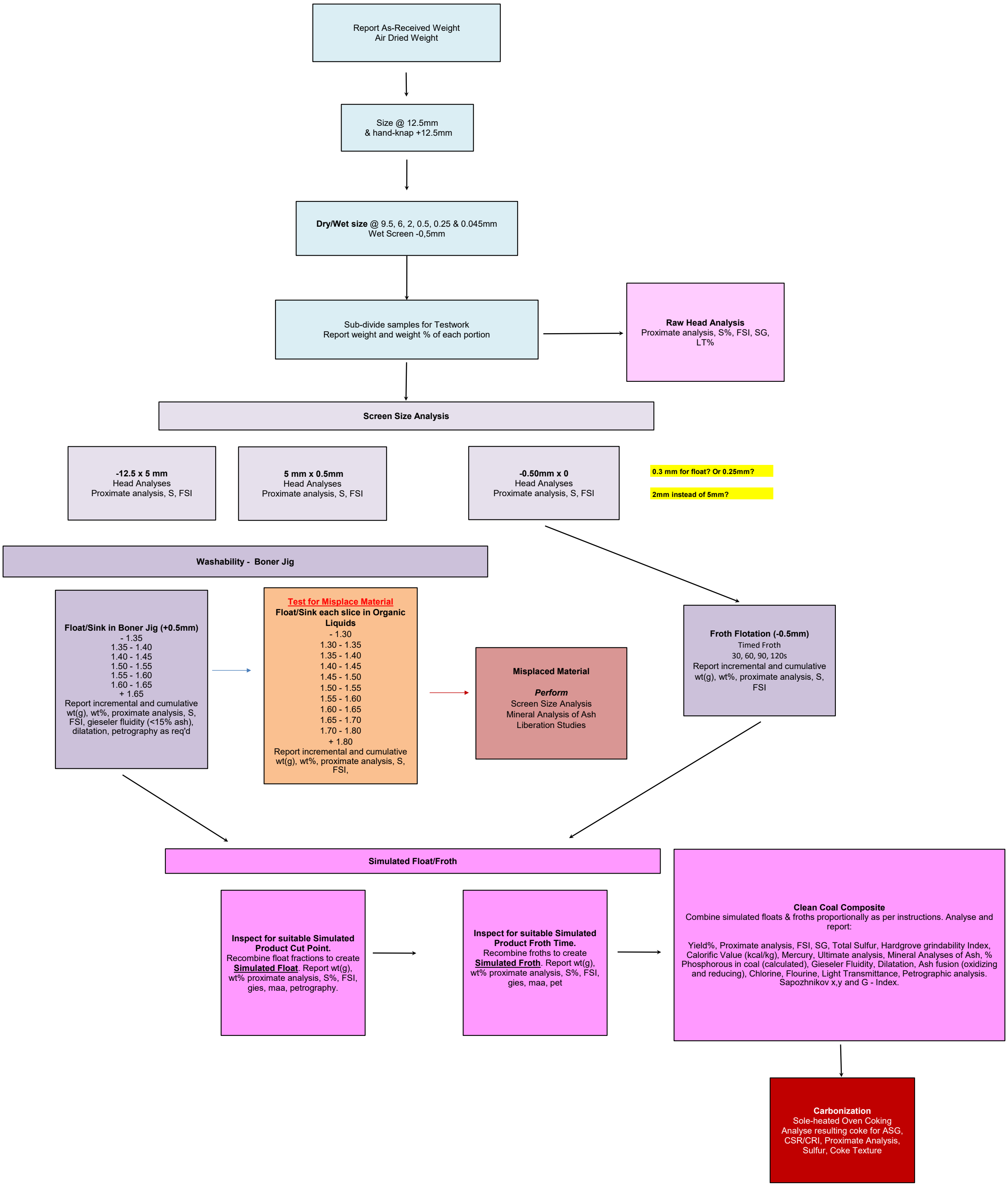
Roben Jig Project Phase 2
Analytical Flowsheet
Flowsheet ReJig



Roben Jig Project Phase 2
Float/Sink Size Fractions Analytical Flowsheet
Flowsheet OL Sizes



Roben Jig Project Phase 2
Roben Jig Sizes Analytical Flowsheet
Flowsheet Jig Sizes



Appendix C: Coal Analytical Results

GWIL INDUSTRIES Birtley Coal & Minerals Testing Division

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CERTIFICATE OF ANALYSIS

CLIENT: **Canadian Carbonization Research Association**

LAB#: 183148 (6 bbl raw coal)

RECEIVED DATE: April 26, 2018

REPORT DATE: December 18, 2018 updated

SCREEN SIZE ANALYSIS, air dried basis								
SIZE	WT%	MOIST%	ASH%	VOL%	F.C.%	S%	FSI	BASIS
12.5mm X 0.5mm	68.09	1.08	26.11	25.43	47.38	0.46	6.0	adb
0.5mm X 0	31.91	1.24	15.00	27.62	56.14	0.55	8.5	adb
CUMULATIVE	100.00	1.13	22.56	26.13	50.18	0.49	6.8	adb

original results

EVAPORATION RATES (2 different containers):

Novec 7000	150 ml beaker	100 ml Grad Cyl	**Novec 7000 (Lot#20142) SG = 1.422**
T= 0	100	100	
T= 4 hours	70	94	
T = 8 hours	48	88	
T = 24 hours	0	66	

Novec 7700	150 ml beaker	100 ml Grad Cyl	**Novec 7700 (Lot #20012) SG = 1.805**
T= 0	100	100	
T= 4 hours	100	100	
T = 8 hours	100	100	
T = 24 hours	98	100	

1.50 mixture	150 ml beaker	100 ml Grad Cyl	**SG = 1.50 before evaporation test**
T= 0	100	100	(bottle was tightly sealed)
T= 4 hours	80	95	
T = 8 hours	60	91	
T = 24 hours	25	73	

1.60 mixture	150 ml beaker	100 ml Grad Cyl	**SG = 1.60 before evaporation test**
T= 0	100	100	(bottle was tightly sealed)
T= 4 hours	81	97	
T = 8 hours	70	93	
T = 24 hours	49	80	

1.70 mixture	150 ml beaker	100 ml Grad Cyl	**SG - 1.70 before evaporation test**
T= 0	100	100	(bottle was tightly sealed)
T= 4 hours	87	98	
T = 8 hours	85	96	
T = 24 hours	75	88	

NOVEC - FLOAT SINK ANALYSIS (12.5mmx0.5mm), air dried basis (ASTM D4371)													
								CUMUALATIVE					
S.G.	WT(g)	WT%	MOIST%	ASH %	VM %	FC %	FSI	WT%	MOIST%	ASH %	VM %	FC %	FSI
1.42 FLT	3488	66.82	0.77	5.44	29.07	64.72	8.0	66.82	0.77	5.44	29.07	64.72	8.0
1.42 - 1.50	117	2.24	0.72	22.16	23.72	53.40	3.5	69.06	0.77	5.98	28.90	64.35	7.9
1.50 - 1.60	73	1.40	0.66	33.01	21.97	44.36	3.0	70.46	0.77	6.52	28.76	63.96	7.8
1.60 - 1.70	66	1.26	0.70	42.46	19.92	36.92	2.5	71.72	0.77	7.15	28.60	63.48	7.7
1.70 - 1.805	99	1.90	0.78	51.87	17.68	29.67	1.5	73.62	0.77	8.30	28.32	62.61	7.5
1.805 SNK	1377	26.38	0.81	78.70	11.57	8.92	0.0	100.00	0.78	26.87	23.90	48.45	5.5
	5220	**5269**	**49**	**grams loss**									

PERC - FLOAT SINK ANALYSIS (12.5mmx0.5mm), air dried basis (ASTM D4371)													
								CUMUALATIVE					
S.G.	WT(g)	WT%	MOIST%	ASH %	VM %	FC %	FSI	WT%	MOIST%	ASH %	VM %	FC %	FSI
1.40 FLT	3414	65.50	1.08	5.40	29.27	64.25	8.0	65.50	1.08	5.40	29.27	64.25	8.0
1.40 - 1.50	179	3.43	1.00	20.53	23.34	55.13	3.5	68.94	1.08	6.15	28.97	63.80	7.8
1.50 - 1.60	78	1.50	0.90	31.65	22.03	45.42	3.0	70.43	1.07	6.70	28.83	63.41	7.7
1.60 - 1.70	78	1.50	1.10	41.90	19.57	37.43	2.5	71.93	1.07	7.43	28.63	62.86	7.6
1.70 - 1.80	68	1.30	0.92	50.72	17.90	30.46	1.5	73.23	1.07	8.20	28.44	62.29	7.5
1.80 SNK	1395	26.77	0.97	78.60	11.37	9.06	0.0	100.00	1.04	27.04	23.87	48.04	5.5
	5212	**5241**	**29**	**grams loss**									

GIESELER FLUIDITY TEST (ASTM D2639)						
	TEMPERATURES °C					Date Tested
SAMPLE ID	INITIAL SOFT (1 DDPM)	MAX. FLUIDITY	SOLIDIFI-CATION	RANGE	MAX. DDPM	
1.42 FLT - Nov	417	454	481	64	**343**	11-Dec
1.40 FLT - Perc	417	455	480	63	**282**	11-Dec

RHUR DILATATION (ASTM D5515)								
SAMPLE ID	SOFT TEMP	TMCONT.	TMDIL.	%CONT.	%DIL	DIL	**%SD 2.5**	
1.42 FLT - Nov	376	431	463	26	99	125	**102**	10-Dec
1.40 FLT - Perc	373	428	463	26	83	109	**89**	10-Dec

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2018-1

CERTIFICATE OF ANALYSIS

CLIENT: **Canadian Carbonization Research Association**

LAB#: 183148 (6 bbl raw coal)

REPORT DATE: December 24, 2018

Clean Coal Composite made up from NOVEC or PERC organic liquids (no froth)

Simulated Clean Analysis, air dried basis											
ID	MOIST%	ASH%	VOL%	F.C.%	S%	FSI	Cl ppm	F ppm	HGI	%LT	BASIS
ASTM #	ASTM D3173	ASTM D3174	ASTM D3175		ASTM D4239	ASTM D720	ASTM D4208	ASTM D3761	ASTM D409	@ 17mm path D5263	
NOVEC CCC @1.60 SG	0.91	6.46	29.91	62.72	0.54	8.0	110	163	79	94.5	adb
		6.52	30.18	63.30	0.54		111	164			db
PERC CCC @1.60 SG	1.13	6.55	29.91	62.41	0.54	8.0	2200	156	78	94.5	adb
		6.62	30.25	63.12	0.55		2225	158			db

ULTIMATE ANALYSIS, air dried basis (ASTM D5373)									
ID	%MOIST.	%C	%H	%N	%S	%ASH	%O b/d	%P in coal db	BASIS
NOVEC CCC @1.60 SG	0.91	79.42	4.85	1.65	0.54	6.46	6.17	0.047	adb
		80.15	4.89	1.67	0.54	6.52	6.23		db
PERC CCC @1.60 SG	1.13	79.44	4.81	1.64	0.54	6.55	5.89	0.042	adb
		80.35	4.87	1.66	0.55	6.62	5.95		db

GIESELER FLUIDITY TEST (ASTM D2639)	TEMPERATURES °C					Date Tested
SAMPLE ID	INITIAL SOFT (1 DDPM)	MAX. FLUIDITY	SOLIDIFI-CATION	RANGE	MAX. DDPM	
NOVEC CCC	419	458	490	71	**336**	17-Dec
PERC CCC	416	455	488	72	**275**	17-Dec

RHUR DILATATION (ASTM D5515)								Date Tested
SAMPLE ID	SOFT TEMP	TMCONT.	TMDIL.	%CONT.	%DIL	DIL	**%SD 2.5**	
NOVEC CCC	376	434	466	22	91	113	**94**	17-Dec
PERC CCC	376	433	466	23	77	100	**78**	17-Dec

MINERAL ANALYSIS OF ASH (ASTM D3682)												
SAMPLE ID	SiO_2	Al_2O_3	TiO_2	CaO	BaO	SrO	$Fe_2 0_3$	MgO	Na_2O	$K_2 0$	$P_2 0_5$	SO_3	Undet.
NOVEC CCC	57.75	31.37	1.42	2.43	0.36	0.21	0.97	0.30	0.38	0.71	1.66	0.25	2.19
PERC CCC	56.94	33.52	1.34	2.67	0.39	0.19	1.09	0.36	0.40	0.73	1.45	0.65	0.27

Heather Dexter
Operations Manager
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CERTIFICATE OF ANALYSIS

CLIENT: **Canadian Carbonization Research Association**

SAMPLE ID: **2018-1 (6 barrels clean)**

LAB#: 183147

RECEIVED DATE: April 26, 2018

REPORT DATE: MAY 15, 2018 updated November 1, 2018

As Received weight = 826 Kg

ADM%	MOIST%	ASH%	VOL%	F.C.%	%S	Fluorine ppm	Chlorine ppm	HGI	SG	FSI	%P in Coal (db)	BASIS
6.75	1.00	8.01	28.42	62.57	0.53	143	206	75	1.33	8.5	0.045	adb
	7.68	7.47	26.50	58.35	0.49	133	192					arb
		8.09	28.71	63.20	0.54	144	208					db

GIESELER FLUIDITY TEST TEMPERATURES °C					
INITIAL SOFT (1 DDPM)	MAX. FLUIDITY	SOLIDIFI-CATION	RANGE	MAX. DDPM	
416	454	491	75	**848**	Run date: April 30, 2018
414	453	483	69	**212**	Run date: Sept 12, 2018

RHUR DILATATION (ASTM D5515)							
SOFT TEMP	TMCONT.	TMDIL.	%CONT.	%DIL	% TOTAL DIL	**%SD 2.5**	
373	433	468	28	149	177	**150**	Run date: April 30, 2018

MINERAL ANALYSIS OF ASH												
SiO_2	Al_2O_3	TiO_2	CaO	BaO	SrO	Fe_20_3	MgO	Na_2O	K_20	P_20_5	SO_3	Undet.
58.86	29.78	1.53	1.48	0.28	0.12	3.17	0.48	0.09	1.22	1.28	0.21	1.50

3 barrels (as received) + 1 pail (air dried & crushed to pass 12.5mm) ready to ship to CANMET

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2018-1

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CERTIFICATE OF ANALYSIS

CLIENT: **Canadian Carbonization Research Association**

LAB#: 183148 (6 bbl raw coal)

RECEIVED DATE: April 26, 2018

REPORT DATE: June 15, 2018 updated

As Received weight = 927 Kg   Coal screened @12.5mm and oversize crushed to pass 12.5mm and homogenized with natural 12.5mmx0

Head Raw Analysis, air dried basis								
ADM%	MOIST%	ASH%	VOL%	F.C.%	S%	FSI	SG	BASIS
ASTM D3302	ASTM D3173	ASTM D3174	ASTM D3175		ASTM D4239	ASTM D720	ISO 1014	
3.51	1.19	21.77	26.09	50.95	0.49	7.0	1.44	adb
	4.66	21.01	25.17	49.16	0.47			arb
		22.03	26.40	51.56	0.50			db

WET SCREEN SIZE ANALYSIS, air dried basis (ASTM D4749)					
SIZE	WT (KG)	WT%	Ash%	CUM Wt%	CUM Ash%
12.5mm X 9.5mm	3.427	8.54	42.73	8.54	42.73
9.5mm X 6.3mm	3.952	9.84	36.22	18.38	39.24
6.3mm X 4mm	3.964	9.87	27.64	28.26	35.19
4mm X 2mm	6.668	16.61	21.77	44.87	30.22
2mm X 0.5mm	8.946	22.29	17.25	67.15	25.92
0.5mm x 0.25mm	4.945	12.32	14.09	79.47	24.08
0.25mm x 0.045mm	5.563	13.86	13.75	93.33	22.55
0.045mm X 1	2.678	6.67	16.20	100.00	22.13

40 Kg split

SCREEN SIZE ANALYSIS, air dried basis								
SIZE	WT%	MOIST%	ASH%	VOL%	F.C.%	S%	FSI	BASIS
12.5mm X 0.5mm	68.09	1.08	26.11	25.43	47.38	0.46	6.0	adb
0.5mm X 0	31.91	1.24	15.00	27.62	56.14	0.55	8.5	adb
CUMULATIVE	100.00	1.13	22.56	26.13	50.18	0.49	6.8	adb

500 Kg split (bulk wet screened @0.5mm)

FLOAT SINK ANALYSIS (12.5mmx0.5mm), air dried basis (ASTM D4371)																	
									CUMUALATIVE								
S.G.	WT(g)	WT%	MOIST%	ASH %	VM %	FC %	%S	FSI	WT%	MOIST%	ASH %	VM %	FC %	%S	FSI		
1.30 FLT	25647	46.63	1.27	3.15	30.78	64.80	0.56	8.0	46.63	1.27	3.15	30.78	64.80	0.56	8.0		
1.30 - 1.35	6091	11.07	0.97	7.21	29.37	62.45	0.51	6.0	57.70	1.21	3.93	30.51	64.35	0.55	7.6		
1.35 - 1.40	3127	5.69	1.16	13.23	25.36	60.25	0.44	5.0	63.39	1.21	4.76	30.05	63.98	0.54	7.4		
1.40 - 1.45	1688	3.07	1.15	18.25	24.48	56.12	0.43	4.0	66.46	1.21	5.39	29.79	63.62	0.54	7.2		
1.45 - 1.50	621	1.13	1.17	21.53	24.17	53.13	0.43	3.5	67.59	1.20	5.66	29.70	63.44	0.53	7.2		
1.50 - 1.55	408	0.74	1.05	24.13	23.68	51.14	0.43	3.0	68.33	1.20	5.86	29.63	63.31	0.53	7.1		
1.55 - 1.60	386	0.70	1.19	29.35	22.94	46.52	0.42	3.0	69.03	1.20	6.10	29.56	63.14	0.53	7.1		
1.60 - 1.65	340	0.62	1.47	34.31	21.76	42.46	0.42	2.5	69.65	1.21	6.35	29.49	62.96	0.53	7.0	Yield = 47.42	
1.65 - 1.70	358	0.65	1.32	39.78	20.67	38.23	0.41	2.0	70.30	1.21	6.66	29.41	62.73	0.53	7.0		
1.70 - 1.80	771	1.40	1.62	45.93	19.31	33.14	0.40	1.5	71.70	1.21	7.42	29.21	62.15	0.53	6.9		
1.80 SNK	15565	28.30	1.69	76.80	12.19	9.32	0.17	0.5	100.00	1.35	27.06	24.40	47.20	0.43	5.1		
	55002	55100	98	grams loss													

JIG ANALYSIS (12.5mmx0.5mm), air dried basis																
									CUMUALATIVE							
ARD *	WT(g)	WT%	MOIST%	ASH %	VM %	FC %	%S	FSI	WT%	MOIST%	ASH %	VM %	FC %		FSI	
1.18	33656	24.98	1.08	4.12	31.02	63.78	N/A	8.5	24.98	1.08	4.12	31.02	63.78		8.5	
1.29	15637	11.60	1.07	4.54	30.46	63.93	N/A	8.5	36.58	1.08	4.25	30.84	63.83		8.5	
1.31	14817	11.00	1.04	5.65	29.97	63.34	N/A	8.0	47.57	1.07	4.58	30.64	63.71		8.4	
1.33	9341	6.93	0.85	7.36	29.64	62.15	N/A	8.0	54.51	1.04	4.93	30.51	63.52		8.3	
1.36	7501	5.57	0.85	9.65	28.42	61.08	N/A	6.0	60.07	1.02	5.37	30.32	63.29		8.1	
1.43	5482	4.07	0.85	18.63	25.50	55.02	N/A	5.0	64.14	1.01	6.21	30.01	62.77		7.9	
1.54	7376	5.47	0.90	29.41	22.95	46.74	N/A	3.0	69.61	1.00	8.03	29.46	61.51		7.5	Yield = 47.40
1.79	9767	7.25	1.00	47.74	18.29	32.97	N/A	2.5	76.86	1.00	11.78	28.41	58.81		7.1	
2.28	31179	23.14	0.96	76.42	12.51	10.11	N/A	0.5	100.00	0.99	26.73	24.73	47.55		5.5	

* Apparent Relative Density - this is considered an average of the "slice"

FROTH FLOTATION (0.5mm X 0) (ASTM D5114)																
									CUMUALATIVE							
TIME	Wt(g)	WT%	MOIST%	ASH %	VM %	FC %	%S	FSI	WT%	MOIST%	ASH %	VM %	FC %	%S	FSI	
30 sec	57426	62.51	1.27	7.07	30.29	61.37	0.59	8.5	62.51	1.27	7.07	30.29	61.37	0.59	8.5	
60 sec	10944	11.91	1.34	8.10	29.43	61.13	0.59	7.5	74.43	1.28	7.23	30.15	61.33	0.59	8.3	
complete	5534	6.02	1.29	10.44	28.63	59.64	0.58	7.0	80.45	1.28	7.47	30.04	61.20	0.59	8.2	Yield = 25.67
TAILS	17959	19.55	1.12	43.41	20.37	35.10	0.37	3.5	100.00	1.25	14.50	28.15	56.10	0.55	7.3	

PARAMETERS: 10% PULP DENSITY, COND. TIME 1 MINUTE
0.667 Kg/T 10:1 Kero:MIBC, DENVER 9L CELL, 1500 RPM

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2018-1

CERTIFICATE OF ANALYSIS

CLIENT:	**Canadian Carbonization Research Association**
LAB#:	183148 (6 bbl raw coal)
RECEIVED DATE:	April 26, 2018
REPORT DATE:	June 15, 2018 updated

Roben JIG REPORT

Lab Ref No: **183148 JIG**

Description: **crushed 12.5mm x 0.5mm**

RAW ash = 22.56% (adb)

12.5x0.5mm = 26.11% Ash (adb)

Roben Jig	**ARD mesh vessel DRY tare**	**ARD mesh vessel WET tare**	**Assumed Damp Moisture %**					
	0	**306**	**5**					
Tray Number	Rotations		Dry Coal mass (g)	Relative Density Fractional*	ASH %	Mass%	Cum mass %	Cum ASH %
1			31179	2.28	76.42	23.14	100.00	26.78
2			9767	1.79	47.74	7.25	76.86	11.83
3			7376	1.54	29.41	5.47	69.61	8.10
4			5482	1.43	18.63	4.07	64.14	6.28
5			3578	1.37	11.05	2.66	60.07	5.44
6			3923	1.35	8.83	2.91	57.42	5.18
7			4421	1.34	7.74	3.28	54.51	4.99
8			4920	1.32	7.24	3.65	51.23	4.81
9			7666	1.31	6.26	5.69	47.57	4.62
10			7151	1.30	5.24	5.31	41.89	4.40
11			6884	1.28	4.77	5.11	36.58	4.28
12			8753	1.29	4.51	6.50	31.47	4.20
13			33656	1.18	4.12	24.98	24.98	4.12
			134756					

Tube #	**1**	
starting weight =	**135385**	
fraction weight =	134756	**Ash%**
Jig Slurry wt =	208	37.09
ARD slurry wt =	403	7.11
Total End Weight =	**135367**	
Fine Losses = (Jig Slurry likely)	**18**	
cumulative Ash% =	**26.74**	

*Apparent Relative Density - this is considered an average of the "slice" taken

Combining some jig fractions according to ARD & Ash%

Roben Jig 3 batches of 15.5 Kg	**ARD mesh vessel DRY tare**	**ARD mesh vessel WET tare**	**Assumed Damp Moisture %**					
	0	**306**	**5**					
Tray Number	Rotations		Dry Coal mass (g)	Relative Density Fractional	ASH %	Mass%	Cum mass %	Cum ASH %
1			31179	2.28	76.42	23.14	100.00	26.73
2			9767	1.79	47.74	7.25	76.86	11.78
3			7376	1.54	29.41	5.47	69.61	8.03
4			5482	1.43	18.63	4.07	64.14	6.21
5,6			7501	1.36	9.65	5.57	60.07	5.37
7,8			9341	1.33	7.36	6.93	54.51	4.93
9,10			14817	1.31	5.65	11.00	47.57	4.58
11,12			15637	1.29	4.54	11.60	36.58	4.25
13			33656	1.18	4.12	24.98	24.98	4.12
			134756					

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LAB#: 183148 (6 bbl raw coal)

RECEIVED DATE: April 26, 2018

REPORT DATE: JULY 26, 2018

FLOAT SINK ANALYSIS: TRAY #1 (76.42% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	36	0.12	4.79	0.12	4.79
1.30 - 1.40	287	0.98	12.49	1.10	11.63
1.40 - 1.50	373	1.27	20.60	2.37	16.44
1.50 - 1.60	313	1.06	32.09	3.43	21.29
1.60 - 1.70	353	1.20	41.19	4.63	26.45
1.70 - 1.80	583	1.98	50.36	6.62	33.62
1.80 SNK	27455	93.38	80.08	100.00	77.01

FLOAT SINK ANALYSIS: TRAY #2 (47.74% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	176	2.05	4.62	2.05	4.62
1.30 - 1.40	1215	14.16	11.32	16.21	10.47
1.40 - 1.50	936	10.91	19.84	27.11	14.24
1.50 - 1.60	493	5.74	31.39	32.86	17.24
1.60 - 1.70	441	5.14	41.00	37.99	20.45
1.70 - 1.80	670	7.81	50.44	45.80	25.56
1.80 SNK	4652	54.20	70.64	100.00	49.99

FLOAT SINK ANALYSIS: TRAY #3 (29.41% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	344	11.57	4.06	11.57	4.06
1.30 - 1.40	912	30.67	10.89	42.23	9.02
1.40 - 1.50	380	12.78	20.06	55.01	11.58
1.50 - 1.60	208	6.99	32.02	62.00	13.89
1.60 - 1.70	194	6.52	41.85	68.53	16.55
1.70 - 1.80	164	5.51	50.23	74.04	19.06
1.80 SNK	772	25.96	68.87	100.00	31.99

FLOAT SINK ANALYSIS: TRAY #4 (18.63% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	590	26.54	4.09	26.54	4.09
1.30 - 1.40	985	44.31	10.57	70.85	8.14
1.40 - 1.50	237	10.66	21.86	81.51	9.94
1.50 - 1.60	105	4.72	34.69	86.23	11.29
1.60 - 1.70	74	3.33	43.67	89.56	12.50
1.70 - 1.80	57	2.56	50.98	92.13	13.57
1.80 SNK	175	7.87	68.61	100.00	17.90

FLOAT SINK ANALYSIS: TRAY #5/6 (9.65% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	885	43.34	3.44	43.34	3.44
1.30 - 1.40	846	41.43	9.77	84.77	6.53
1.40 - 1.50	167	8.18	19.57	92.95	7.68
1.50 - 1.60	62	3.04	31.38	95.98	8.43
1.60 - 1.70	26	1.27	40.85	97.26	8.85
1.70 - 1.80	13	0.64	47.71	97.89	9.11
1.80 SNK	43	2.11	70.25	100.00	10.40

FLOAT SINK ANALYSIS: TRAY #7/8 (7.36% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	1521	59.69	3.42	59.69	3.42
1.30 - 1.40	826	32.42	9.56	92.11	5.58
1.40 - 1.50	129	5.06	19.98	97.17	6.33
1.50 - 1.60	35	1.37	31.36	98.55	6.68
1.60 - 1.70	11	0.43	38.79	98.98	6.82
1.70 - 1.80	4	0.16	44.55	99.14	6.88
1.80 SNK	22	0.86	74.87	100.00	7.47

FLOAT SINK ANALYSIS: TRAY #9/10 (5.65% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	4270	72.52	3.23	72.52	3.23
1.30 - 1.40	1402	23.81	9.94	96.33	4.89
1.40 - 1.50	156	2.65	19.95	98.98	5.29
1.50 - 1.60	30	0.51	31.47	99.49	5.43
1.60 - 1.70	7	0.12	37.73	99.61	5.46
1.70 - 1.80	3	0.05	47.00	99.66	5.49
1.80 SNK	20	0.34	73.99	100.00	5.72

FLOAT SINK ANALYSIS: TRAY #11/12 (4.54% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	4850	77.23	2.50	77.23	2.50
1.30 - 1.40	1188	18.92	9.83	96.15	3.94
1.40 - 1.50	168	2.68	20.78	98.82	4.40
1.50 - 1.60	29	0.46	30.57	99.28	4.52
1.60 - 1.70	6	0.10	37.90	99.38	4.55
1.70 - 1.80	4	0.06	49.01	99.44	4.58
1.80 SNK	35	0.56	76.90	100.00	4.98

FLOAT SINK ANALYSIS: TRAY #13 (4.12% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	13470	81.50	2.14	81.50	2.14
1.30 - 1.40	2539	15.36	9.23	96.87	3.26
1.40 - 1.50	344	2.08	18.61	98.95	3.59
1.50 - 1.60	51	0.31	27.63	99.26	3.66
1.60 - 1.70	19	0.11	35.51	99.37	3.70
1.70 - 1.80	11	0.07	45.81	99.44	3.73
1.80 SNK	93	0.56	75.83	100.00	4.13

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CERTIFICATE OF ANALYSIS

CLIENT: **Canadian Carbonization Research Association**

LAB#: 183148 (6 bbl raw coal)

RECEIVED DATE: April 26, 2018

REPORT DATE: JULY 31, 2018 updated

12.5x0.5mm size fraction

GIESELER FLUIDITY TEST (ASTM D2639)							
		TEMPERATURES °C					
SAMPLE ID	12.5mm x 0.50mm ASH %	INITIAL SOFT (1 DDPM)	MAX. FLUIDITY	SOLIDIFICATION	RANGE	MAX. DDPM	Date Tested
1.30 FLT	3.15	407	452	486	79	**713**	Jun 20
1.30 - 1.35	7.21	416	450	487	71	**424**	Jun 20
1.35 - 1.40	13.23	423	453	481	58	**40**	Jun 20
1.18 ARD	4.12	412	456	488	76	**675**	Jun 20
1.28 ARD	4.54	411	452	486	75	**615**	Jun 21
1.31 ARD	5.65	411	454	487	76	**620**	Jun 21
1.33 ARD	7.36	413	453	487	74	**519**	Jun 21
1.36 ARD	9.65	416	450	487	71	**395**	Jun 21
1.28 REJIG	4.21	414	454	488	74	**448**	July 30
1.33 REJIG	6.54	415	454	487	72	**384**	July 30
1.37 REJIG	8.90	411	453	485	74	**287**	July 30

RHUR DILATATION (ASTM D5515)								
SAMPLE ID	SOFT TEMP	TMCONT	TMDIL.	%CONT.	%DIL	% TOTAL DIL	%SD 2.5	Date Tested
1.30 FLT	370	424	461	27	161	188	**172**	Jun 20
1.30 - 1.35	385	434	463	23	60	83	**68**	Jun 20
1.35 - 1.40	385	445	493	19	-15	4	**-17**	Jun 20
1.18 ARD	379	425	463	26	171	197	**181**	Jun 20
1.28 ARD	368	428	463	25	147	172	**157**	Jun 21
1.31 ARD	370	428	464	27	123	150	**131**	Jun 21
1.33 ARD	370	429	464	24	102	126	**107**	Jun 21
1.36 ARD	369	431	463	25	68	93	**70**	Jun 21
1.28 REJIG	385	432	467	26	128	154	**140**	July 30
1.33 REJIG	388	436	465	24	95	119	**104**	July 30
1.37 REJIG	391	436	466	26	61	87	**64**	July 30

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2018-1

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CLIENT: **Canadian Carbonization Research Association**

LAB#: 183148 (6 bbl raw coal)

REPORT DATE: August 7, 2018

Simulated Clean Analysis, air dried basis														
ID	MOIST%	ASH%	VOL%	F.C.%	S%	FSI	Cal/g	Cl ppm	F ppm	Hg ppb	HGI	SG	%LT	BASIS
ASTM #	ASTM D3173	ASTM D3174	ASTM D3175		ASTM D4239	ASTM D720	ASTM D5865	ASTM D4208	ASTM D3761	ASTM D6722	ASTM D409	ISO 1014	@ 17mm path D5263	
SIM FS	1.10	6.17	29.58	63.15	0.55	7.5	-	-	-	-	-	-	-	adb
@ 1.65 SG		6.24	29.91	63.85	0.56									db
SIM JIG	1.33	8.12	29.72	60.83	0.53	7.0	-	-	-	-	-	-	-	adb
@ 1.54 ARD		8.23	30.12	61.65	0.54									db
SIM Froth	1.15	7.64	30.03	61.18	0.57	8.0	-	-	-	-	-	-	-	adb
@ comp		7.73	30.38	61.89	0.58									db
FS CCC	1.20	6.74	29.59	62.47	0.54	8.0	7852	2570	158	24	78	1.31	94.3	adb
12.5x0.5		6.82	29.95	63.23	0.55		7947	2601	160	24				db
JIG CCC	1.38	7.80	29.15	61.67	0.54	8.0	7705	432	162	17	79	1.35	93.5	adb
12.5x0.5		7.91	29.56	62.53	0.55		7813	438	164	17				db
REJIG	1.32	6.21	29.52	62.95	0.53	7.0	-	-	-	-	-	-	-	adb
@1.45 ard		6.29	29.91	63.79	0.54									db
REJIG CCC	1.22	6.68	29.36	62.74	0.55	8.0	7850	321	163	21	80	1.36	95.1	adb
12.5x0.5		6.76	29.72	63.51	0.56		7947	325	165	21				db
SIM FS @1.60	1.20	7.28	28.88	62.64	0.50	7.5	-	-	-	-	-	-	-	adb
12.5x2mm		7.37	29.23	63.40	0.51									db
SIM FS @1.60	1.44	4.97	30.88	62.71	0.55	7.5	-	-	-	-	-	-	-	adb
2x0.5mm		5.04	31.33	63.63	0.56									db
SIM JIG @1.54	1.22	7.93	29.01	61.84	0.52	7.5	-	-	-	-	-	-	-	adb
12.5x2mm		8.03	29.37	62.60	0.53									db
SIM JIG @1.40	1.09	6.89	29.41	62.61	0.55	7.5	-	-	-	-	-	-	-	adb
2x0.5mm		6.97	29.73	63.30	0.56									db
FS CCC	1.29	6.81	29.32	62.58	0.54	8.5	7833	2280	171	19	79	1.37	93.8	adb
sizes		6.90	29.70	63.40	0.55		7935	2310	173	19				db
JIG CCC	1.21	7.51	30.15	61.13	0.54	8.0	7738	365	172	19	78	1.37	94.5	adb
sizes		7.60	30.52	61.88	0.55		7833	369	174	19				db

ULTIMATE ANALYSIS, air dried basis (ASTM D5373)									
ID	%MOIST.	%C	%H	%N	%S	%ASH	%O b/d	%P in coal db	BASIS
FS CCC	1.20	79.30	4.91	1.67	0.54	6.74	5.64	0.043	adb
12.5x0.5		80.26	4.97	1.69	0.55	6.82	5.71		db
JIG CCC	1.38	77.76	4.75	1.61	0.54	7.80	6.16	0.045	adb
12.5x0.5		78.85	4.81	1.63	0.55	7.91	6.25		db
REJIG CCC	1.22	79.44	4.83	1.65	0.55	6.68	5.63	0.044	adb
12.5x0.5		80.42	4.89	1.67	0.56	6.76	5.70		db
FS CCC	1.29	79.05	4.81	1.63	0.54	6.81	5.87	0.040	adb
sizes		80.08	4.87	1.65	0.55	6.90	5.95		db
JIG CCC	1.21	78.40	4.79	1.63	0.54	7.51	5.92	0.042	adb
sizes		79.36	4.84	1.65	0.55	7.60	6.00		db

FS CCC & Jig CCC sent to CANMET (5 samples)

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2018-1

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CERTIFICATE OF ANALYSIS

CLIENT: **Canadian Carbonization Research Association**

LAB#: 183148 (6 bbl raw coal)

REPORT DATE: August 7, 2018 updated November 1, 2018

GIESELER FLUIDITY TEST (ASTM D2639)	TEMPERATURES °C					Date Tested
SAMPLE ID	INITIAL SOFT (1 DDPM)	MAX. FLUIDITY	SOLIDIFI-CATION	RANGE	MAX. DDPM	
Sim FS 1.65	411	451	485	74	**511**	17-Jul
Sim Jig 1.54	413	453	483	70	**419**	31-Jul
Sim Froth	412	454	490	78	**539**	22-Jun
FS CCC 12.5x.5	429	452	486	57	**415**	17-Jul
FS CCC 12.5x.5	411	449	479	68	**281**	13-Sep
Jig CCC 12.5x.5	414	453	483	69	**412**	01-Aug
Jig CCC 12.5x.5	411	450	483	72	**298**	13-Sep
REJIG 1.45	413	453	484	71	**442**	01-Aug
REJIG CCC	415	453	484	69	**406**	01-Aug
REJIG CCC	410	446	480	70	**322**	12-Sep
Sim FS +9M	414	452	482	68	**390**	01-Aug
SIM FS -9M	411	450	484	73	**435**	01-Aug
Sim Jig +9M	415	452	486	71	**334**	02-Aug
Sim Jig -9M	414	454	484	70	**393**	02-Aug
FS CCC sizes	412	451	484	72	**392**	02-Aug
FS CCC sizes	412	450	480	68	**290**	12-Sep
Jig CCC sizes	415	453	486	71	**395**	02-Aug
Jig CCC sizes	409	447	480	71	**274**	13-Sep

RHUR DILATATION (ASTM D5515)								
SAMPLE ID	SOFT TEMP	TMCONT.	TMDIL.	%CONT.	%DIL	% TOTAL DIL	**%SD 2.5**	
Sim Froth	380	430	465	23	169	192	**169**	22-Jun
FS CCC 12.5x.5	385	427	462	28	112	140	**118**	17-Jul
Jig CCC 12.5x.5	385	432	465	25	118	143	**127**	01-Aug
REJIG CCC	391	433	464	26	125	151	**133**	01-Aug
FS CCC sizes	379	430	466	25	107	132	**108**	02-Aug
Jig CCC sizes	382	429	463	25	121	146	**120**	02-Aug

MINERAL ANALYSIS OF ASH (ASTM D3682)													
SAMPLE ID	SiO_2	Al_2O_3	TiO_2	CaO	BaO	SrO	Fe_2O_3	MgO	Na_2O	K_2O	P_2O_5	SO_3	Undet.
FS CCC 12.5x.5	57.56	32.79	1.56	1.97	0.31	0.14	1.50	0.53	0.05	1.22	1.46	0.30	0.61
Jig CCC 12.5x.5	59.57	29.61	1.41	1.26	0.32	0.14	1.62	0.56	0.07	1.66	1.30	0.23	2.25
REJIG CCC	58.27	31.16	1.52	1.83	0.29	0.17	1.60	0.51	0.07	1.41	1.49	0.23	1.45
FS CCC sizes	58.50	31.44	1.57	1.43	0.28	0.15	1.46	0.48	0.08	1.16	1.32	0.27	1.86
Jig CCC sizes	59.76	29.60	1.47	1.46	0.31	0.14	1.59	0.58	0.08	1.51	1.26	0.27	1.97

	ASH FUSION TEMPERATURES (°C) (ASTM D1857)							
	REDUCING				OXIDIZING			
SAMPLE ID	IDT	ST	HT	FT	IDT	ST	HT	FT
FS CCC 12.5x.5	+1500	+1500	+1500	+1500	+1500	+1500	+1500	+1500
Jig CCC 12.5x.5	+1500	+1500	+1500	+1500	+1500	+1500	+1500	+1500
REJIG CCC	+1500	+1500	+1500	+1500	+1500	+1500	+1500	+1500
FS CCC sizes	+1500	+1500	+1500	+1500	+1500	+1500	+1500	+1500
Jig CCC sizes	+1500	+1500	+1500	+1500	+1500	+1500	+1500	+1500

FS CCC & Jig CCC sent to CANMET (5 samples)

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CERTIFICATE OF ANALYSIS

CLIENT: **Canadian Carbonization Research Association**

LAB#: 183148 (6 bbl raw coal)

REPORT DATE: August 7, 2018

Clean Coal Composite made up from Simulated Float Sink Fractions @1.65 SG and Bulk Simulated Froth

Simulated Clean Analysis, air dried basis														
ID	**MOIST%**	**ASH%**	**VOL%**	**F.C.%**	**S%**	**FSI**	**Cal/g**	**Cl ppm**	**F ppm**	**Hg ppb**	**HGI**	**SG**	**%LT**	**BASIS**
ASTM #	**ASTM D3173**	**ASTM D3174**	**ASTM D3175**		**ASTM D4239**	**ASTM D720**	**ASTM D5865**	**ASTM D4208**	**ASTM D3761**	**ASTM D6722**	**ASTM D409**	**ISO 1014**	@ 17mm path **D5263**	
SIM FS @ 1.65 SG	1.10	6.17	29.58	63.15	0.55	7.5	-	-	-	-	-	-	-	adb
		6.24	29.91	63.85	0.56									db
SIM Froth @ comp	1.15	7.64	30.03	61.18	0.57	8.0	-	-	-	-	-	-	-	adb
		7.73	30.38	61.89	0.58									db
FS CCC 12.5x0.5	1.20	6.74	29.59	62.47	0.54	8.0	7852	2570	158	24	78	1.31	94.3	adb
		6.82	29.95	63.23	0.55		7947	2601	160	24				db

ULTIMATE ANALYSIS, air dried basis (ASTM D5373)									
ID	%MOIST.	%C	%H	%N	%S	%ASH	%O b/d	%P in coal db	BASIS
FS CCC 12.5x0.5	1.20	79.30	4.91	1.67	0.54	6.74	5.64	0.043	adb
		80.26	4.97	1.69	0.55	6.82	5.71		db

GIESELER FLUIDITY TEST (ASTM D2639)						
	TEMPERATURES °C					Date
SAMPLE ID	INITIAL SOFT (1 DDPM)	MAX. FLUIDITY	SOLIDIFI-CATION	RANGE	MAX. DDPM	Tested
Sim FS 1.65	411	451	485	74	**511**	17-Jul
Sim Froth	412	454	490	78	**539**	22-Jun
FS CCC 12.5x.5	429	452	486	57	**415**	17-Jul
FS CCC 12.5x.5	411	449	479	68	**281**	13-Sep

RHUR DILATATION (ASTM D5515)								
SAMPLE ID	SOFT TEMP	TMCONT.	TMDIL.	%CONT.	%DIL	DIL	**%SD 2.5**	
Sim Froth	380	430	465	23	169	192	**169**	22-Jun
FS CCC 12.5x.5	385	427	462	28	112	140	**118**	17-Jul

MINERAL ANALYSIS OF ASH (ASTM D3682)													
SAMPLE ID	SiO_2	Al_2O_3	TiO_2	CaO	BaO	SrO	Fe_20_3	MgO	Na_2O	K_20	P_20_5	SO_3	Undet.
FS CCC 12.5x.5	57.56	32.79	1.56	1.97	0.31	0.14	1.50	0.53	0.05	1.22	1.46	0.30	0.61

	ASH FUSION TEMPERATURES (°C) (ASTM D1857)							
	REDUCING				OXIDIZING			
SAMPLE ID	IDT	ST	HT	FT	IDT	ST	HT	FT
FS CCC 12.5x.5	+1500	+1500	+1500	+1500	+1500	+1500	+1500	+1500

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CERTIFICATE OF ANALYSIS

CLIENT: **Canadian Carbonization Research Association**

LAB#: 183148 (6 bbl raw coal)

REPORT DATE: August 7, 2018

Clean Coal Composite made up from Simulated JIG Fractions @1.54 ARD and Bulk Simulated Froth

Simulated Clean Analysis, air dried basis														
ID	MOIST%	ASH%	VOL%	F.C.%	S%	FSI	Cal/g	Cl ppm	F ppm	Hg ppb	HGI	SG	%LT	BASIS
ASTM #	ASTM D3173	ASTM D3174	ASTM D3175		ASTM D4239	ASTM D720	ASTM D5865	ASTM D4208	ASTM D3761	ASTM D6722	ASTM D409	ISO 1014	@ 17mm path D5263	
SIM JIG @ 1.54 ARD	1.33	8.12	29.72	60.83	0.53	7.0	-	-	-	-	-	-	-	adb
		8.23	30.12	61.65	0.54									db
SIM Froth @ comp	1.15	7.64	30.03	61.18	0.57	8.0	-	-	-	-	-	-	-	adb
		7.73	30.38	61.89	0.58									db
JIG CCC 12.5x0.5	1.38	7.80	29.15	61.67	0.54	8.0	7705	432	162	17	79	1.35	93.5	adb
		7.91	29.56	62.53	0.55		7813	438	164	17				db

ULTIMATE ANALYSIS, air dried basis (ASTM D5373)									
ID	%MOIST.	%C	%H	%N	%S	%ASH	%O b/d	%P in coal db	BASIS
JIG CCC 12.5x0.5	1.38	77.76	4.75	1.61	0.54	7.80	6.16	0.045	adb
		78.85	4.81	1.63	0.55	7.91	6.25		db

GIESELER FLUIDITY TEST (ASTM D2639)						
	TEMPERATURES °C					
SAMPLE ID	INITIAL SOFT (1 DDPM)	MAX. FLUIDITY	SOLIDIFI-CATION	RANGE	MAX. DDPM	Date Tested
Sim Jig 1.54	413	453	483	70	**419**	31-Jul
Sim Froth	412	454	490	78	**539**	22-Jun
Jig CCC 12.5x.5	414	453	483	69	**412**	01-Aug
Jig CCC 12.5x.5	411	450	483	72	**298**	13-Sep

RHUR DILATATION (ASTM D5515)								
SAMPLE ID	SOFT TEMP	TMCONT.	TMDIL.	%CONT.	%DIL	DIL	**%SD 2.5**	Date Tested
Sim Froth	380	430	465	23	169	192	**169**	22-Jun
Jig CCC 12.5x.5	385	432	465	25	118	143	**127**	01-Aug

MINERAL ANALYSIS OF ASH (ASTM D3682)													
SAMPLE ID	SiO_2	Al_2O_3	TiO_2	CaO	BaO	SrO	Fe_2O_3	MgO	Na_2O	K_2O	P_2O_5	SO_3	Undet.
Jig CCC 12.5x.5	59.57	29.61	1.41	1.26	0.32	0.14	1.62	0.56	0.07	1.66	1.30	0.23	2.25

	ASH FUSION TEMPERATURES (°C) (ASTM D1857)							
	REDUCING				OXIDIZING			
SAMPLE ID	IDT	ST	HT	FT	IDT	ST	HT	FT
Jig CCC 12.5x.5	+1500	+1500	+1500	+1500	+1500	+1500	+1500	+1500

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CERTIFICATE OF ANALYSIS

CLIENT: **Canadian Carbonization Research Association**

LAB#: 183148 (6 bbl raw coal)

REPORT DATE: August 7, 2018

Clean Coal Composite made up from Simulated re-JIG Fractions @1.45 ARD and Bulk Simulated Froth

Simulated Clean Analysis, air dried basis														
ID	**MOIST%**	**ASH%**	**VOL%**	**F.C.%**	**S%**	**FSI**	**Cal/g**	**Cl ppm**	**F ppm**	**Hg ppb**	**HGI**	**SG**	**%LT**	**BASIS**
ASTM #	**ASTM D3173**	**ASTM D3174**	**ASTM D3175**		**ASTM D4239**	**ASTM D720**	**ASTM D5865**	**ASTM D4208**	**ASTM D3761**	**ASTM D6722**	**ASTM D409**	**ISO 1014**	@ 17mm path **D5263**	
REJIG	1.32	6.21	29.52	62.95	0.53	7.0	-	-	-	-	-	-	-	adb
@1.45 ard		6.29	29.91	63.79	0.54									db
SIM Froth	1.15	7.64	30.03	61.18	0.57	8.0	-	-	-	-	-	-	-	adb
@ comp		7.73	30.38	61.89	0.58									db
REJIG CCC	1.22	6.68	29.36	62.74	0.55	8.0	7850	321	163	21	80	1.36	95.1	adb
12.5x0.5		6.76	29.72	63.51	0.56		7947	325	165	21				db

ULTIMATE ANALYSIS, air dried basis (ASTM D5373)									
ID	%MOIST.	%C	%H	%N	%S	%ASH	%O b/d	%P in coal db	BASIS
REJIG CCC	1.22	79.44	4.83	1.65	0.55	6.68	5.63	0.044	adb
12.5x0.5		80.42	4.89	1.67	0.56	6.76	5.70		db

GIESELER FLUIDITY TEST (ASTM D2639)						
	TEMPERATURES °C					
SAMPLE ID	INITIAL SOFT (1 DDPM)	MAX. FLUIDITY	SOLIDIFI-CATION	RANGE	MAX. DDPM	Date Tested
Sim Froth	412	454	490	78	**539**	22-Jun
REJIG 1.45	413	453	484	71	**442**	01-Aug
REJIG CCC	415	453	484	69	**406**	01-Aug
REJIG CCC	410	446	480	70	**322**	12-Sep

RHUR DILATATION (ASTM D5515)								
SAMPLE ID	SOFT TEMP	TMCONT.	TMDIL.	%CONT.	%DIL	DIL	**%SD 2.5**	
Sim Froth	380	430	465	23	169	192	**169**	22-Jun
REJIG CCC	391	433	464	26	125	151	**133**	01-Aug

MINERAL ANALYSIS OF ASH (ASTM D3682)													
SAMPLE ID	SiO_2	Al_2O_3	TiO_2	CaO	BaO	SrO	Fe_2O_3	MgO	Na_2O	K_2O	P_2O_5	SO_3	Undet.
REJIG CCC	58.27	31.16	1.52	1.83	0.29	0.17	1.60	0.51	0.07	1.41	1.49	0.23	1.45

	ASH FUSION TEMPERATURES (°C) (ASTM D1857)							
	REDUCING				OXIDIZING			
SAMPLE ID	IDT	ST	HT	FT	IDT	ST	HT	FT
REJIG CCC	+1500	+1500	+1500	+1500	+1500	+1500	+1500	+1500

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CERTIFICATE OF ANALYSIS

CLIENT: **Canadian Carbonization Research Association**

LAB#: 183148 (6 bbl raw coal)

REPORT DATE: August 7, 2018

Clean Coal Composite made up from Simulated Float Sink Fractions @1.60 SG (both size fractions) and Bulk Simulated Froth

Simulated Clean Analysis, air dried basis														
ID	MOIST%	ASH%	VOL%	F.C.%	S%	FSI	Cal/g	Cl ppm	F ppm	Hg ppb	HGI	SG	%LT	BASIS
ASTM #	ASTM D3173	ASTM D3174	ASTM D3175		ASTM D4239	ASTM D720	ASTM D5865	ASTM D4208	ASTM D3761	ASTM D6722	ASTM D409	ISO 1014	@ 17mm path D5263	
SIM FS @1.60 12.5x2mm	1.20	7.28	28.88	62.64	0.50	7.5	-	-	-	-	-	-	-	adb
		7.37	29.23	63.40	0.51									db
SIM FS @1.60 2x0.5mm	1.44	4.97	30.88	62.71	0.55	7.5	-	-	-	-	-	-	-	adb
		5.04	31.33	63.63	0.56									db
SIM Froth @ comp	1.15	7.64	30.03	61.18	0.57	8.0	-	-	-	-	-	-	-	adb
		7.73	30.38	61.89	0.58									db
FS CCC sizes	1.29	6.81	29.32	62.58	0.54	8.5	7833	2280	171	19	79	1.37	93.8	adb
		6.90	29.70	63.40	0.55		7935	2310	173	19				db

ULTIMATE ANALYSIS, air dried basis (ASTM D5373)									
ID	%MOIST.	%C	%H	%N	%S	%ASH	%O b/d	%P in coal db	BASIS
FS CCC sizes	1.29	79.05	4.81	1.63	0.54	6.81	5.87	0.040	adb
		80.08	4.87	1.65	0.55	6.90	5.95		db

GIESELER FLUIDITY TEST (ASTM D2639)	TEMPERATURES °C					
SAMPLE ID	INITIAL SOFT (1 DDPM)	MAX. FLUIDITY	SOLIDIFI-CATION	RANGE	MAX. DDPM	Date Tested
Sim FS +9M	414	452	482	68	**390**	01-Aug
SIM FS -9M	411	450	484	73	**435**	01-Aug
Sim Froth	412	454	490	78	**539**	22-Jun
FS CCC sizes	412	451	484	72	**392**	02-Aug
FS CCC sizes	412	450	480	68	**290**	12-Sep

RHUR DILATATION (ASTM D5515)								
SAMPLE ID	SOFT TEMP	TMCONT.	TMDIL.	%CONT.	%DIL	DIL	%SD 2.5	Date
Sim Froth	380	430	465	23	169	192	**169**	22-Jun
FS CCC sizes	379	430	466	25	107	132	**108**	02-Aug

MINERAL ANALYSIS OF ASH (ASTM D3682)												
SAMPLE ID	SiO_2	Al_2O_3	TiO_2	CaO	BaO	SrO	Fe_2O_3	MgO	Na_2O	K_2O	P_2O_5	SO_3	Undet.
FS CCC sizes	58.50	31.44	1.57	1.43	0.28	0.15	1.46	0.48	0.08	1.16	1.32	0.27	1.86

	ASH FUSION TEMPERATURES (°C) (ASTM D1857)							
	REDUCING				OXIDIZING			
SAMPLE ID	IDT	ST	HT	FT	IDT	ST	HT	FT
FS CCC sizes	+1500	+1500	+1500	+1500	+1500	+1500	+1500	+1500

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CLIENT: **Canadian Carbonization Research Association**

LAB#: 183148 (6 bbl raw coal)

REPORT DATE: August 7, 2018

Clean Coal Composite made up from Simulated JIG Fractions @1.54 ARD (both size fractions) and Bulk Simulated Froth

Simulated Clean Analysis, air dried basis

ID	MOIST%	ASH%	VOL%	F.C.%	S%	FSI	Cal/g	Cl ppm	F ppm	Hg ppb	HGI	SG	%LT	BASIS
ASTM #	ASTM D3173	ASTM D3174	ASTM D3175		ASTM D4239	ASTM D720	ASTM D5865	ASTM D4208	ASTM D3761	ASTM D6722	ASTM D409	ISO 1014	@ 17mm path D5263	
SIM JIG @1.54	1.22	7.93	29.01	61.84	0.52	7.5	-	-	-	-	-	-	-	adb
12.5x2mm		8.03	29.37	62.60	0.53									db
SIM JIG @1.40	1.09	6.89	29.41	62.61	0.55	7.5	-	-	-	-	-	-	-	adb
2x0.5mm		6.97	29.73	63.30	0.56									db
SIM Froth	1.15	7.64	30.03	61.18	0.57	8.0	-	-	-	-	-	-	-	adb
@ comp		7.73	30.38	61.89	0.58									db
JIG CCC	1.21	7.51	30.15	61.13	0.54	8.0	7738	365	172	19	78	1.37	94.5	adb
sizes		7.60	30.52	61.88	0.55		7833	369	174	19				db

ULTIMATE ANALYSIS, air dried basis (ASTM D5373)

ID	%MOIST.	%C	%H	%N	%S	%ASH	%O b/d	%P in coal db	BASIS
FS CCC	1.21	78.40	4.79	1.63	0.54	7.51	5.92	0.042	adb
sizes		79.36	4.84	1.65	0.55	7.60	6.00		db

GIESELER FLUIDITY TEST (ASTM D2639)

SAMPLE ID	TEMPERATURES °C INITIAL SOFT (1 DDPM)	MAX. FLUIDITY	SOLIDIFI-CATION	RANGE	MAX. DDPM	Date Tested
Sim Jig +9M	415	452	486	71	**334**	02-Aug
Sim Jig -9M	414	454	484	70	**393**	02-Aug
Sim Froth	412	454	490	78	**539**	22-Jun
Jig CCC sizes	415	453	486	71	**395**	02-Aug
Jig CCC sizes	409	447	480	71	**274**	13-Sep

RHUR DILATATION (ASTM D5515)

SAMPLE ID	SOFT TEMP	TMCONT.	TMDIL.	%CONT.	%DIL	DIL	%SD 2.5	
Sim Froth	380	430	465	23	169	192	**169**	22-Jun
Jig CCC sizes	382	429	463	25	121	146	**120**	02-Aug

MINERAL ANALYSIS OF ASH (ASTM D3682)

SAMPLE ID	SiO_2	Al_2O_3	TiO_2	CaO	BaO	SrO	Fe_2O_3	MgO	Na_2O	K_2O	P_2O_5	SO_3	Undet.
Jig CCC sizes	59.76	29.60	1.47	1.46	0.31	0.14	1.59	0.58	0.08	1.51	1.26	0.27	1.97

ASH FUSION TEMPERATURES (°C) (ASTM D1857)

	REDUCING				OXIDIZING			
SAMPLE ID	IDT	ST	HT	FT	IDT	ST	HT	FT
JIG CCC sizes	+1500	+1500	+1500	+1500	+1500	+1500	+1500	+1500

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CERTIFICATE OF ANALYSIS

CLIENT: **Canadian Carbonization Research Association**

LAB#: 183148 (6 bbl raw coal) **RE-JIG of cumulative 1.54 ARD simulated clean**

RECEIVED DATE: April 26, 2018

REPORT DATE: July 23, 2018

Roben JIG REPORT

Lab Ref No: **183148**

Description: **crushed 12.5mm x 0.5mm REJIG**

RAW ash = 22.56% (adb)

12.5x0.5mm clean JIG = 8.03% Ash (adb)

Roben Jig 12.5mmx0.5mm	ARD mesh vessel DRY tare	ARD mesh vessel WET tare	Assumed Damp Moisture %					
	0	306	5					
Tray Number	Rotations		Dry Coal mass (g)	Relative Density Fractional*	ASH %	Mass%	Cum mass %	Cum ASH %
1	lid +1		2244	1.59	36.61	6.73	100.00	8.49
2	2.0		858	1.45	20.22	2.57	93.27	6.46
3	2.0		884	1.43	15.85	2.65	90.70	6.07
4	3.0		1333	1.37	11.67	4.00	88.05	5.77
5	2.0		924	1.36	9.39	2.77	84.05	5.49
6	1.5		629	1.37	8.38	1.89	81.28	5.36
7	2.0		896	1.35	7.66	2.69	79.40	5.29
8	2.5		1074	1.35	7.53	3.22	76.71	5.20
9	3.0		1382	1.33	6.84	4.14	73.49	5.10
10	3.0		1239	1.34	6.37	3.71	69.35	5.00
11	3.0		1335	1.32	6.30	4.00	65.63	4.92
12	3.0		1213	1.32	5.81	3.64	61.63	4.83
13	3.0		1292	1.32	5.62	3.87	57.99	4.77
14	3.0		1331	1.31	5.73	3.99	54.12	4.71
15	6.0		2497	1.31	5.31	7.49	50.13	4.63
16	10.0		4400	1.31	5.09	13.19	42.64	4.51
17	6.0		2466	1.29	4.68	7.39	29.45	4.25
18	18.0		7355	1.28	4.10	22.05	22.05	4.10
			33352.0					

Tube #	1	Ash%
starting weight =	33694	
fraction weight =	33352	
Jig Slurry wt =	60	26.98
ARD slurry wt =	64	6.60
Total End Weight =	33476	

Fine Losses = 218 (Jig Slurry likely)

cumulative Ash% = 8.52

*Apparent Relative Density - this is considered an average of the "slice" taken

Combining some jig fractions according to ARD & Ash%

Roben Jig 3 batches of 15.5 Kg	ARD mesh vessel DRY tare	ARD mesh vessel WET tare	Assumed Damp Moisture %					
	0	306	5					
Tray Number	Rotations		Dry Coal mass (g)	Relative Density Fractional	ASH %	Mass%	Cum mass %	Cum ASH %
1			2244	1.59	36.61	6.73	100.00	8.49
2			858	1.45	20.22	2.57	93.27	6.46
3			884	1.43	15.85	2.65	90.70	6.07
4			1333	1.37	11.67	4.00	88.05	5.77
5-6			1553	1.37	8.98	4.66	84.05	5.49
7-8			1970	1.35	7.59	5.91	79.40	5.29
9-11			3956	1.33	6.51	11.86	73.49	5.11
12-16			10733	1.31	5.37	32.18	61.63	4.83
17-18			9821	1.28	4.25	29.45	29.45	4.25
			33352.0					

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CERTIFICATE OF ANALYSIS

CLIENT: **Canadian Carbonization Research Association**

LAB#: 183148 (6 bbl raw coal)

RECEIVED DATE: April 26, 2018

REPORT DATE: July 25, 2018

RE-JIG of cumulative 1.54 ARD simulated clean

JIG ANALYSIS (12.5mmx0.5mm), air dried basis															
								CUMUALATIVE							
ARD *	WT(g)	WT%	MOIST%	ASH %	VM %	FC %	FSI	WT%	MOIST%	ASH %	VM %	FC %	FSI		
1.28	9821	29.45	1.22	4.21	30.54	64.03	8.0	29.45	1.22	4.21	30.54	64.03	8.0		
1.31	10733	32.18	1.31	5.37	29.94	63.38	8.5	61.63	1.27	4.82	30.23	63.69	8.3		
1.33	3956	11.86	1.23	6.54	29.81	62.42	8.5	73.49	1.26	5.09	30.16	63.49	8.3		
1.35	1970	5.91	1.10	7.54	29.05	62.31	8.0	79.40	1.25	5.28	30.08	63.40	8.3		
1.37	1553	4.66	1.18	8.90	28.65	61.27	8.0	84.05	1.25	5.48	30.00	63.28	8.3		
1.37	1333	4.00	1.07	11.67	27.39	59.87	6.0	88.05	1.24	5.76	29.88	63.13	8.2		
1.43	884	2.65	1.17	15.85	26.86	56.12	6.5	90.70	1.24	6.05	29.79	62.92	8.1		
1.45	858	2.57	1.09	20.22	25.58	53.11	5.0	93.27	1.23	6.44	29.68	62.65	8.0		Yield = 44.21
1.59	2244	6.73	1.06	36.61	21.20	41.13	3.5	100.00	1.22	8.47	29.10	61.20	7.7		
	33352														

* Apparent Relative Density - this is considered an average of the "slice"

Total Yield = 69.88%

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CERTIFICATE OF ANALYSIS

CLIENT: **Canadian Carbonization Research Association**

LAB#: 183148 (6 bbl raw coal) **RE-JIG of cumulative 1.54 ARD simulated clean**

RECEIVED DATE: April 26, 2018

REPORT DATE: AUGUST 17, 2018

FLOAT SINK ANALYSIS: TRAY #1 (36.61% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	109	5.54	5.01	5.54	5.01
1.30 - 1.40	632	32.01	12.07	37.54	11.03
1.40 - 1.50	307	15.56	20.84	53.10	13.90
1.50 - 1.60	127	6.41	31.07	59.52	15.75
1.60 - 1.70	127	6.44	40.95	65.95	18.21
1.70 - 1.80	104	5.26	49.29	71.21	20.51
1.80 SNK	568	28.79	70.34	100.00	34.85

FLOAT SINK ANALYSIS: TRAY #2 (20.22% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	73	20.28	4.74	20.28	4.74
1.30 - 1.40	164	45.67	10.67	65.94	8.85
1.40 - 1.50	43	12.03	20.23	77.97	10.60
1.50 - 1.60	22	6.11	32.46	84.08	12.19
1.60 - 1.70	17	4.83	41.60	88.92	13.79
1.70 - 1.80	13	3.64	50.68	92.56	15.24
1.80 SNK	27	7.44	66.57	100.00	19.06

FLOAT SINK ANALYSIS: TRAY #3 (15.85% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	99	25.06	4.20	25.06	4.20
1.30 - 1.40	194	49.01	10.22	74.08	8.18
1.40 - 1.50	41	10.38	20.84	84.46	9.74
1.50 - 1.60	19	4.73	31.49	89.19	10.89
1.60 - 1.70	16	4.05	40.68	93.24	12.19
1.70 - 1.80	10	2.51	49.61	95.75	13.17
1.80 SNK	17	4.25	66.60	100.00	15.44

FLOAT SINK ANALYSIS: TRAY #4 (11.67% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	216	35.15	3.87	35.15	3.87
1.30 - 1.40	303	49.31	10.49	84.46	7.73
1.40 - 1.50	53	8.62	21.99	93.08	9.06
1.50 - 1.60	17	2.70	33.13	95.79	9.73
1.60 - 1.70	13	2.18	42.30	97.97	10.46
1.70 - 1.80	6	0.98	51.06	98.94	10.86
1.80 SNK	7	1.06	64.02	100.00	11.42

FLOAT SINK ANALYSIS: TRAY #5/6 (8.98% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	346	50.14	3.99	50.14	3.99
1.30 - 1.40	287	41.59	10.35	91.74	6.87
1.40 - 1.50	39	5.65	21.27	97.39	7.71
1.50 - 1.60	10	1.45	27.93	98.84	8.01
1.60 - 1.70	4	0.58	30.89	99.42	8.14
1.70 - 1.80	2	0.29	45.38	99.71	8.25
1.80 SNK	2	0.29	59.96	100.00	8.40

FLOAT SINK ANALYSIS: TRAY #7/8 (7.59% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	545	60.29	3.85	60.29	3.85
1.30 - 1.40	307	33.96	10.19	94.25	6.13
1.40 - 1.50	36	3.98	19.93	98.23	6.69
1.50 - 1.60	8	0.88	28.82	99.12	6.89
1.60 - 1.70	3	0.33	36.60	99.45	6.99
1.70 - 1.80	2	0.22	47.02	99.67	7.08
1.80 SNK	3	0.33	63.97	100.00	7.27

FLOAT SINK ANALYSIS: TRAY #9-11 (6.51% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	1198	67.91	3.36	67.91	3.36
1.30 - 1.40	483	27.38	9.86	95.29	5.23
1.40 - 1.50	54	3.06	19.89	98.36	5.68
1.50 - 1.60	12	0.68	29.58	99.04	5.85
1.60 - 1.70	5	0.28	37.58	99.32	5.94
1.70 - 1.80	3	0.17	47.94	99.49	6.01
1.80 SNK	9	0.51	63.84	100.00	6.31

FLOAT SINK ANALYSIS: TRAY #12-16 (5.37% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	3495	76.51	2.65	76.51	2.65
1.30 - 1.40	861	18.85	9.26	95.36	3.96
1.40 - 1.50	131	2.87	18.61	98.23	4.38
1.50 - 1.60	29	0.63	31.03	98.86	4.56
1.60 - 1.70	13	0.28	41.88	99.15	4.66
1.70 - 1.80	9	0.20	49.79	99.34	4.75
1.80 SNK	30	0.66	70.65	100.00	5.18

FLOAT SINK ANALYSIS: TRAY #17/18 (4.25% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	3605	81.97	2.44	81.97	2.44
1.30 - 1.40	654	14.87	8.78	96.84	3.41
1.40 - 1.50	82	1.86	18.41	98.70	3.70
1.50 - 1.60	19	0.43	30.91	99.14	3.82
1.60 - 1.70	9	0.20	38.52	99.34	3.89
1.70 - 1.80	6	0.14	43.67	99.48	3.94
1.80 SNK	23	0.52	69.83	100.00	4.29

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2018-1

CERTIFICATE OF ANALYSIS

CLIENT: **Canadian Carbonization Research Association**

LAB#: 183148 (6 bbl raw coal)

RECEIVED DATE: April 26, 2018

REPORT DATE: July 6, 2018

FLOAT SINK ANALYSIS (12.5mmx2mm), air dried basis (ASTM D4371)

									CUMULATIVE						
S.G.	WT(g)	WT%	MOIST%	ASH %	VM %	FC %	FSI		WT%	MOIST%	ASH %	VM %	FC %	FSI	
1.30 FLT	11347	36.67	1.19	3.08	30.90	64.83	8.0		36.67	1.19	3.08	30.90	64.83	8.0	
1.30 - 1.35	4692	15.16	1.31	8.15	28.88	61.66	7.5		51.84	1.23	4.56	30.31	63.90	7.9	
1.35 - 1.40	1503	4.86	1.28	13.07	25.31	60.34	5.0		56.70	1.23	5.29	29.88	63.60	7.6	
1.40 - 1.45	961	3.11	1.19	16.87	23.97	57.97	4.0		59.80	1.23	5.89	29.57	63.31	7.4	
1.45 - 1.50	443	1.43	1.01	21.88	23.56	53.55	3.5	ck'd	61.23	1.22	6.27	29.43	63.08	7.3	
1.50 - 1.55	516	1.67	1.44	23.82	23.03	51.71	4.0	ck'd	62.90	1.23	6.73	29.26	62.78	7.2	
1.55 - 1.60	232	0.75	1.22	33.32	22.03	43.43	2.5		63.65	1.23	7.05	29.18	62.55	7.2	Yield = 28.56
1.60 - 1.65	209	0.68	1.15	38.76	20.40	39.69	2.5		64.33	1.23	7.38	29.09	62.31	7.1	
1.65 - 1.70	216	0.70	1.16	43.39	19.63	35.82	2.0		65.02	1.23	7.77	28.98	62.02	7.1	
1.70 - 1.80	441	1.43	1.29	49.91	18.08	30.72	2.0		66.45	1.23	8.67	28.75	61.35	7.0	
1.80 SNK	10381	33.55	1.28	78.86	11.35	8.51	0.5		100.00	1.25	32.22	22.91	43.62	4.8	
	30941	**30923**	**18**	**grams gain**											

FLOAT SINK ANALYSIS (2mmx0.5mm), air dried basis (ASTM D4371)

									CUMULATIVE						
S.G.	WT(g)	WT%	MOIST%	ASH %	VM %	FC %	FSI		WT%	MOIST%	ASH %	VM %	FC %	FSI	
1.30 FLT	9434	59.78	1.51	2.15	30.91	65.43	8.5		59.78	1.51	2.15	30.91	65.43	8.5	
1.30 - 1.35	1412	8.95	1.38	7.85	28.47	62.30	8.0		68.73	1.49	2.89	30.59	65.02	8.4	
1.35 - 1.40	946	5.99	1.61	12.16	26.16	60.07	7.0		74.72	1.50	3.64	30.24	64.63	8.3	
1.40 - 1.45	373	2.36	1.50	16.75	24.68	57.07	3.5		77.09	1.50	4.04	30.07	64.39	8.2	
1.45 - 1.50	308	1.95	1.80	21.96	24.15	52.09	3.5		79.04	1.51	4.48	29.92	64.09	8.1	
1.50 - 1.55	147	0.93	1.53	28.39	23.16	46.92	3.5		79.97	1.51	4.76	29.84	63.89	8.0	
1.55 - 1.60	111	0.70	1.43	32.94	22.48	43.15	3.0		80.67	1.51	5.00	29.78	63.71	8.0	Yield = 17.98
1.60 - 1.65	111	0.70	1.45	37.87	21.30	39.38	3.0		81.38	1.51	5.29	29.70	63.50	7.9	
1.65 - 1.70	107	0.68	1.68	41.20	20.42	36.70	3.0		82.05	1.51	5.59	29.63	63.28	7.9	
1.70 - 1.80	197	1.25	1.41	49.65	18.84	30.10	2.5		83.30	1.51	6.25	29.47	62.78	7.8	
1.80 SNK	2635	16.70	1.49	77.12	11.90	9.49	0.5		100.00	1.51	18.08	26.53	53.88	6.6	
	15781	**15643**	**138**	**grams gain**											

Total Float Yield = 46.54%
Total Yield = 72.21%

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CERTIFICATE OF ANALYSIS

CLIENT: **Canadian Carbonization Research Association**

LAB#: 183148 (6 bbl raw coal)

RECEIVED DATE: April 26, 2018

REPORT DATE: July 25, 2018

JIG ANALYSIS (12.5mmx2mm), air dried basis

								CUMULATIVE						
ARD *	WT(g)	WT%	MOIST%	ASH %	VM %	FC %	FSI	WT%	MOIST%	ASH %	VM %	FC %	FSI	
1.28	5366	11.58	1.23	3.39	30.71	64.67	9.0	11.58	1.23	3.39	30.71	64.67	9.0	
1.30	7977	17.21	1.16	4.66	30.30	63.88	8.5	28.79	1.19	4.15	30.46	64.20	8.7	
1.32	5061	10.92	1.25	5.93	29.40	63.42	8.5	39.71	1.21	4.64	30.17	63.98	8.6	
1.34	2472	5.33	1.06	7.89	28.65	62.40	7.5	45.04	1.19	5.02	29.99	63.80	8.5	
1.37	2446	5.28	1.06	9.19	27.63	62.12	5.5	50.32	1.17	5.46	29.74	63.62	8.2	
1.41	2659	5.74	1.00	12.32	27.08	59.60	5.0	56.06	1.16	6.16	29.47	63.21	7.9	
1.47	1361	2.94	0.95	18.27	25.72	55.06	4.5	58.99	1.15	6.77	29.28	62.80	7.7	
1.54	1898	4.10	1.05	29.36	22.46	47.13	4.0	63.09	1.14	8.23	28.84	61.79	7.5	Yield = 28.31
1.99	8502	18.34	0.97	63.88	14.89	20.26	1.0	81.43	1.10	20.77	25.70	52.43	6.0	
2.47	8607	18.57	1.04	82.76	11.08	5.12	0.5	100.00	1.09	32.28	22.98	43.65	5.0	
	46349													

JIG ANALYSIS (2mmx0.5mm), air dried basis

								CUMULATIVE						
ARD *	WT(g)	WT%	MOIST%	ASH %	VM %	FC %	FSI	WT%	MOIST%	ASH %	VM %	FC %	FSI	
1.29	4400	33.02	1.11	5.00	30.15	63.74	8.5	33.02	1.11	5.00	30.15	63.74	8.5	
1.39	2826	21.21	1.11	6.43	29.93	62.53	8.5	54.23	1.11	5.56	30.06	63.27	8.5	
1.43	2070	15.53	1.10	6.36	29.77	62.77	8.0	69.76	1.11	5.74	30.00	63.16	8.4	
1.40	1328	9.97	1.09	12.54	28.35	58.02	8.0	79.73	1.11	6.59	29.79	62.51	8.3	Yield = 17.77
1.84	1054	7.91	1.23	36.16	21.52	41.09	4.0	87.64	1.12	9.26	29.05	60.58	7.9	
2.32	1647	12.36	1.07	75.15	13.47	10.31	1.0	100.00	1.11	17.40	27.12	54.37	7.1	
	13325													

* Apparent Relative Density - this is considered an average of the "slice"

Total JIG Yield = 46.08%
Total Yield = 71.75%

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CERTIFICATE OF ANALYSIS

CLIENT: **Canadian Carbonization Research Association**

LAB#: 183148 (6 bbl raw coal)

RECEIVED DATE: April 26, 2018

REPORT DATE: July 6, 2018

Roben JIG REPORT

Lab Ref No	Description
183148	**crushed 12.5mm x 0.5mm**

RAW ash = 22.56% (adb)

12.5mmx2mm = 30.22% Ash (adb)

Roben Jig 12.5mmx2mm	ARD mesh vessel DRY tare	ARD mesh vessel WET tare	Assumed Damp Moisture %					
	0	306	5					
Tray Number	Rotations		Dry Coal mass (g)	Relative Density Fractional*	ASH %	Mass%	Cum mass %	Cum ASH %
1	lid +5		8607	2.47	82.76	18.57	100.00	32.21
2	10.0		8502	1.99	63.88	18.34	81.43	20.68
3	3.0		1898	1.54	29.36	4.10	63.09	8.12
4	1.5		813	1.48	19.41	1.75	58.99	6.65
5	1.0		548	1.45	15.71	1.18	57.24	6.26
6	2.0		1381	1.41	12.59	2.98	56.06	6.06
7	2.0		1278	1.40	11.32	2.76	53.08	5.69
8	2.5		1179	1.37	9.91	2.54	50.32	5.38
9	2.0		1267	1.36	8.62	2.73	47.77	5.14
10	2.0		1259	1.34	7.79	2.72	45.04	4.93
11	2.0		1213	1.34	7.49	2.62	42.32	4.75
12	2.0		1447	1.32	6.35	3.12	39.71	4.57
13	3.0		1713	1.32	5.88	3.70	36.59	4.41
14	3.0		1901	1.31	5.43	4.10	32.89	4.25
15	3.0		1517	1.31	4.84	3.27	28.79	4.08
16	6.0		3825	1.30	4.41	8.25	25.52	3.98
17	5.0		2635	1.29	4.74	5.69	17.26	3.78
18	4.0		2233	1.28	3.65	4.82	11.58	3.31
19	8.0		3133	1.28	3.06	6.76	6.76	3.06
			46349.0					

Tube #	1	
starting weight =	**46671**	
fraction weight =	46349	**Ash%**
Jig Slurry wt =	56	26.87
ARD slurry wt =	19	16.59
Total End Weight =	**46424**	
Fine Losses =	**247**	
(Jig Slurry likely)		
cumulative Ash% =	**32.20**	

*Apparent Relative Density - this is considered an average of the "slice" taken

Combining some jig fractions according to ARD & Ash%

Roben Jig 3 batches of 15.5 Kg	ARD mesh vessel DRY tare	ARD mesh vessel WET tare	Assumed Damp Moisture %					
	0	306	5					
Tray Number	Rotations		Dry Coal mass (g)	Relative Density Fractional	ASH %	Mass%	Cum mass %	Cum ASH %
1			8607	2.47	82.76	18.57	100.00	32.21
2			8502	1.99	63.88	18.34	81.43	20.68
3			1898	1.54	29.36	4.10	63.09	8.12
4-5			1361	1.47	17.94	2.94	58.99	6.65
6-7			2659	1.41	11.98	5.74	56.06	6.06
8-9			2446	1.37	9.24	5.28	50.32	5.38
10-11			2472	1.34	7.64	5.33	45.04	4.93
12-14			5061	1.32	5.85	10.92	39.71	4.57
15-17			7977	1.30	4.60	17.21	28.79	4.08
18-19			5366	1.28	3.31	11.58	11.58	3.31
			46349.0					

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CERTIFICATE OF ANALYSIS

CLIENT: **Canadian Carbonization Research Association**

LAB#: 183148 (6 bbl raw coal)

RECEIVED DATE: April 26, 2018

REPORT DATE: July 6, 2018

Roben JIG REPORT

Lab Ref No: **183148**

Description: **crushed 12.5mm x 0.5mm**

RAW ash = 22.56% (adb)

2mmx0.5mm = 17.25% Ash (adb)

Roben Jig 2mmx0.5mm	**ARD mesh vessel DRY tare**	**ARD mesh vessel WET tare**	**Assumed Damp Moisture %**					
	0	**306**	**5**					
Tray Number	Rotations		Dry Coal mass (g)	Relative Density Fractional*	ASH %	Mass%	Cum mass %	Cum ASH %
1	1.0		1647	2.32	75.15	12.36	100.00	17.32
2	3.0		1054	1.84	36.16	7.91	87.64	9.16
3	5.0		1328	1.40	12.54	9.97	79.73	6.48
4	3.0		874	1.42	6.57	6.56	69.76	5.62
5	2.0		603	1.45	5.76	4.53	63.20	5.52
6	2.0		593	1.43	5.34	4.45	58.68	5.50
7	3.0		627	1.48	5.72	4.71	54.23	5.52
8	3.0		974	1.36	6.02	7.31	49.52	5.50
9	3.0		1225	1.36	7.11	9.19	42.21	5.41
10	3.0		1085	1.33	5.59	8.14	33.02	4.93
11	1.5		1001	1.35	5.26	7.51	24.88	4.72
12	8.0		2314	1.24	4.48	17.37	17.37	4.48
			13325.0					

Tube #	**3**	
starting weight =	**13608**	
fraction weight =	13325	**Ash%**
Jig Slurry wt =	90	54.36
ARD slurry wt =	84	8.30
Total End Weight =	**13499**	
Fine Losses =	**109**	
(Jig Slurry likely)		
cumulative Ash% =	**17.51**	

*Apparent Relative Density - this is considered an average of the "slice" taken

Combining some jig fractions according to ARD & Ash%

Roben Jig 3 batches of 15.5 Kg	**ARD mesh vessel DRY tare**	**ARD mesh vessel WET tare**	**Assumed Damp Moisture %**					
	0	**306**	**5**					
Tray Number	Rotations		Dry Coal mass (g)	Relative Density Fractional	ASH %	Mass%	Cum mass %	Cum ASH %
1			1647	2.32	75.15	12.36	100.00	17.32
2			1054	1.84	36.16	7.91	87.64	9.16
3			1328	1.40	12.54	9.97	79.73	6.48
4-6			2070	1.43	5.98	15.53	69.76	5.62
7-9			2826	1.39	6.43	21.21	54.23	5.52
10-12			4400	1.29	4.93	33.02	33.02	4.93
			13325.0					

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CERTIFICATE OF ANALYSIS

CLIENT: **Canadian Carbonization Research Association**

LAB#: 183148 (6 bbl raw coal)

RECEIVED DATE: April 26, 2018

REPORT DATE: AUGUST 17, 2018

FLOAT SINK ANALYSIS: TRAY #1 (82.76% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	0	0.00	0.00	0.00	0.00
1.30 - 1.40	0	0.00	0.00	0.00	0.00
1.40 - 1.50	0	0.00	0.00	0.00	0.00
1.50 - 1.60	0	0.00	0.00	0.00	0.00
1.60 - 1.70	0	0.00	0.00	0.00	0.00
1.70 - 1.80	11	0.34	49.36	0.34	49.36
1.80 SNK	3205	99.66	82.92	100.00	82.81

FLOAT SINK ANALYSIS: TRAY #2 (63.88% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	3	0.08	7.59	0.08	7.59
1.30 - 1.40	136	3.63	12.23	3.71	12.13
1.40 - 1.50	213	5.68	21.26	9.39	17.65
1.50 - 1.60	144	3.84	31.68	13.24	21.73
1.60 - 1.70	175	4.67	42.20	17.91	27.07
1.70 - 1.80	283	7.55	50.71	25.46	34.08
1.80 SNK	2793	74.54	73.74	100.00	63.64

FLOAT SINK ANALYSIS: TRAY #3 (29.36% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	12	1.09	7.22	1.09	7.22
1.30 - 1.40	424	37.56	12.01	38.65	11.87
1.40 - 1.50	269	23.85	20.92	62.50	15.33
1.50 - 1.60	110	9.73	31.47	72.23	17.50
1.60 - 1.70	86	7.63	41.64	79.86	19.81
1.70 - 1.80	73	6.48	49.78	86.34	22.06
1.80 SNK	154	13.66	64.98	100.00	27.92

FLOAT SINK ANALYSIS: TRAY #4/5 (17.94% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	62	7.45	5.77	7.45	5.77
1.30 - 1.40	518	61.75	10.88	69.19	10.33
1.40 - 1.50	138	16.50	20.46	85.69	12.28
1.50 - 1.60	47	5.55	31.21	91.24	13.43
1.60 - 1.70	27	3.19	40.57	94.43	14.35
1.70 - 1.80	18	2.15	49.14	96.58	15.12
1.80 SNK	29	3.42	63.78	100.00	16.79

FLOAT SINK ANALYSIS: TRAY #6/7 (11.98% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	403	24.51	5.19	24.51	5.19
1.30 - 1.40	959	58.33	10.53	82.84	8.95
1.40 - 1.50	195	11.83	20.23	94.66	10.36
1.50 - 1.60	45	2.76	30.50	97.42	10.93
1.60 - 1.70	17	1.02	40.33	98.44	11.23
1.70 - 1.80	9	0.55	50.00	98.98	11.45
1.80 SNK	17	1.02	69.39	100.00	12.04

FLOAT SINK ANALYSIS: TRAY #8/9 (9.24% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	679	45.78	4.70	45.78	4.70
1.30 - 1.40	680	45.84	10.47	91.62	7.59
1.40 - 1.50	96	6.44	19.99	98.06	8.40
1.50 - 1.60	15	1.02	30.65	99.08	8.63
1.60 - 1.70	5	0.32	40.15	99.40	8.73
1.70 - 1.80	3	0.18	48.76	99.58	8.80
1.80 SNK	6	0.42	67.79	100.00	9.05

FLOAT SINK ANALYSIS: TRAY #10/11 (7.64% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	889	60.74	4.37	60.74	4.37
1.30 - 1.40	509	34.78	10.40	95.52	6.57
1.40 - 1.50	54	3.69	19.46	99.21	7.05
1.50 - 1.60	7	0.48	29.14	99.69	7.15
1.60 - 1.70	1	0.07	35.84	99.76	7.17
1.70 - 1.80	1	0.03	44.11	99.80	7.18
1.80 SNK	3	0.20	53.75	100.00	7.28

FLOAT SINK ANALYSIS: TRAY #12-14 (5.85% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	2179	71.34	3.53	71.34	3.53
1.30 - 1.40	804	26.32	10.13	97.66	5.31
1.40 - 1.50	61	2.00	19.58	99.66	5.59
1.50 - 1.60	5	0.16	27.09	99.82	5.63
1.60 - 1.70	1	0.03	46.83	99.85	5.64
1.70 - 1.80	1	0.02	43.04	99.87	5.65
1.80 SNK	4	0.13	59.57	100.00	5.72

FLOAT SINK ANALYSIS: TRAY #15-17 (4.60% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	2521	80.79	2.96	80.79	2.96
1.30 - 1.40	559	17.91	9.87	98.70	4.21
1.40 - 1.50	36	1.15	18.29	99.86	4.38
1.50 - 1.60	2	0.06	23.19	99.92	4.39
1.60 - 1.70	1	0.02	31.52	99.94	4.39
1.70 - 1.80	0	0.00		99.94	4.39
1.80 SNK	2	0.06	45.68	100.00	4.42

FLOAT SINK ANALYSIS: TRAY #18/19 (3.31% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	4085	87.19	2.40	87.19	2.40
1.30 - 1.40	559	11.93	8.34	99.12	3.12
1.40 - 1.50	29	0.62	15.82	99.74	3.19
1.50 - 1.60	3	0.06	24.20	99.81	3.21
1.60 - 1.70	1	0.01	33.50	99.82	3.21
1.70 - 1.80	1	0.01	38.27	99.83	3.21
1.80 SNK	8	0.17	72.39	100.00	3.33

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GWIL INDUSTRIES

2018-1

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CERTIFICATE OF ANALYSIS

CLIENT: **Canadian Carbonization Research Association**

LAB#: 183148 (6 bbl raw coal)

RECEIVED DATE: April 26, 2018

REPORT DATE: AUGUST 27, 2018

FLOAT SINK ANALYSIS: TRAY #1 (75.15% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	7	0.45	3.76	0.45	3.76
1.30 - 1.40	15	1.03	13.39	1.49	10.45
1.40 - 1.50	16	1.12	21.99	2.61	15.41
1.50 - 1.60	22	1.50	32.81	4.11	21.76
1.60 - 1.70	27	1.87	42.08	5.98	28.11
1.70 - 1.80	40	2.73	50.58	8.71	35.16
1.80 SNK	1326	91.29	78.32	100.00	74.56

FLOAT SINK ANALYSIS: TRAY #2 (36.16% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	463	48.45	1.99	48.45	1.99
1.30 - 1.40	74	7.74	8.75	56.19	2.92
1.40 - 1.50	11	1.19	19.20	57.38	3.26
1.50 - 1.60	3	0.35	30.26	57.73	3.42
1.60 - 1.70	1	0.13	38.52	57.85	3.50
1.70 - 1.80	2	0.20	51.34	58.05	3.66
1.80 SNK	401	41.95	75.40	100.00	33.76

FLOAT SINK ANALYSIS: TRAY #3 (12.54% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	353	52.25	2.70	52.25	2.70
1.30 - 1.40	193	28.56	10.45	80.80	5.44
1.40 - 1.50	55	8.19	20.47	89.00	6.82
1.50 - 1.60	19	2.75	31.90	91.75	7.57
1.60 - 1.70	14	2.07	43.34	93.82	8.36
1.70 - 1.80	9	1.27	49.67	95.09	8.92
1.80 SNK	33	4.91	72.22	100.00	12.02

FLOAT SINK ANALYSIS: TRAY #4-6 (5.98% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	625	76.69	2.36	76.69	2.36
1.30 - 1.40	134	16.45	10.34	93.14	3.77
1.40 - 1.50	29	3.57	20.38	96.71	4.38
1.50 - 1.60	9	1.07	31.50	97.78	4.68
1.60 - 1.70	4	0.53	40.84	98.31	4.87
1.70 - 1.80	3	0.31	47.86	98.61	5.01
1.80 SNK	11	1.39	69.35	100.00	5.90

FLOAT SINK ANALYSIS: TRAY #7-9 (6.43% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	745	74.26	2.07	74.26	2.07
1.30 - 1.40	169	16.80	9.07	91.06	3.36
1.40 - 1.50	26	2.63	21.20	93.69	3.86
1.50 - 1.60	32	3.16	32.40	96.85	4.79
1.60 - 1.70	6	0.57	38.02	97.42	4.99
1.70 - 1.80	4	0.44	48.08	97.86	5.18
1.80 SNK	22	2.14	71.40	100.00	6.60

FLOAT SINK ANALYSIS: TRAY #10-12 (4.93% Ash)

				CUMUALATIVE	
SG	WT(g)	WT%	ASH %	WT%	ASH %
1.30 FLT	1028	77.97	1.95	77.97	1.95
1.30 - 1.40	222	16.82	8.89	94.78	3.18
1.40 - 1.50	32	2.41	19.92	97.19	3.60
1.50 - 1.60	11	0.80	29.84	97.99	3.81
1.60 - 1.70	6	0.45	39.67	98.45	3.98
1.70 - 1.80	4	0.31	47.58	98.76	4.11
1.80 SNK	16	1.24	68.10	100.00	4.91

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2018-1

CERTIFICATE OF ANALYSIS

CLIENT: **Canadian Carbonization Research Association**

LAB#: 183148 (6 bbl raw coal)

RECEIVED DATE: April 26, 2018

REPORT DATE: July 31, 2018

12.5x2mm size fraction

GIESELER FLUIDITY TEST (ASTM D2639)

SAMPLE ID	12.5mm x 2mm ASH %	TEMPERATURES °C INITIAL SOFT (1 DDPM)	MAX. FLUIDITY	SOLIDIFICATION	RANGE	MAX. DDPM	Date Tested
1.30 FLT	3.08	408	449	484	76	**553**	July 27
1.30 - 1.35	8.15	417	453	482	65	**184**	July 27
1.35 - 1.40	13.07	423	453	479	56	**19**	July 27
1.28 ARD	3.39	411	452	486	75	**535**	July 31
1.32 ARD	5.93	414	453	483	69	**373**	July 31
1.37 ARD	9.19	414	452	482	68	**249**	July 31

RHUR DILATATION (ASTM D5515)

SAMPLE ID	SOFT TEMP	TMCONT	TMDIL.	%CONT.	%DIL	% TOTAL DIL	%SD 2.5	Date Tested
1.30 FLT	375	427	462	28	147	175	**135**	July 27
1.30 - 1.35	379	439	466	22	33	55	**37**	July 27
1.35 - 1.40	385	454	478	20	-19	1	**-19**	July 27
1.28 ARD	382	428	460	26	144	170	**157**	July 31
1.32 ARD	391	438	467	22	88	110	**94**	July 31
1.37 ARD	391	442	468	23	43	66	**46**	July 31

2x0.5mm size fraction

GIESELER FLUIDITY TEST (ASTM D2639)

SAMPLE ID	2mm x 0.5mm ASH %	TEMPERATURES °C INITIAL SOFT (1 DDPM)	MAX. FLUIDITY	SOLIDIFICATION	RANGE	MAX. DDPM	Date Tested
1.30 FLT	3.08	418	450	484	66	**516**	July 27
1.30 - 1.35	8.15	417	451	481	64	**269**	July 27
1.35 - 1.40	13.07	420	452	477	57	**33**	July 27
1.29 ARD	5.00	413	452	485	72	**373**	July 31
1.43 ARD	6.36	411	450	480	69	**317**	July 31

RHUR DILATATION (ASTM D5515)

SAMPLE ID	SOFT TEMP	TMCONT	TMDIL.	%CONT.	%DIL	DIL	%SD 2.5	Date Tested
1.30 FLT	373	424	460	26	167	193	**171**	July 27
1.30 - 1.35	376	433	461	23	51	74	**54**	July 27
1.35 - 1.40	340	439	472	24	-13	11	**-14**	July 27
1.29 ARD	382	431	463	25	148	173	**148**	July 31
1.43 ARD	385	431	467	25	125	150	**136**	July 31

Heather Dexter
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Pearson Coal Petrography

Petrographic Analysis

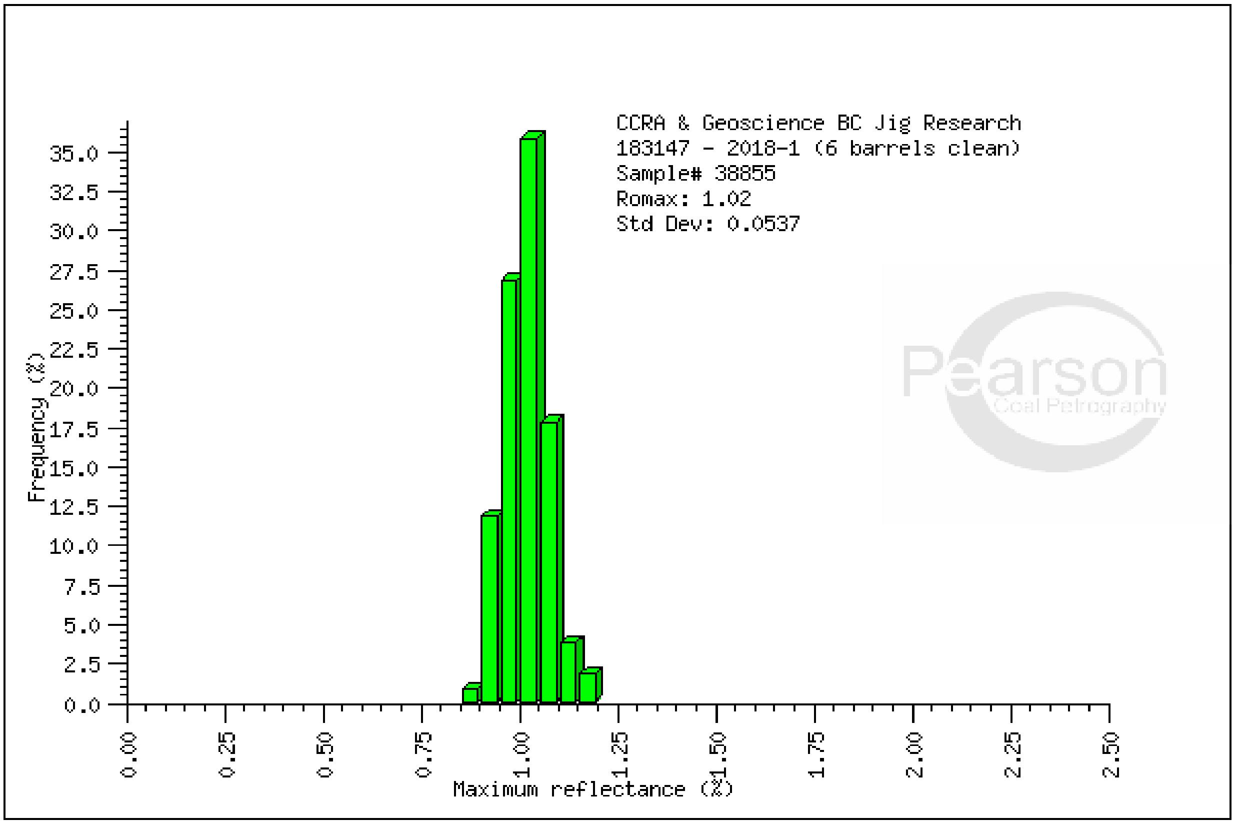
Sample Identification	
Company ID	CCRA & Geoscience BC Jig Research
Laboratory Number	38855
Sample Identifier	183147 - 2018-1 (6 barrels clean)
Date Analyzed	11-23-18
Ash	8.09
Sulphur	0.54
Petrographic Indices	
Mean Maximum Reflectance (RoMax)	1.02
Random Reflectance (calculated)	0.96
Standard Deviation	0.05
Composition Balance Index	0.63
Calculated Strength Index	3.72
Calculated Stability Index	48.00
Estimated Coke Strength DI 30/15	92.79
Predicted Free Swelling Index	8.50
Distribution of Vitrinite Types	
V-8	1.00
V-9	39.00
V-10	54.00
V-11	6.00
Reactive Components	
Vitrinite	68.20
Liptinite	2.30
Reactive Semifusinite	9.40
Total Reactives	**79.90**
Inert Components	
Inert Semifusinite	9.40
Fusinite	4.00
Inertodetrinite	2.10
Macrinite	0.20
Mineral Matter	4.40
Total Inerts	**20.10**

Analyst Jennifer S. Pearson

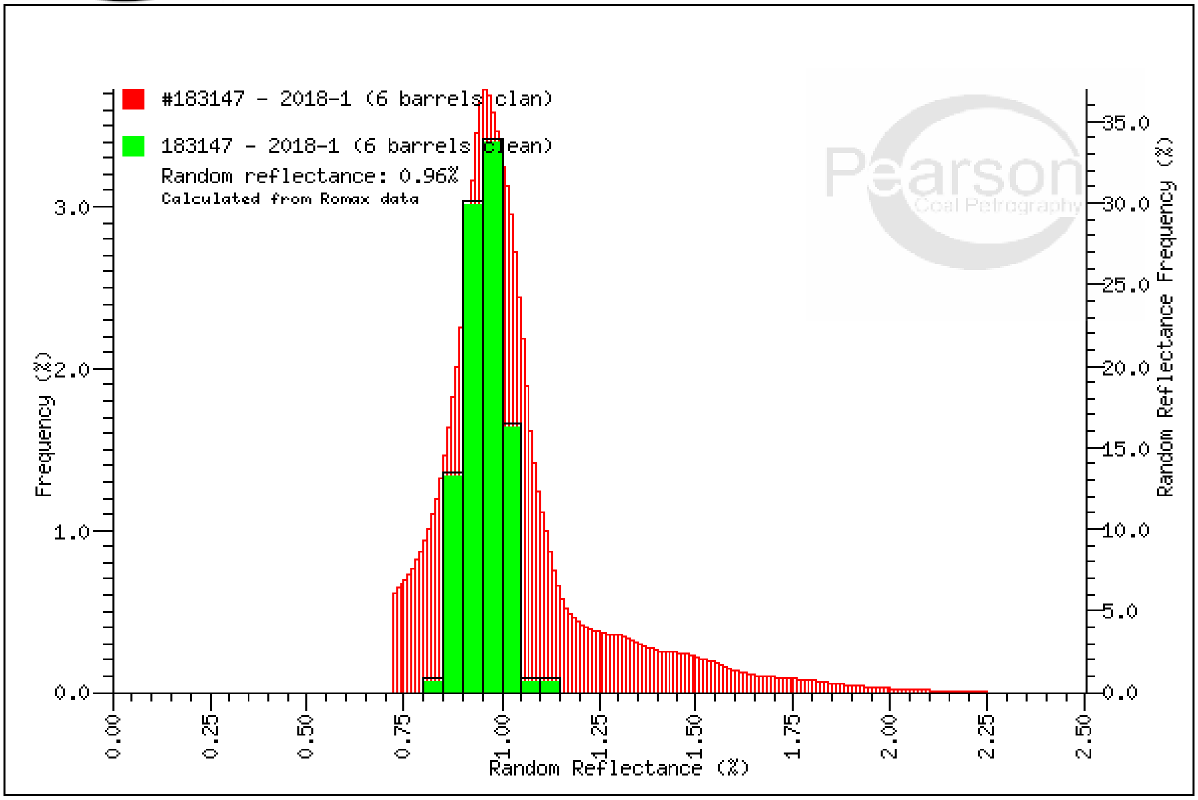
Vitrinite Analysis

CCRA & Geoscience BC Jig Research	
Vitrinite reflectance by	ISO 7404/5
	183147 - 2018-1 (6 barrels clean)
Basic Statistics	
Romax	1.02
Standard Error of the mean	0.01
Coefficient of Variation	5.2935
Variance	0.0029
Standard Deviation	0.0537
Skewness	0.1617
Kurtosis	3.0363
Number of Measurements	100
Vitrinite Distribution	
Vitrinite type (V-Type)	Frequency (%)
V-8	1.00
V-9	39.00
V-10	54.00
V-11	6.00

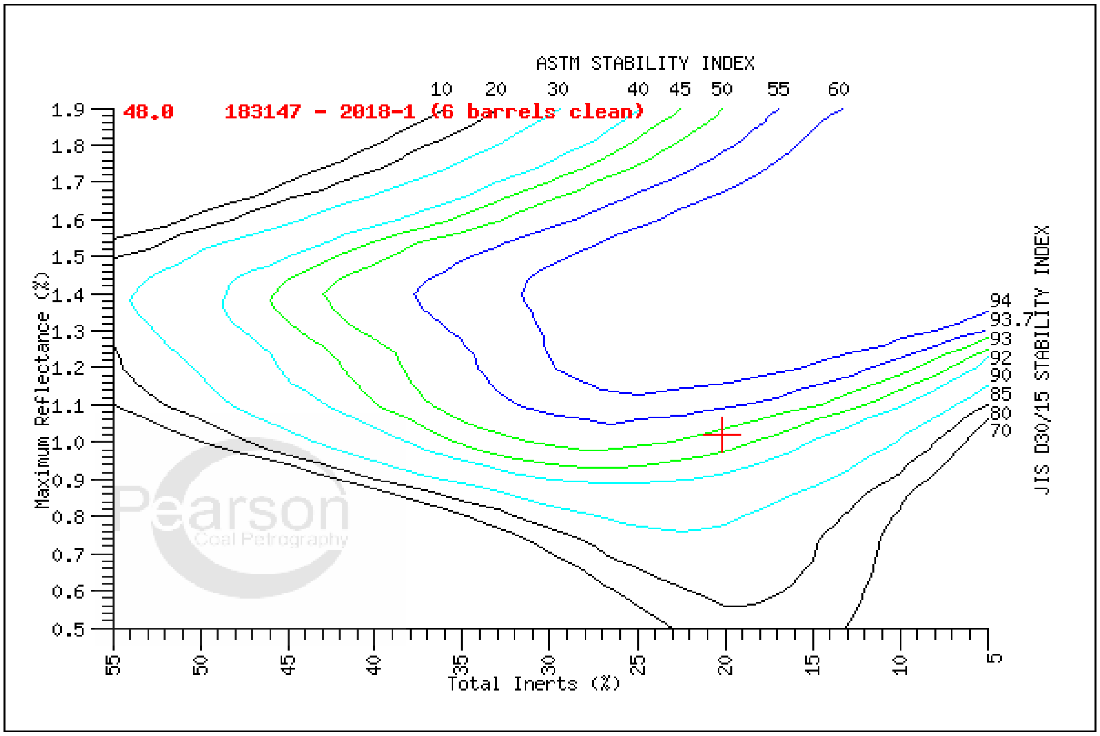
Vitrinite Reflectance Profile



Random Reflectance Graphs

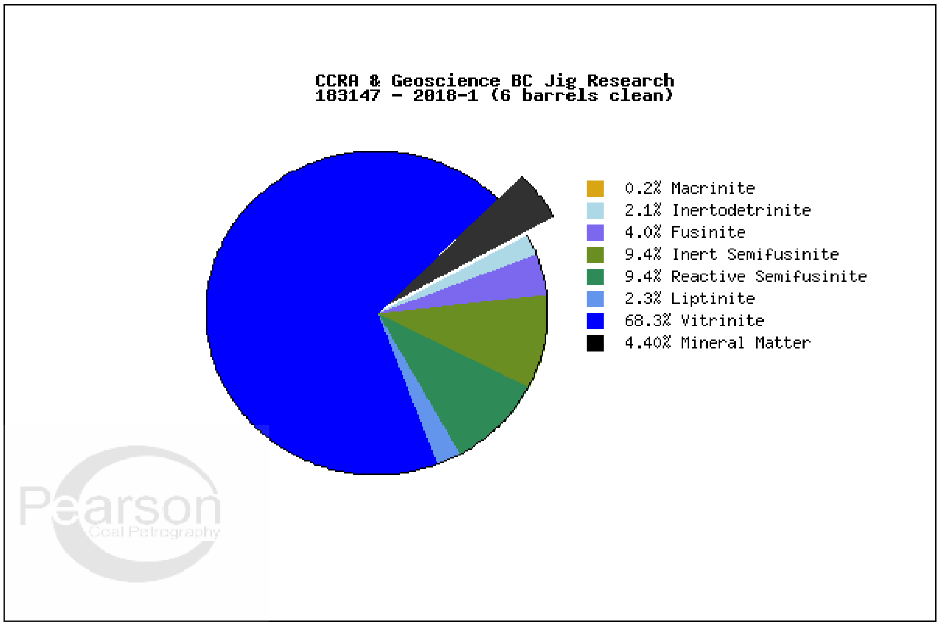


Coke Strength



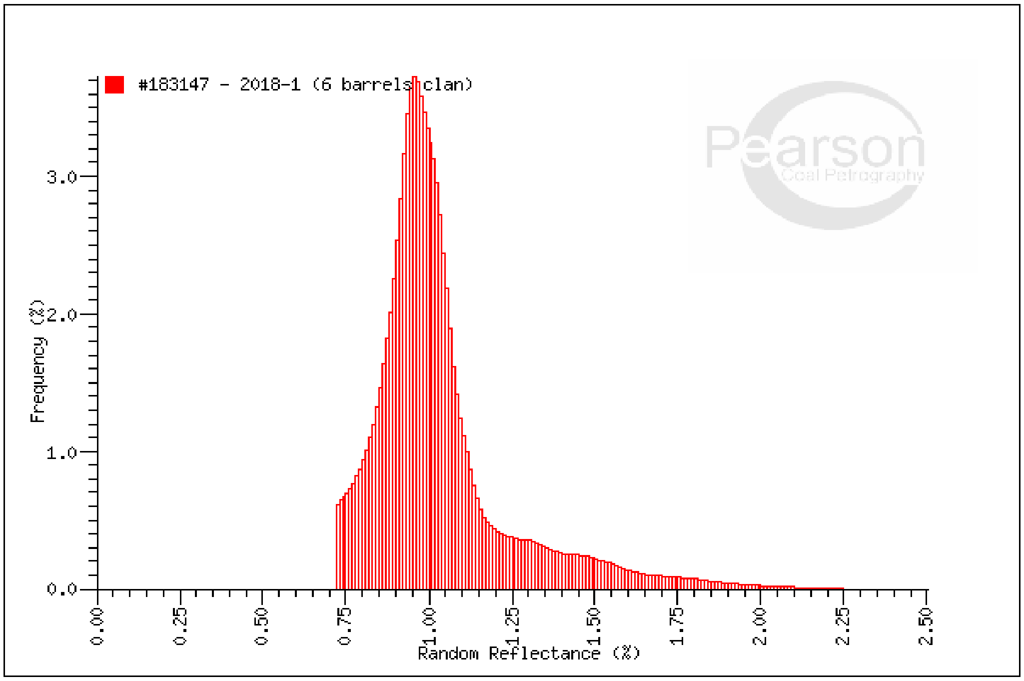
Pearson Coal Petrography

Maceral Distribution



Pearson Coal Petrography

Reflectance Profile



Pearson Coal Petrography

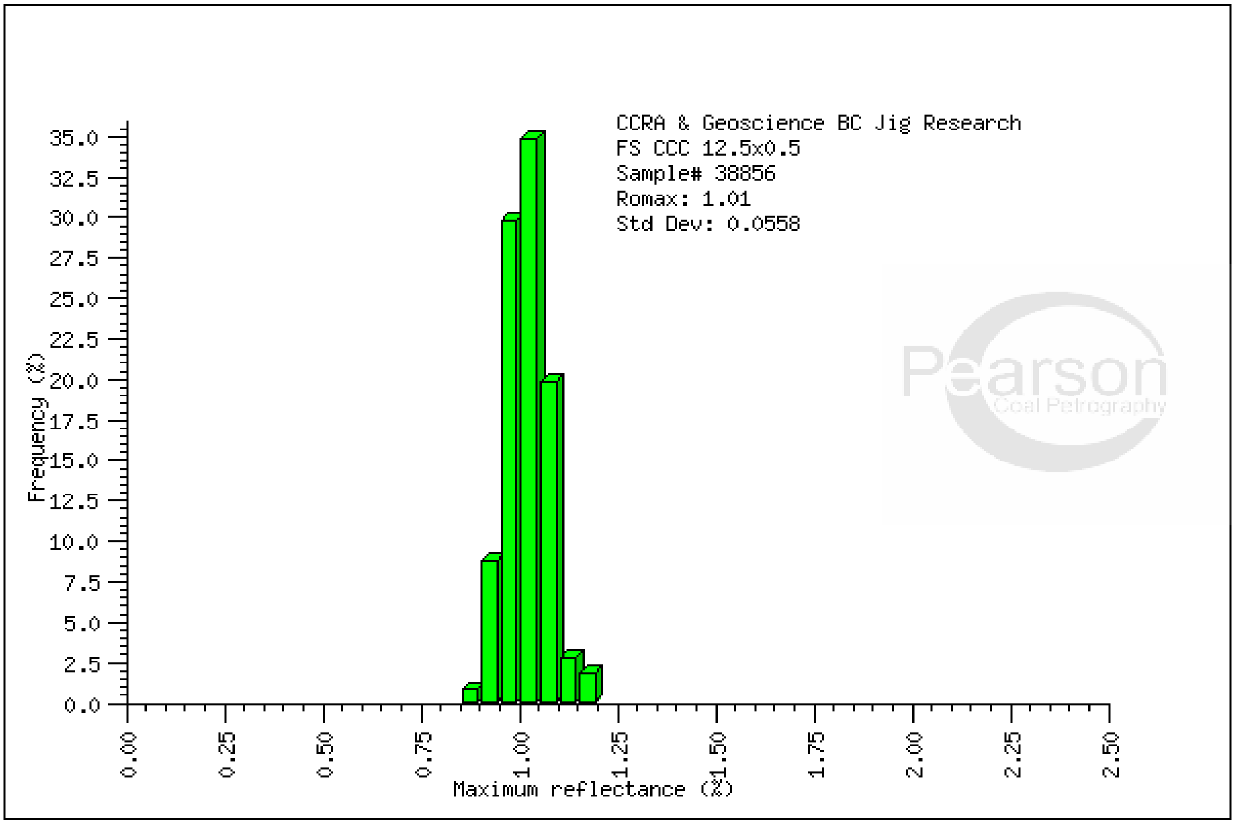
Petrographic Analysis

Sample Identification	
Company ID	CCRA & Geoscience BC Jig Research
Laboratory Number	38856
Sample Identifier	FS CCC 12.5x0.5
Date Analyzed	11-22-18
Ash	6.82
Sulphur	0.55
Petrographic Indices	
Mean Maximum Reflectance (RoMax)	1.01
Random Reflectance (calculated)	0.95
Standard Deviation	0.06
Composition Balance Index	0.45
Calculated Strength Index	3.58
Calculated Stability Index	41.00
Estimated Coke Strength DI 30/15	90.74
Predicted Free Swelling Index	8.50
Distribution of Vitrinite Types	
V-8	1.00
V-9	39.00
V-10	55.00
V-11	5.00
Reactive Components	
Vitrinite	75.40
Liptinite	1.30
Reactive Semifusinite	8.10
Total Reactives	**84.80**
Inert Components	
Inert Semifusinite	8.10
Fusinite	2.50
Inertodetrinite	0.80
Mineral Matter	3.80
Total Inerts	**15.20**

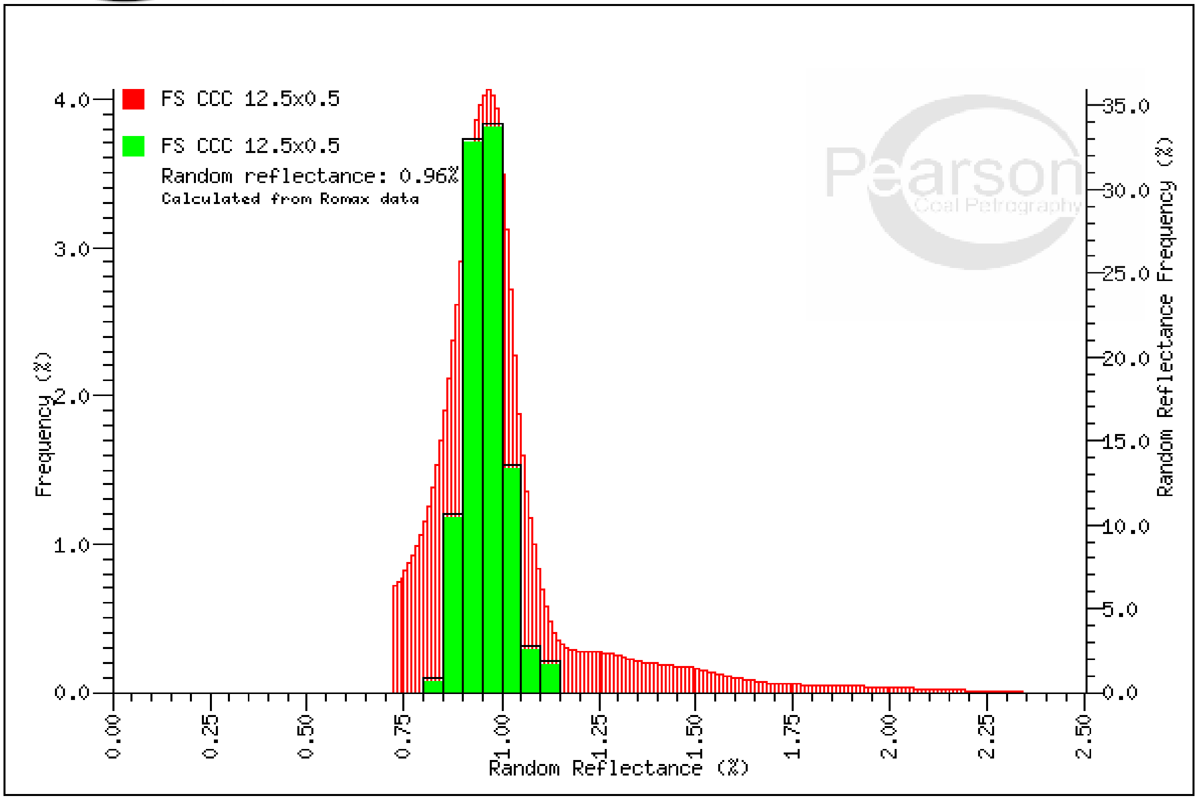
Analyst Andrew Craig

CCRA & Geoscience BC Jig Research	
Vitrinite reflectance by	ISO 7404/5
	FS CCC 12.5x0.5
Basic Statistics	
Romax	1.01
Standard Error of the mean	0.01
Coefficient of Variation	5.4952
Variance	0.0031
Standard Deviation	0.0558
Skewness	0.5316
Kurtosis	3.4009
Number of Measurements	100
Vitrinite Distribution	
Vitrinite type (V-Type)	Frequency (%)
V-8	1.00
V-9	39.00
V-10	55.00
V-11	5.00

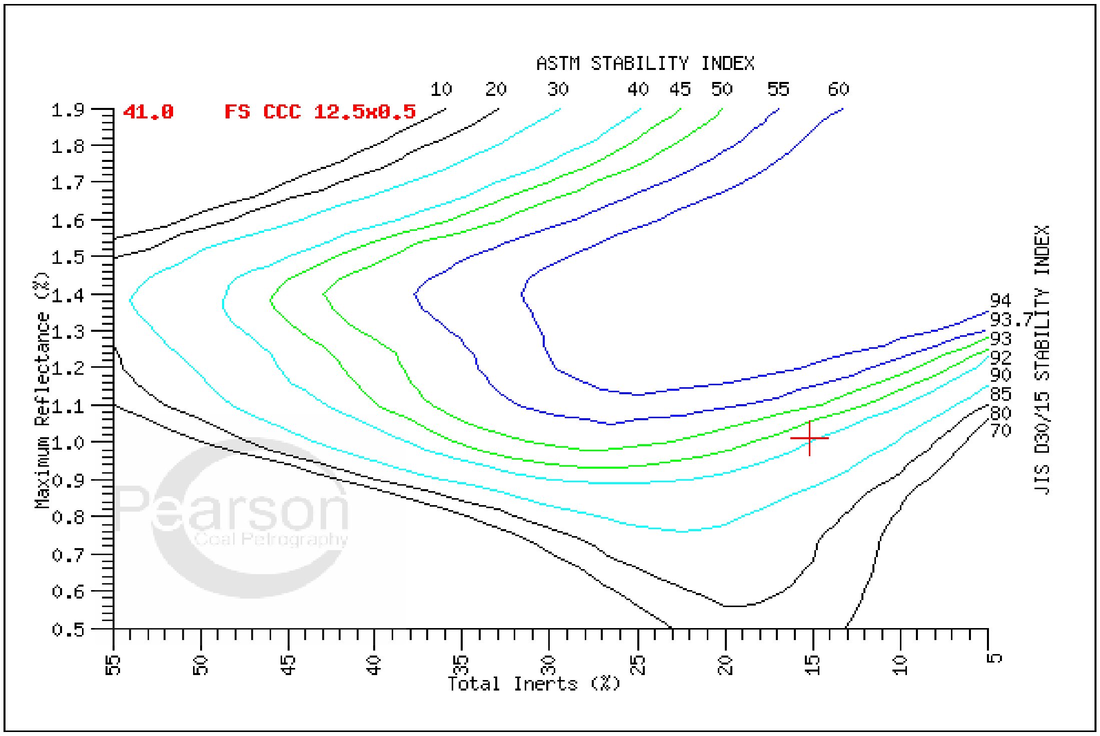
Vitrinite Reflectance Profile



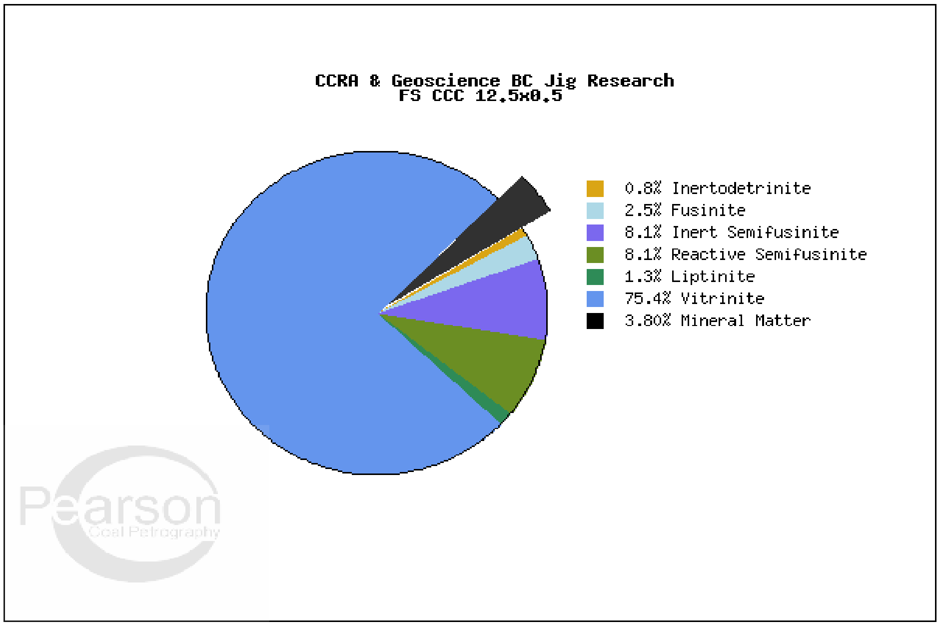
Random Reflectance Graphs



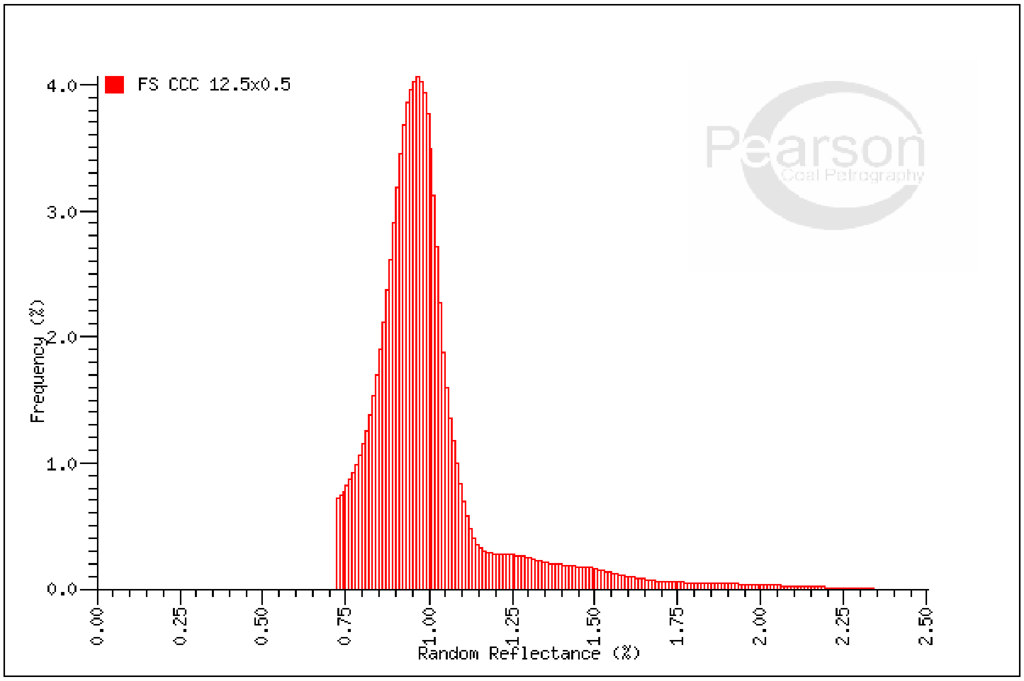
Coke Strength



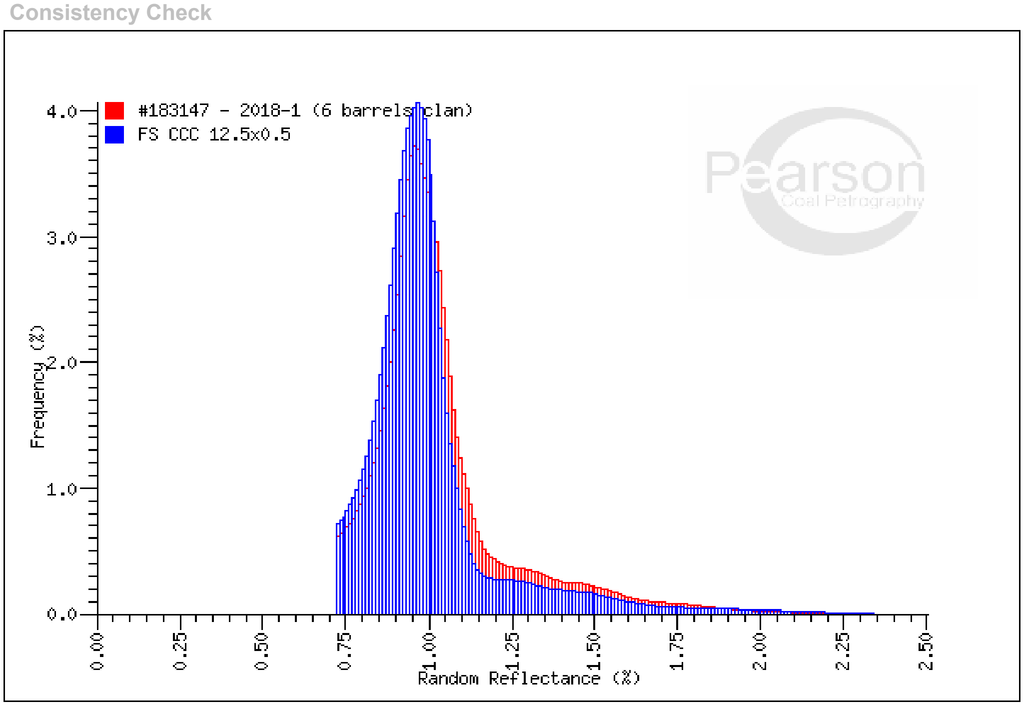
Maceral Distribution



Reflectance Profile



Consistency Check



Pearson Coal Petrography

Petrographic Analysis

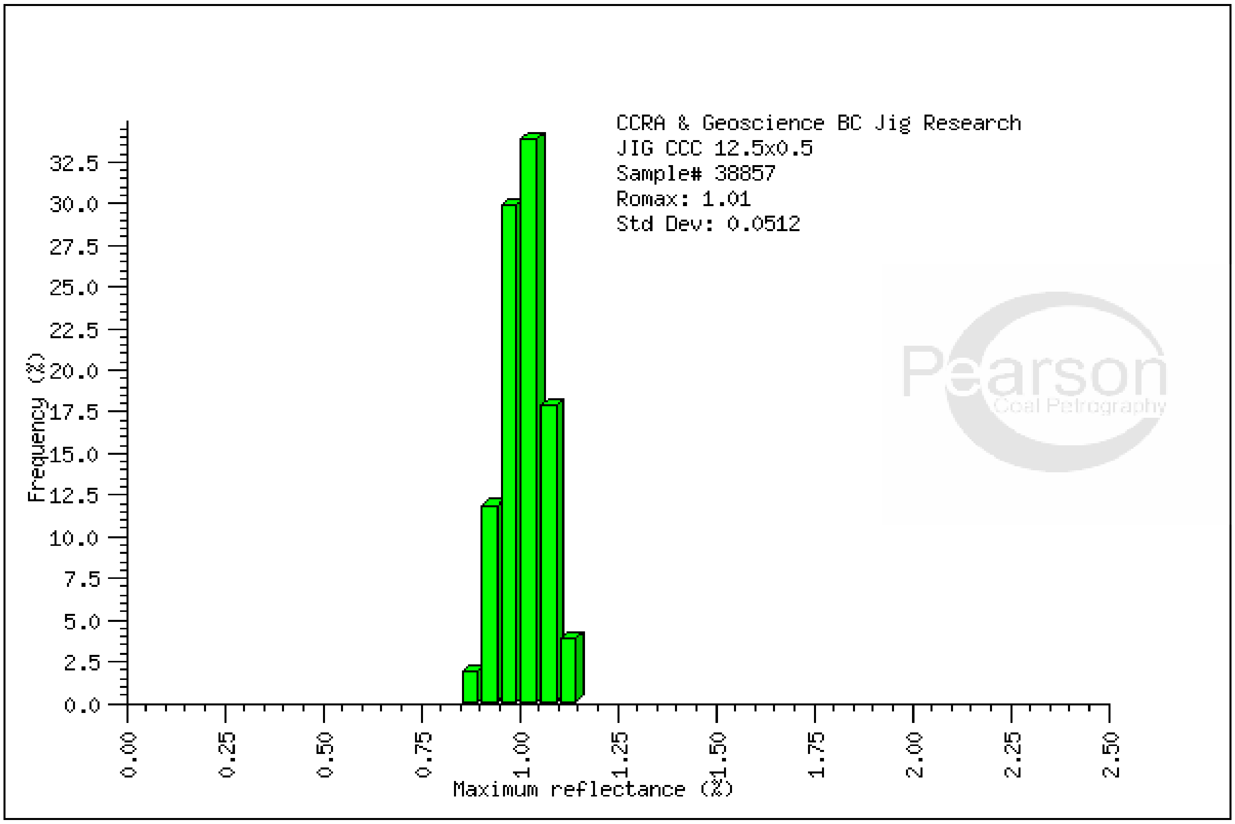
Sample Identification	
Company ID	CCRA & Geoscience BC Jig Research
Laboratory Number	38857
Sample Identifier	JIG CCC 12.5x0.5
Date Analyzed	11-22-18
Ash	7.91
Sulphur	0.55
Petrographic Indices	
Mean Maximum Reflectance (RoMax)	1.01
Random Reflectance (calculated)	0.95
Standard Deviation	0.05
Composition Balance Index	0.48
Calculated Strength Index	3.59
Calculated Stability Index	42.00
Estimated Coke Strength DI 30/15	91.09
Predicted Free Swelling Index	8.50
Distribution of Vitrinite Types	
V-8	2.00
V-9	42.00
V-10	52.00
V-11	4.00
Reactive Components	
Vitrinite	73.20
Liptinite	2.90
Reactive Semifusinite	7.80
Total Reactives	**83.90**
Inert Components	
Inert Semifusinite	7.80
Fusinite	3.20
Inertodetrinite	0.60
Mineral Matter	4.50
Total Inerts	**16.10**

Analyst Jennifer S. Pearson

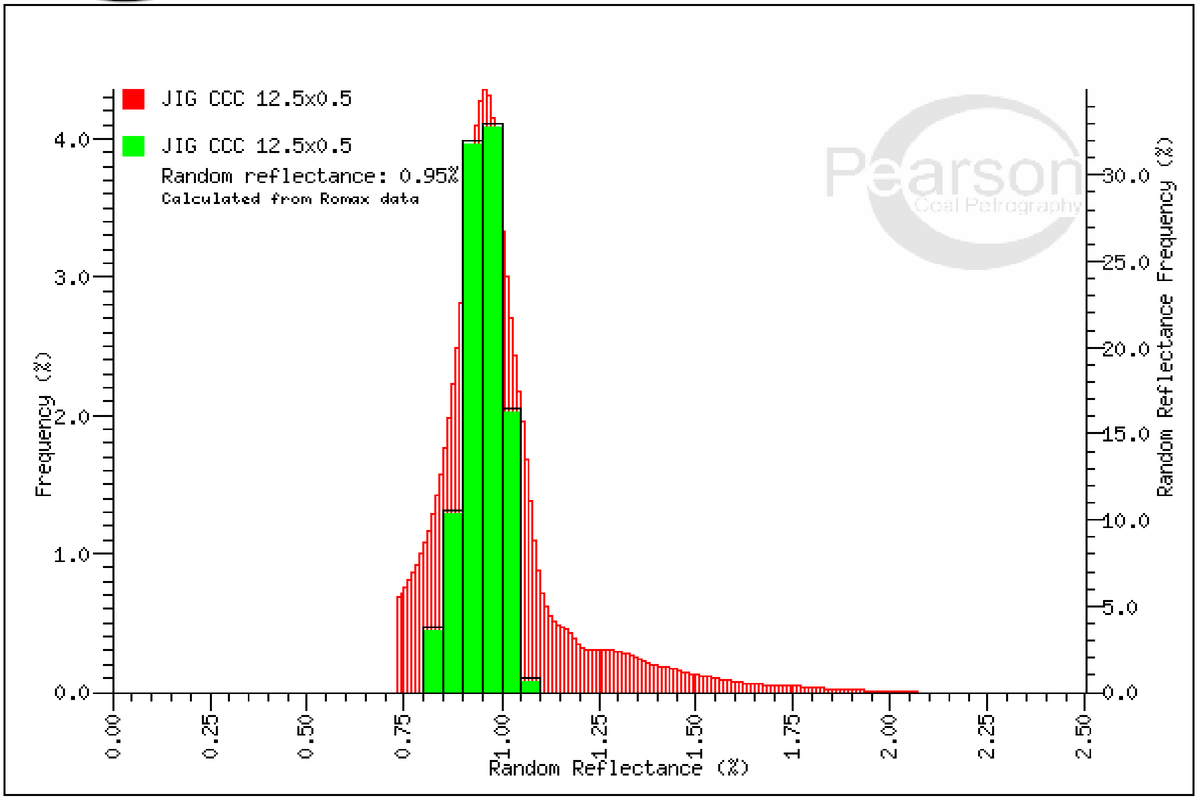
Pearson Coal Petrography — Vitrinite Analysis

CCRA & Geoscience BC Jig Research	
Vitrinite reflectance by	ISO 7404/5
	JIG CCC 12.5x0.5
Basic Statistics	
Romax	1.01
Standard Error of the mean	0.01
Coefficient of Variation	5.0827
Variance	0.0026
Standard Deviation	0.0512
Skewness	-0.0940
Kurtosis	2.5308
Number of Measurements	100
Vitrinite Distribution	
Vitrinite type (V-Type)	Frequency (%)
V-8	2.00
V-9	42.00
V-10	52.00
V-11	4.00

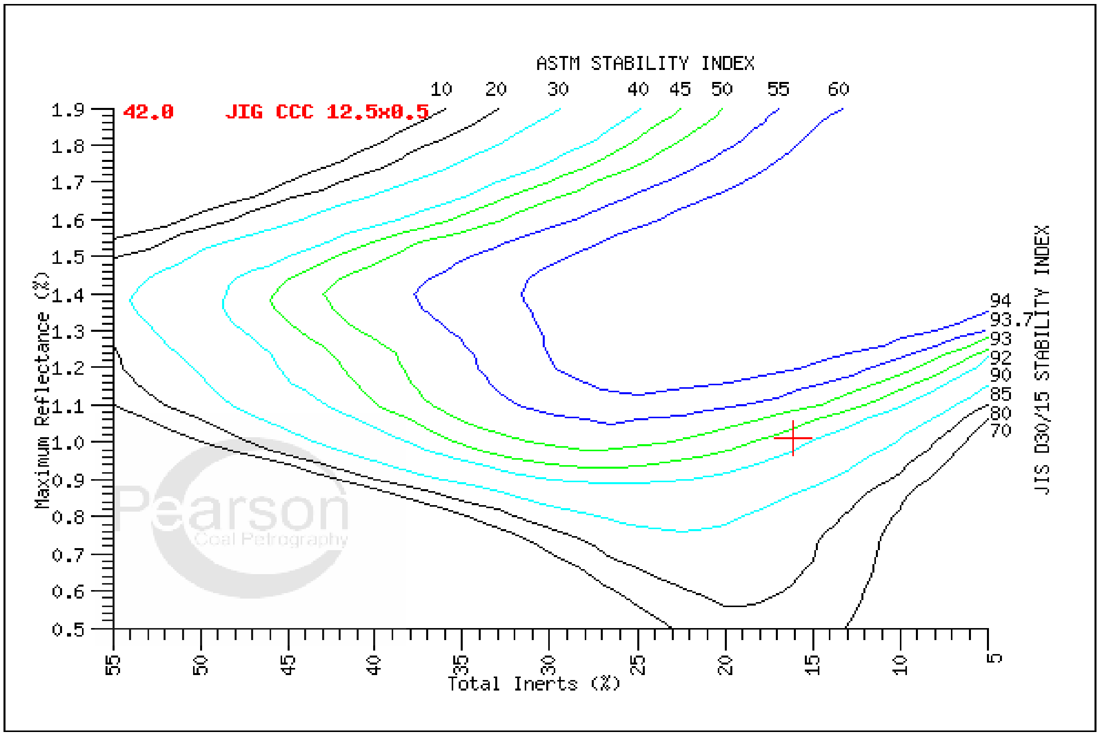
Vitrinite Reflectance Profile



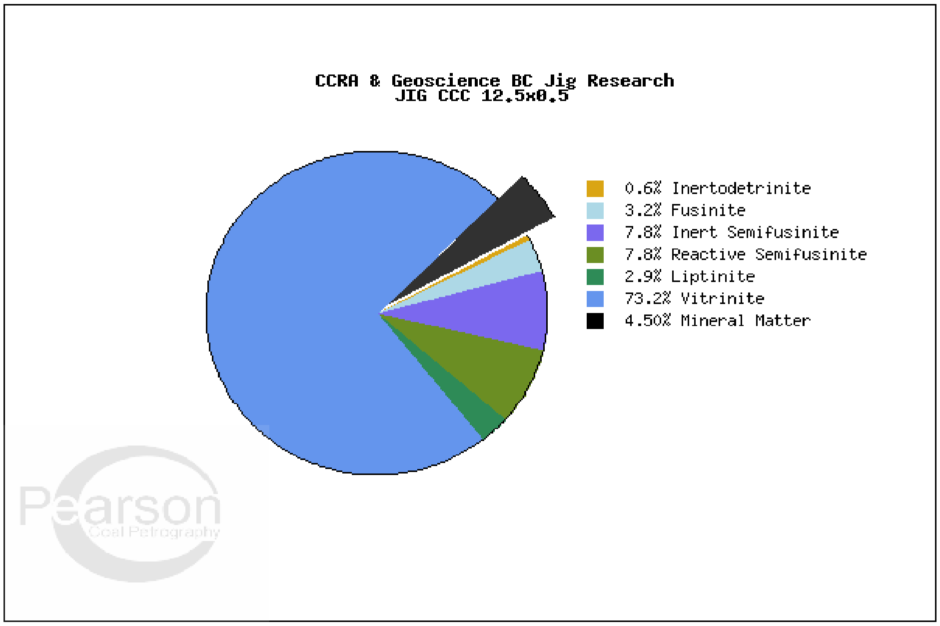
Random Reflectance Graphs



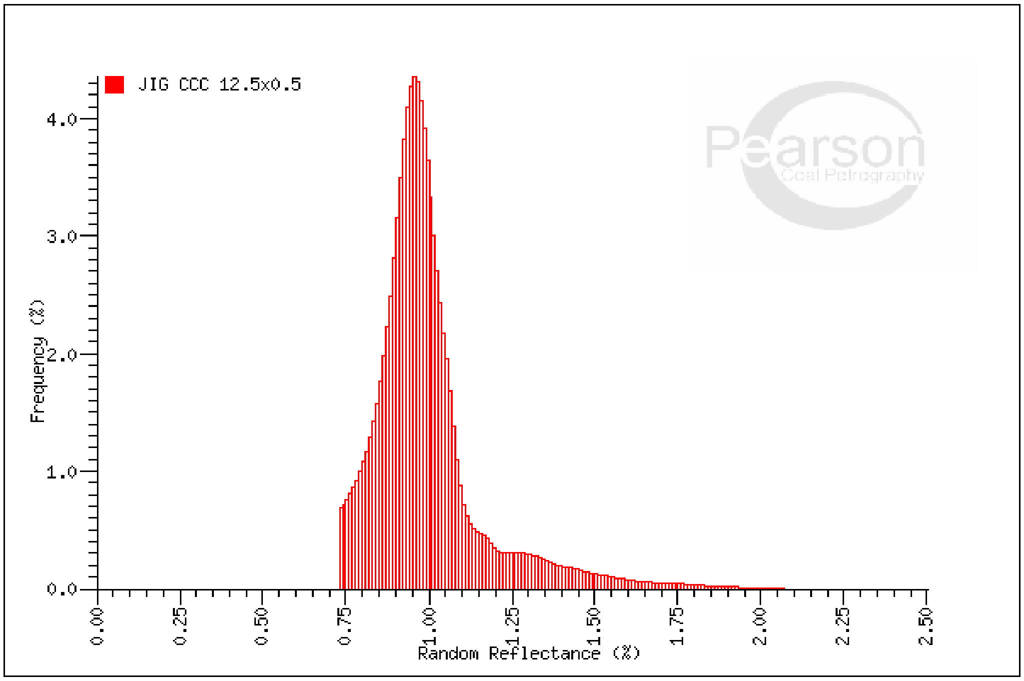
Coke Strength



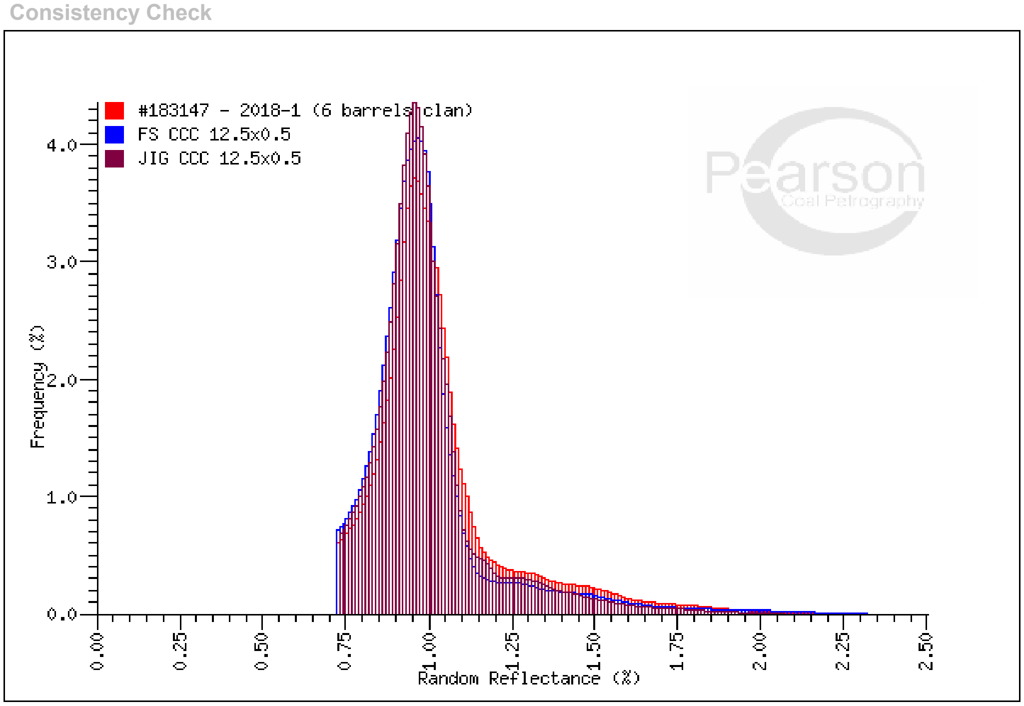
Maceral Distribution



Reflectance Profile



Consistency Check



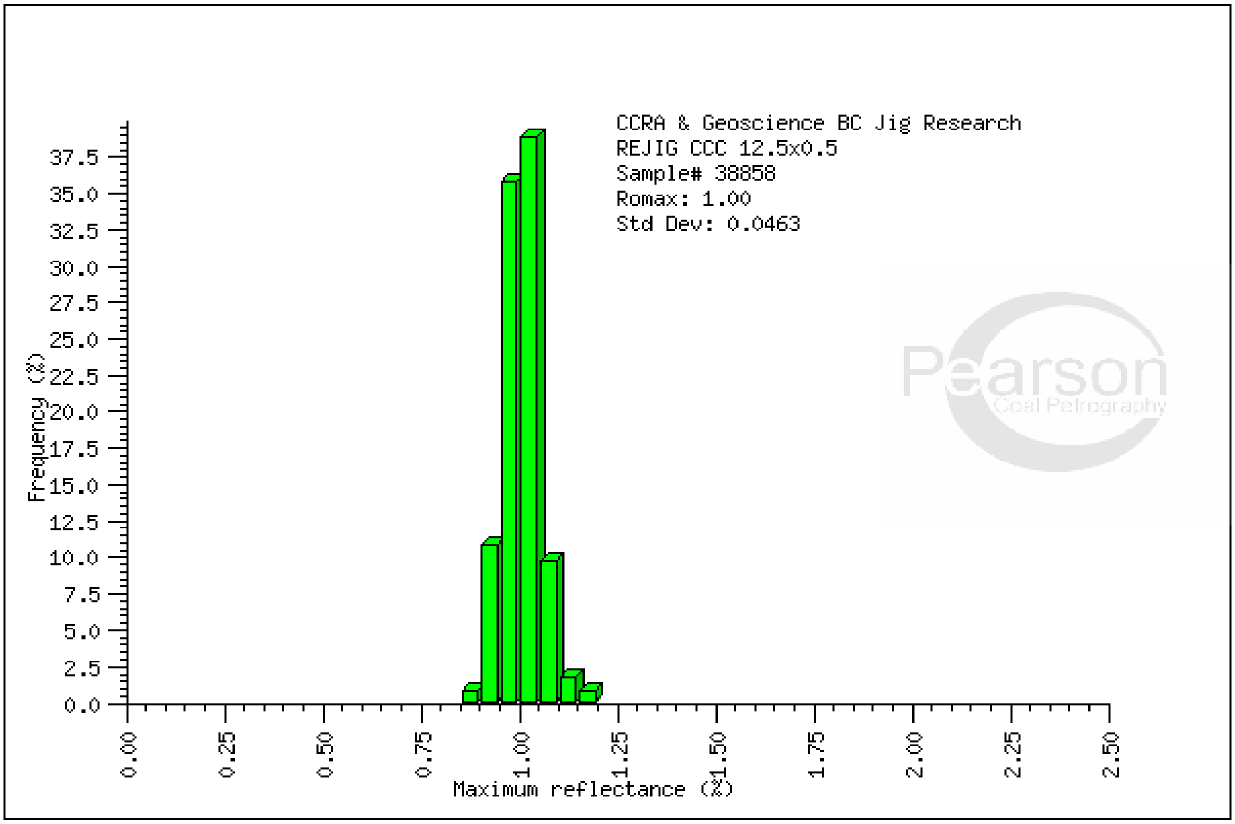
Petrographic Analysis

Sample Identification	
Company ID	CCRA & Geoscience BC Jig Research
Laboratory Number	38858
Sample Identifier	REJIG CCC 12.5x0.5
Date Analyzed	11-22-18
Ash	6.76
Sulphur	0.56
Petrographic Indices	
Mean Maximum Reflectance (RoMax)	1.00
Random Reflectance (calculated)	0.94
Standard Deviation	0.05
Composition Balance Index	0.48
Calculated Strength Index	3.58
Calculated Stability Index	42.00
Estimated Coke Strength DI 30/15	91.09
Predicted Free Swelling Index	8.50
Distribution of Vitrinite Types	
V-8	1.00
V-9	47.00
V-10	49.00
V-11	3.00
Reactive Components	
Vitrinite	73.70
Liptinite	3.10
Reactive Semifusinite	7.10
Total Reactives	**83.90**
Inert Components	
Inert Semifusinite	7.10
Fusinite	4.40
Inertodetrinite	0.60
Macrinite	0.20
Mineral Matter	3.80
Total Inerts	**16.10**

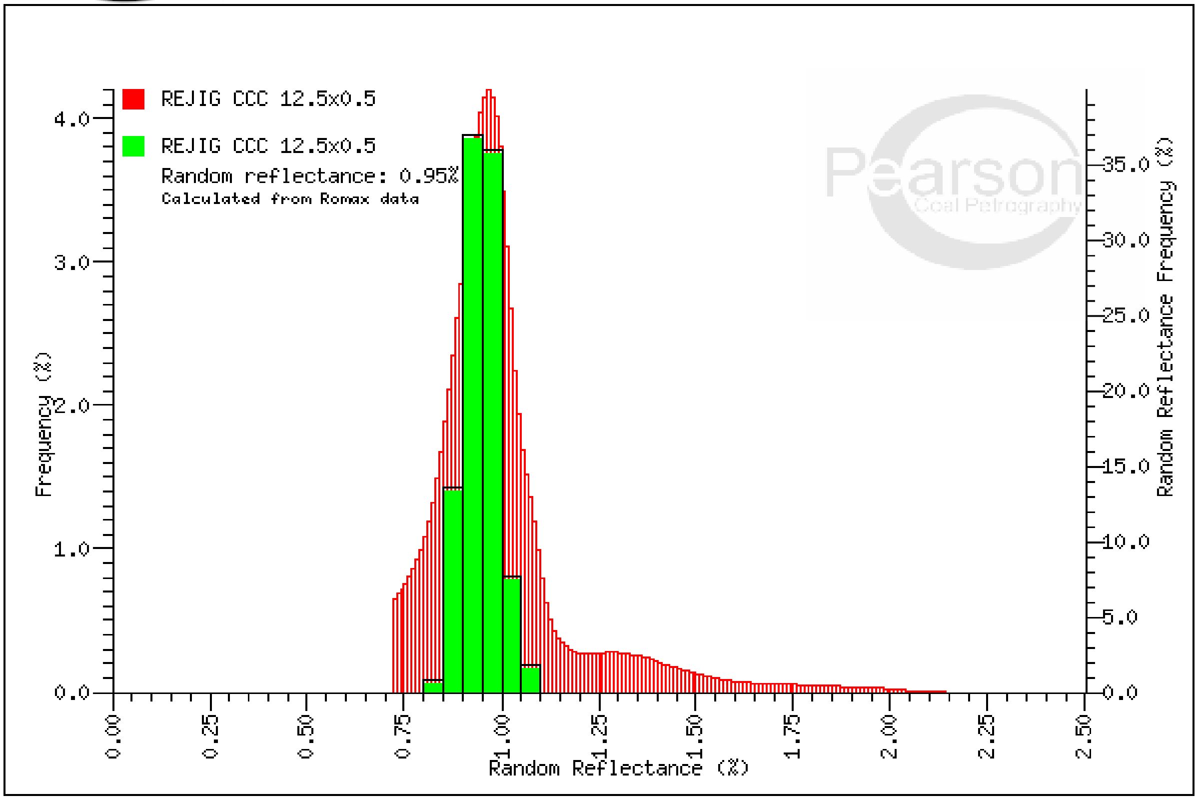
Analyst Jennifer S. Pearson

CCRA & Geoscience BC Jig Research	
Vitrinite reflectance by	ISO 7404/5
	REJIG CCC 12.5x0.5
Basic Statistics	
Romax	1.00
Standard Error of the mean	0.00
Coefficient of Variation	4.6130
Variance	0.0021
Standard Deviation	0.0463
Skewness	0.5553
Kurtosis	3.7427
Number of Measurements	100
Vitrinite Distribution	
Vitrinite type (V-Type)	Frequency (%)
V-8	1.00
V-9	47.00
V-10	49.00
V-11	3.00

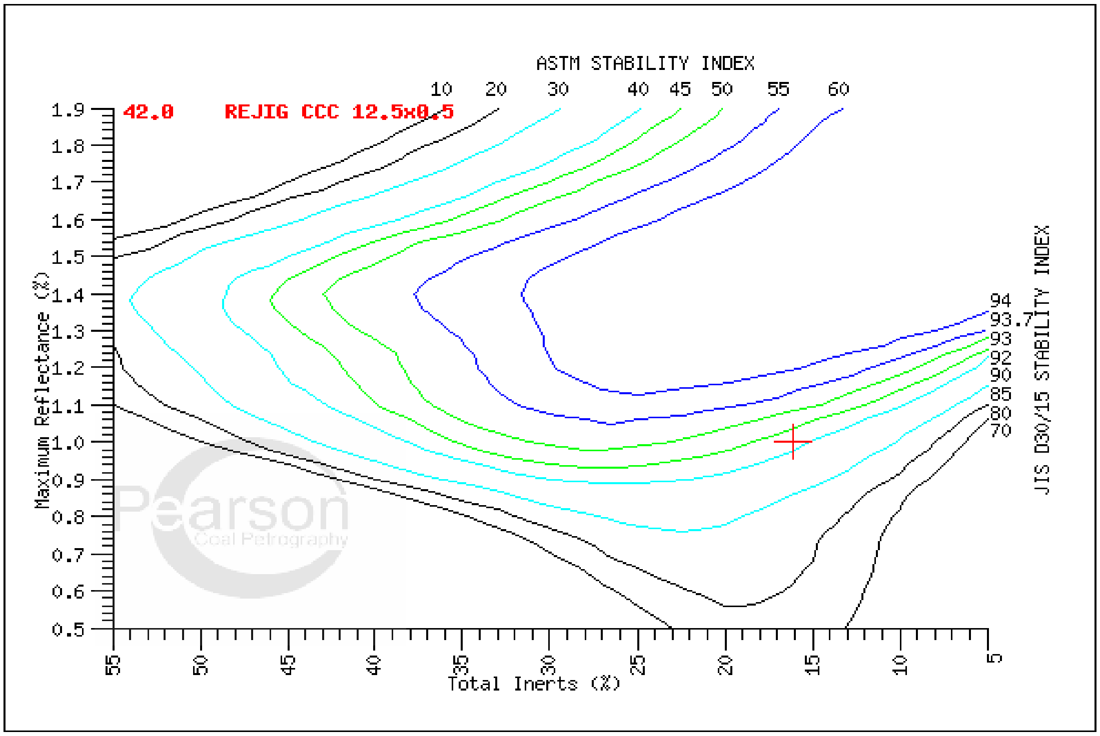
Vitrinite Reflectance Profile



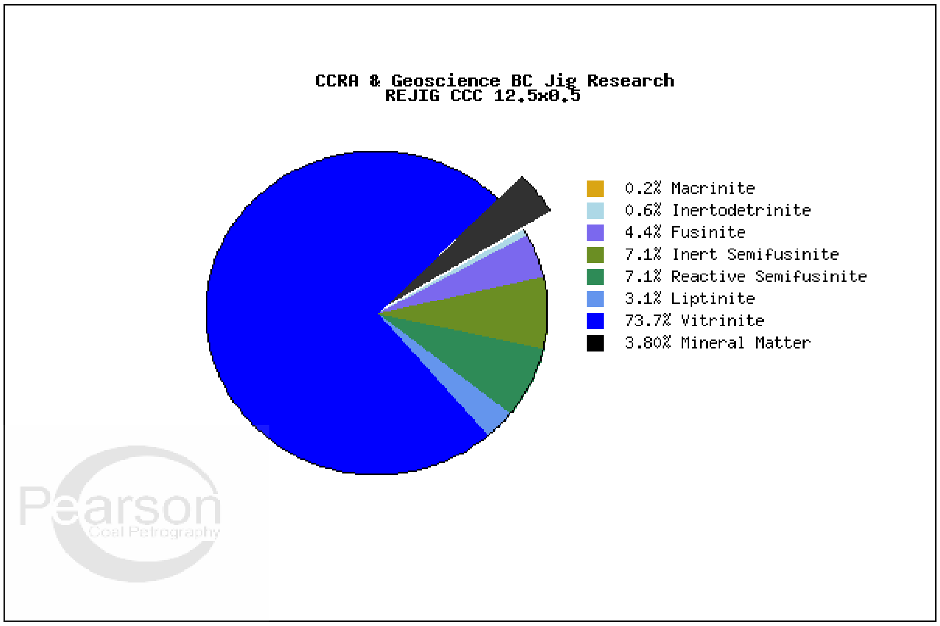
Random Reflectance Graphs



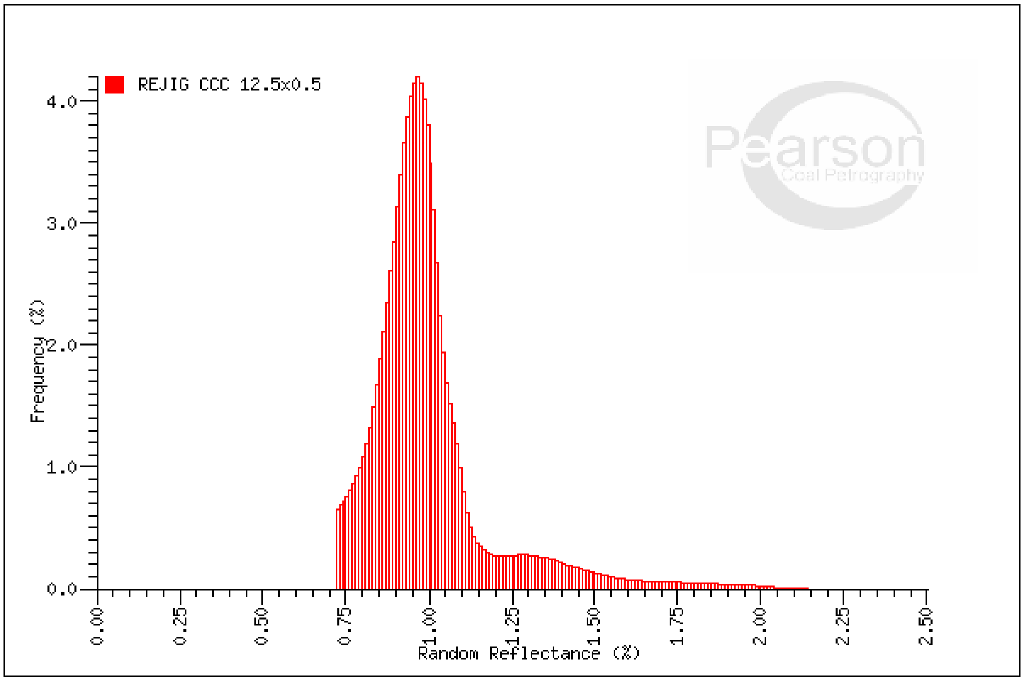
Coke Strength



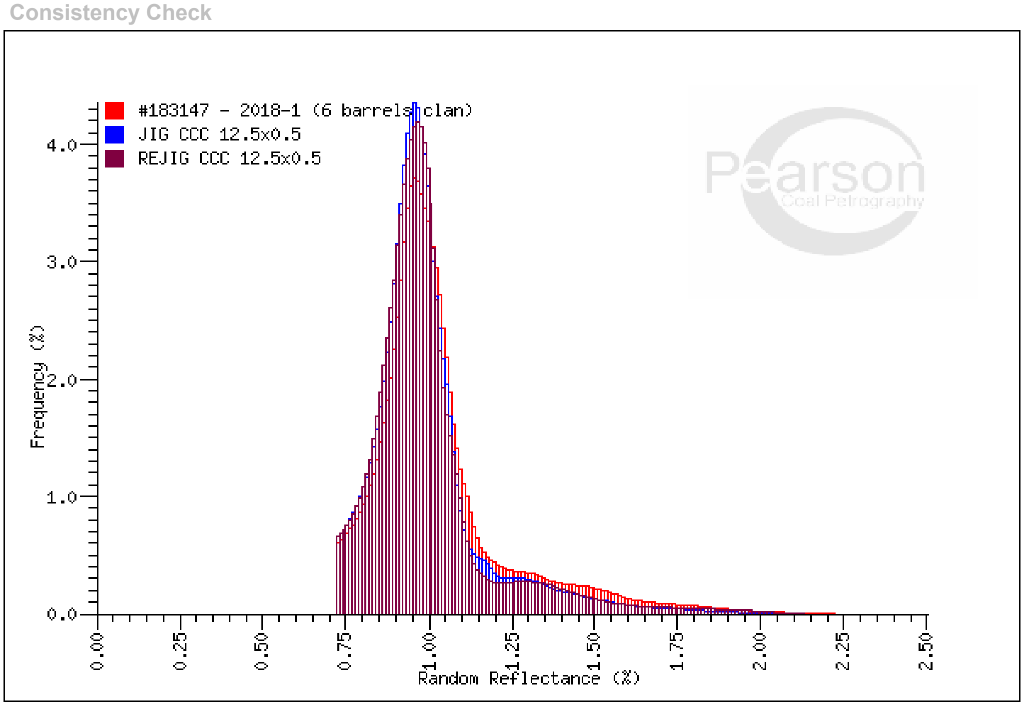
Maceral Distribution



Reflectance Profile



Consistency Check



Pearson Coal Petrography

Petrographic Analysis

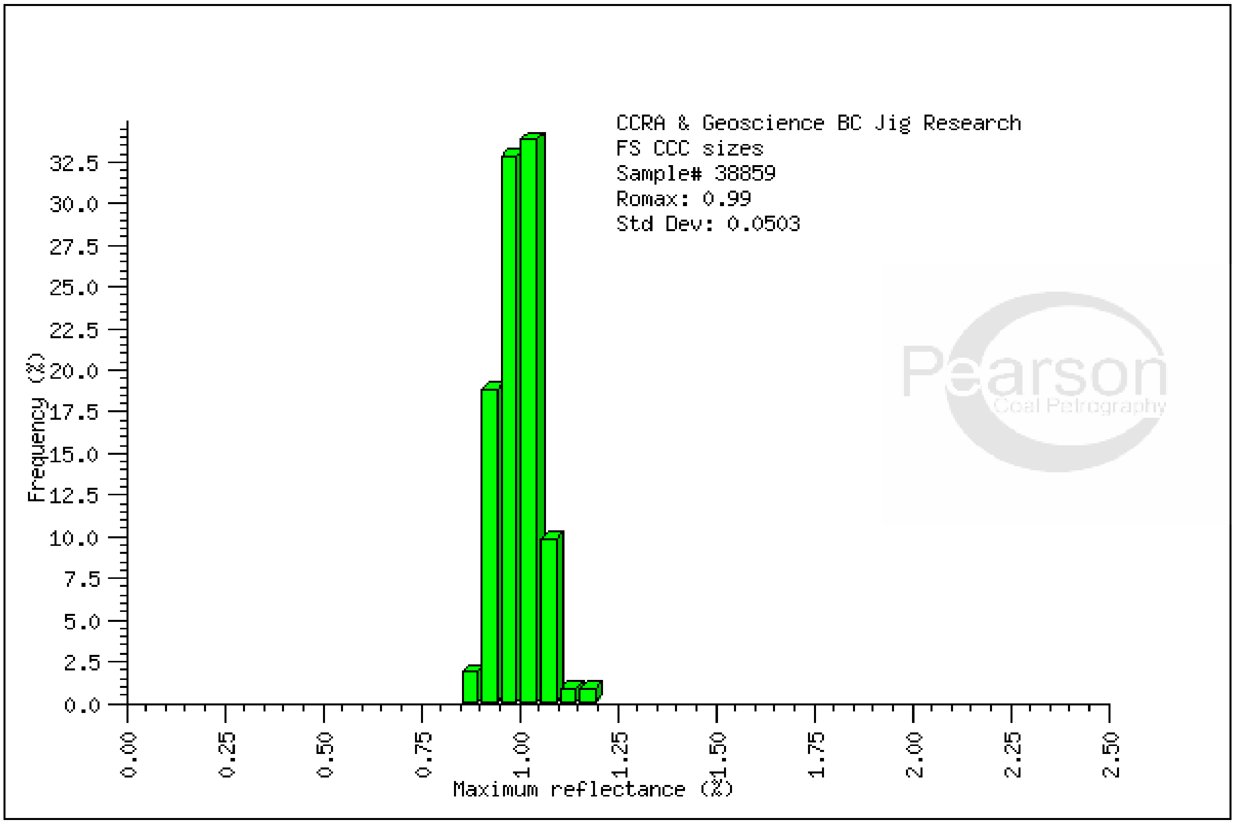
Sample Identification	
Company ID	CCRA & Geoscience BC Jig Research
Laboratory Number	38859
Sample Identifier	FS CCC sizes
Date Analyzed	11-23-18
Ash	6.90
Sulphur	0.55
Petrographic Indices	
Mean Maximum Reflectance (RoMax)	0.99
Random Reflectance (calculated)	0.93
Standard Deviation	0.05
Composition Balance Index	0.48
Calculated Strength Index	3.54
Calculated Stability Index	41.00
Estimated Coke Strength DI 30/15	90.74
Predicted Free Swelling Index	8.50
Distribution of Vitrinite Types	
V-8	2.00
V-9	52.00
V-10	44.00
V-11	2.00
Reactive Components	
Vitrinite	73.80
Liptinite	2.90
Reactive Semifusinite	7.30
Total Reactives	**84.00**
Inert Components	
Inert Semifusinite	7.30
Fusinite	3.70
Inertodetrinite	1.20
Mineral Matter	3.80
Total Inerts	**16.00**

Analyst Jennifer S. Pearson

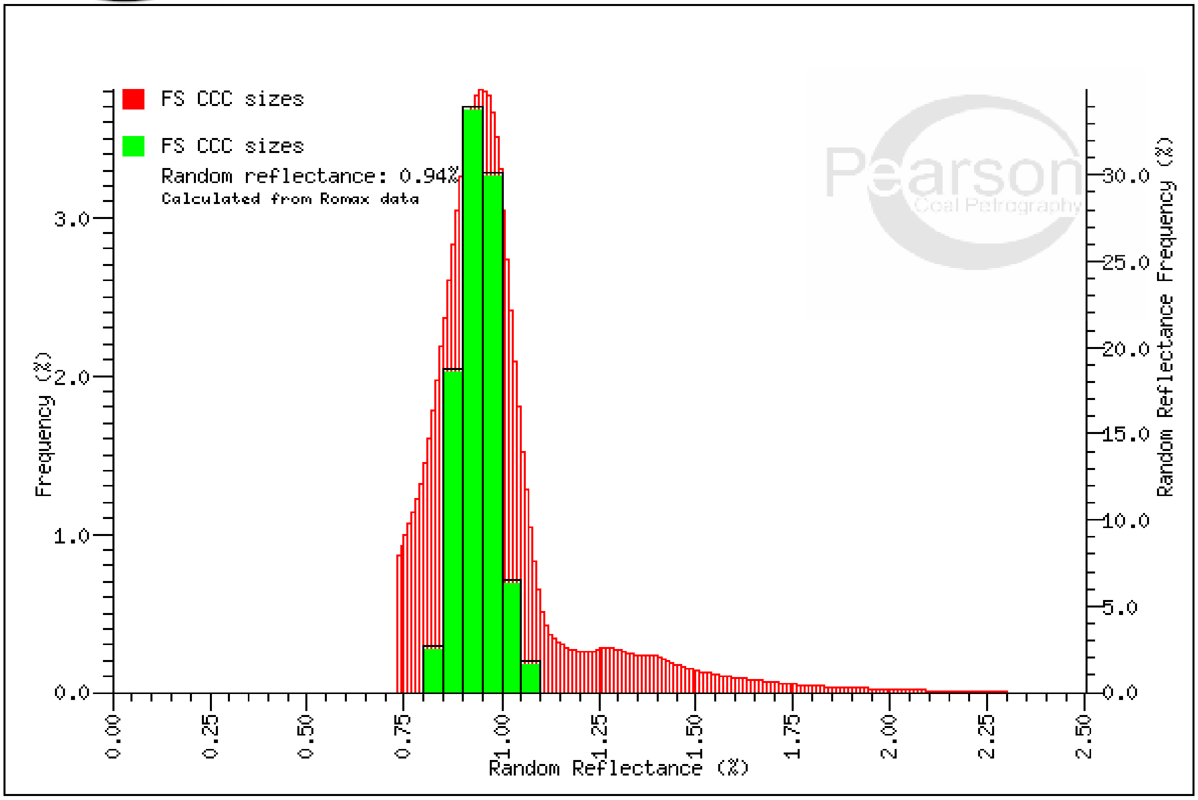
Vitrinite Analysis

CCRA & Geoscience BC Jig Research	
Vitrinite reflectance by	ISO 7404/5
	FS CCC sizes
Basic Statistics	
Romax	0.99
Standard Error of the mean	0.01
Coefficient of Variation	5.0625
Variance	0.0025
Standard Deviation	0.0503
Skewness	0.3026
Kurtosis	3.2987
Number of Measurements	100
Vitrinite Distribution	
Vitrinite type (V-Type)	Frequency (%)
V-8	2.00
V-9	52.00
V-10	44.00
V-11	2.00

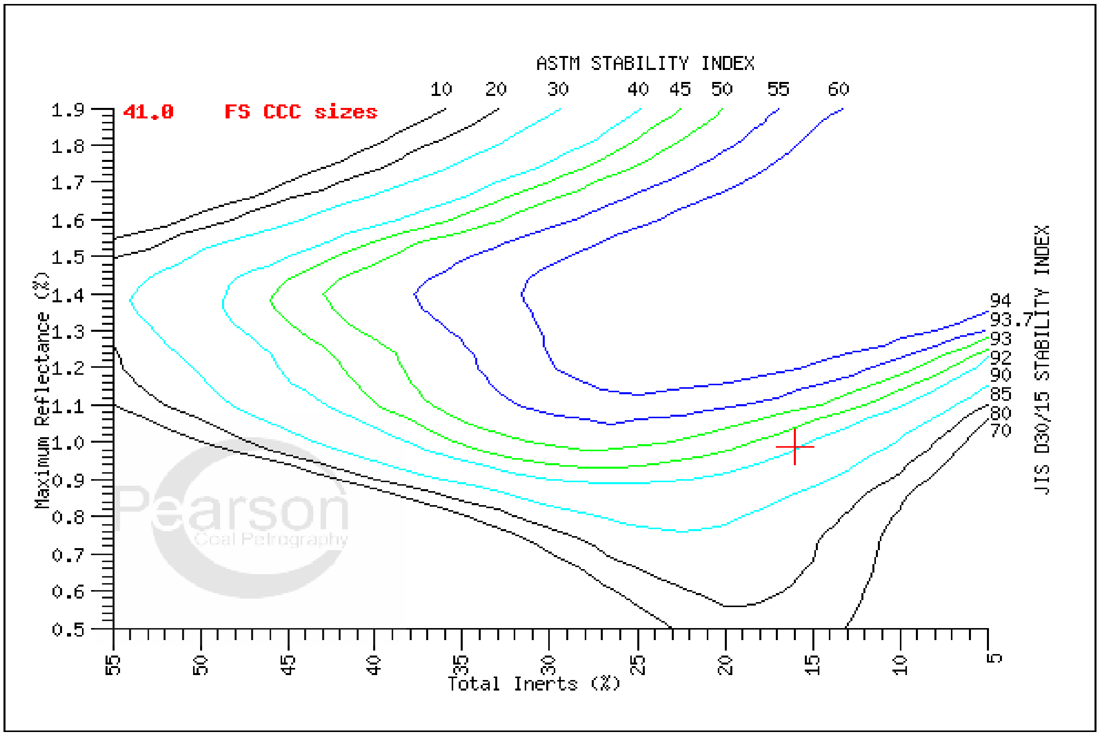
Vitrinite Reflectance Profile



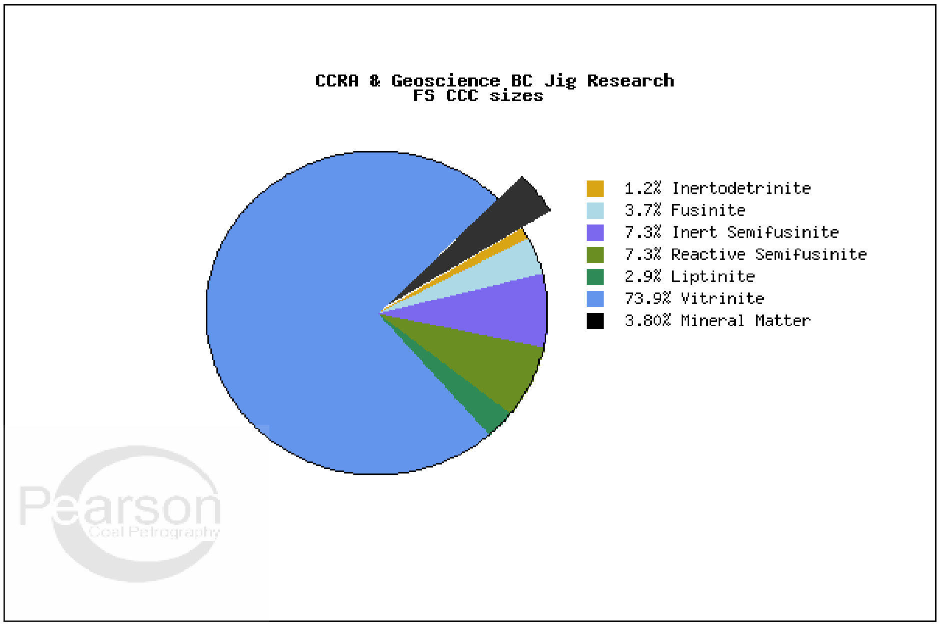
Random Reflectance Graphs



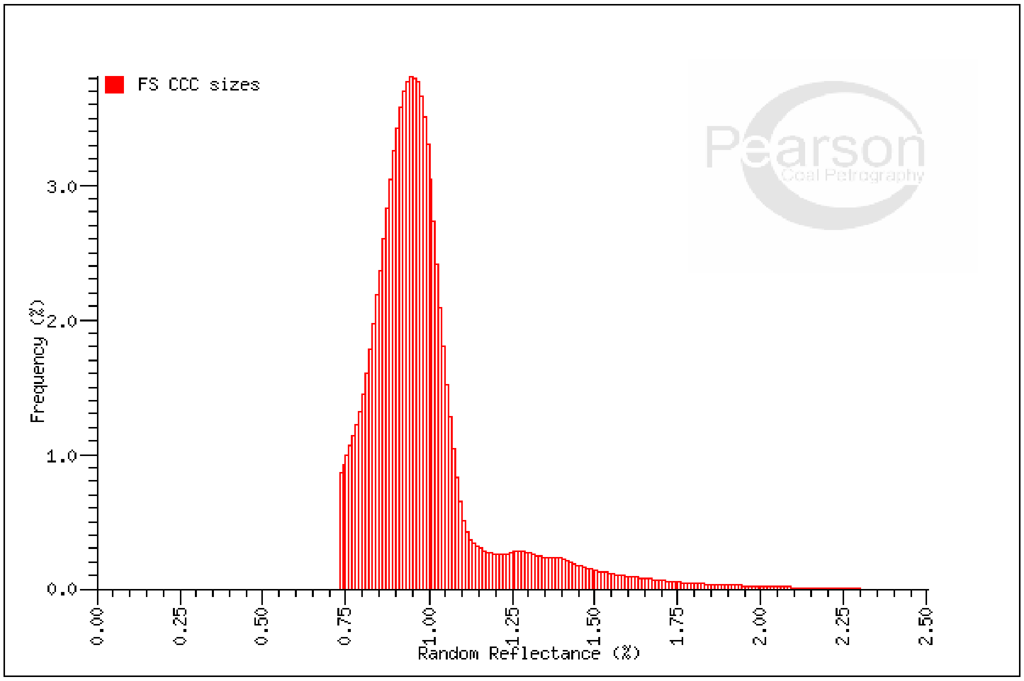
Coke Strength



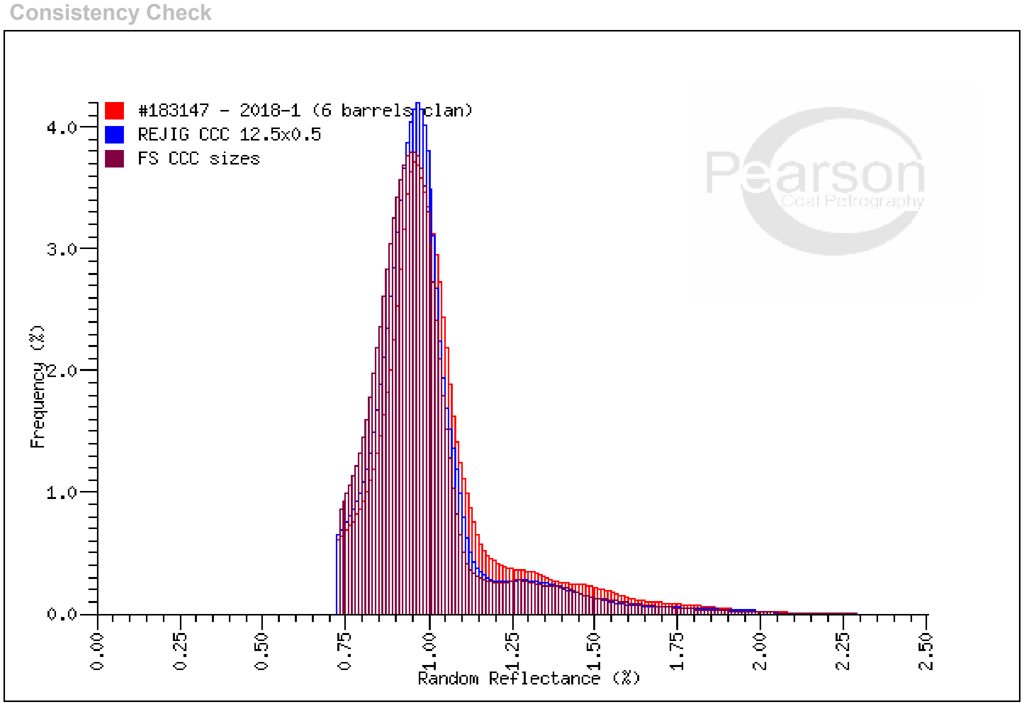
Maceral Distribution



Reflectance Profile



Consistency Check



Petrographic Analysis

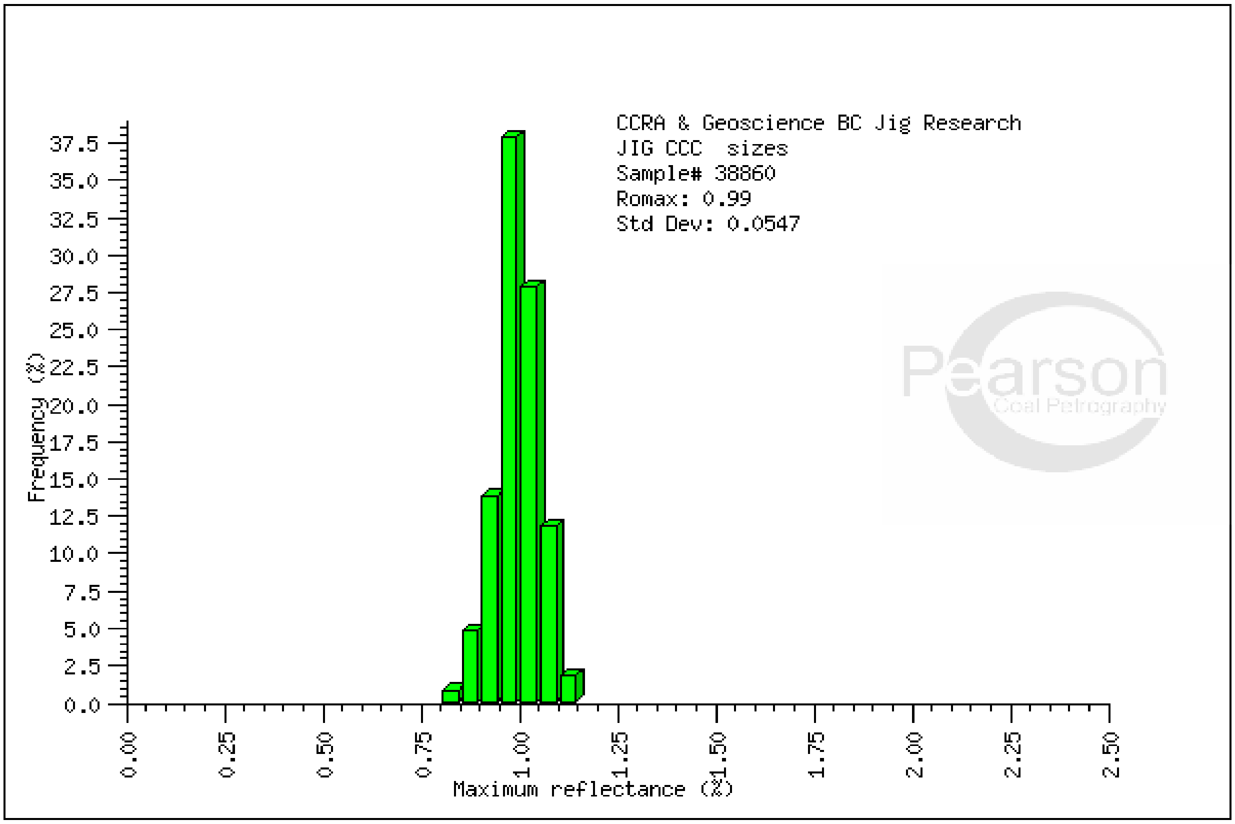
Sample Identification	
Company ID	CCRA & Geoscience BC Jig Research
Laboratory Number	38860
Sample Identifier	JIG CCC sizes
Date Analyzed	11-23-18
Ash	7.60
Sulphur	0.55
Petrographic Indices	
Mean Maximum Reflectance (RoMax)	0.99
Random Reflectance (calculated)	0.93
Standard Deviation	0.05
Composition Balance Index	0.51
Calculated Strength Index	3.54
Calculated Stability Index	42.00
Estimated Coke Strength DI 30/15	91.09
Predicted Free Swelling Index	8.50
Distribution of Vitrinite Types	
V-8	6.00
V-9	52.00
V-10	40.00
V-11	2.00
Reactive Components	
Vitrinite	73.30
Liptinite	2.70
Reactive Semifusinite	7.30
Total Reactives	**83.30**
Inert Components	
Inert Semifusinite	7.30
Fusinite	4.00
Inertodetrinite	1.10
Mineral Matter	4.30
Total Inerts	**16.70**

Analyst Jennifer S. Pearson

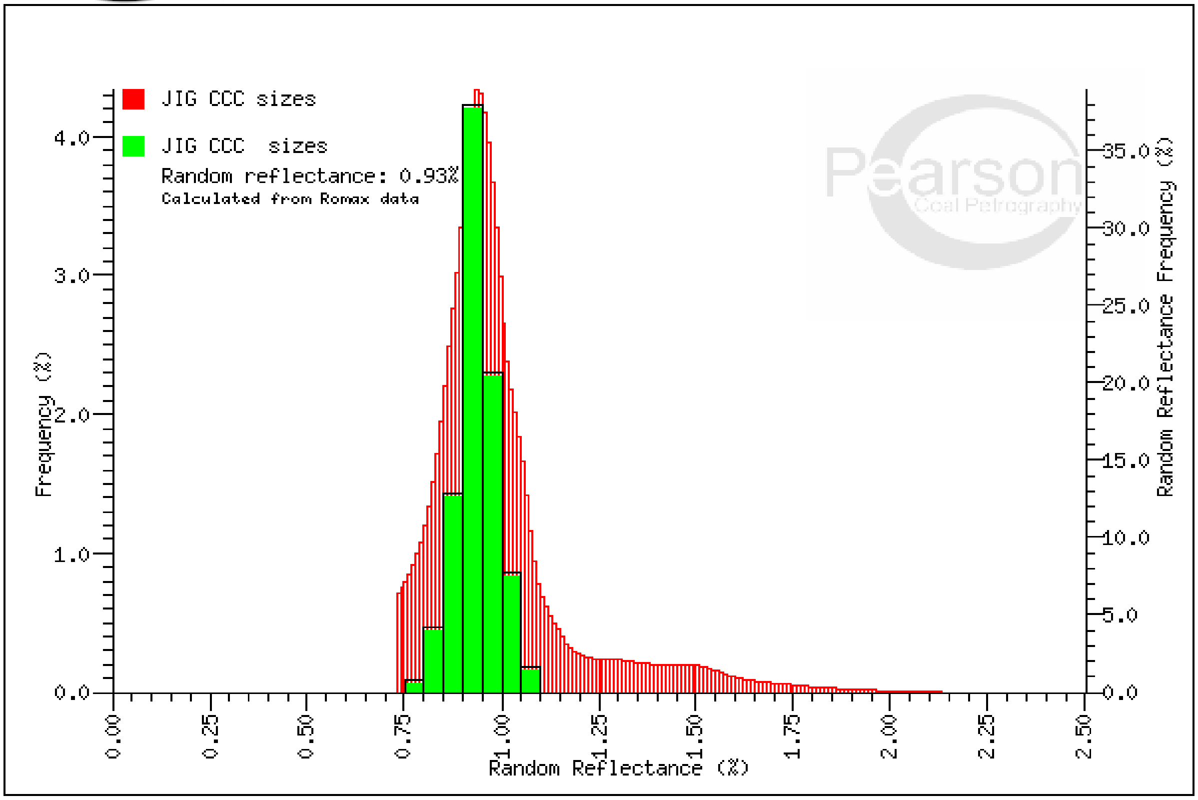
Vitrinite Analysis

CCRA & Geoscience BC Jig Research	
Vitrinite reflectance by	ISO 7404/5
	JIG CCC sizes
Basic Statistics	
Romax	0.99
Standard Error of the mean	0.01
Coefficient of Variation	5.5290
Variance	0.0030
Standard Deviation	0.0547
Skewness	0.1084
Kurtosis	3.4441
Number of Measurements	100
Vitrinite Distribution	
Vitrinite type (V-Type)	Frequency (%)
V-8	6.00
V-9	52.00
V-10	40.00
V-11	2.00

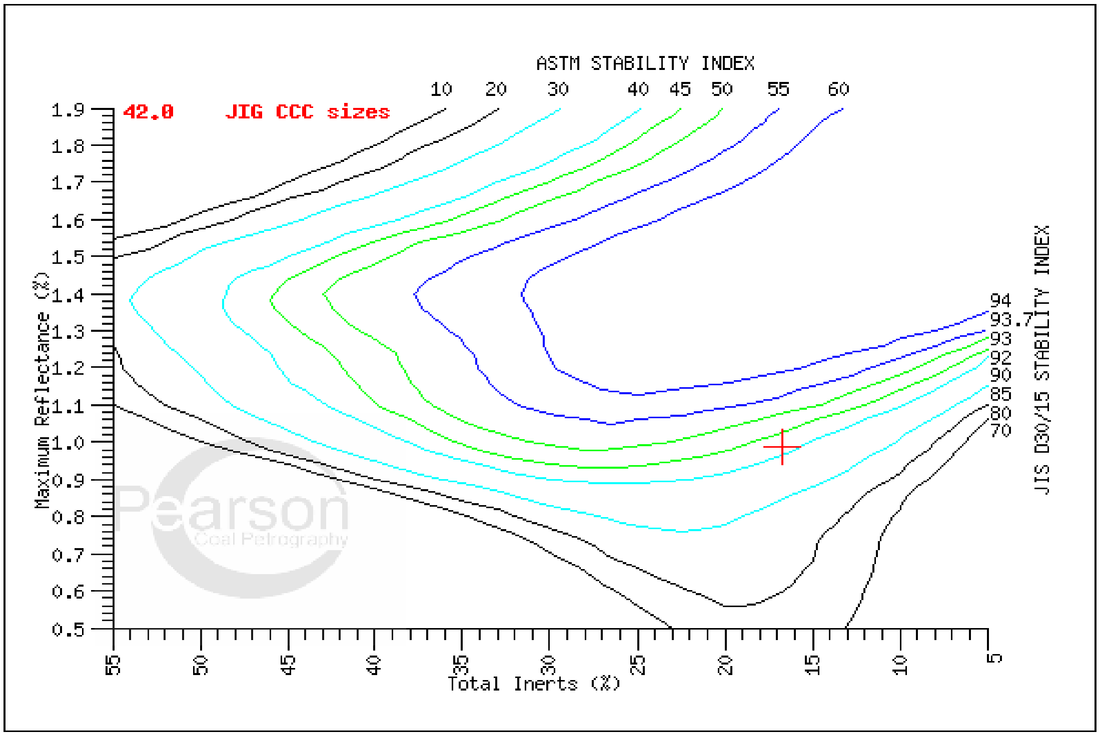
Vitrinite Reflectance Profile



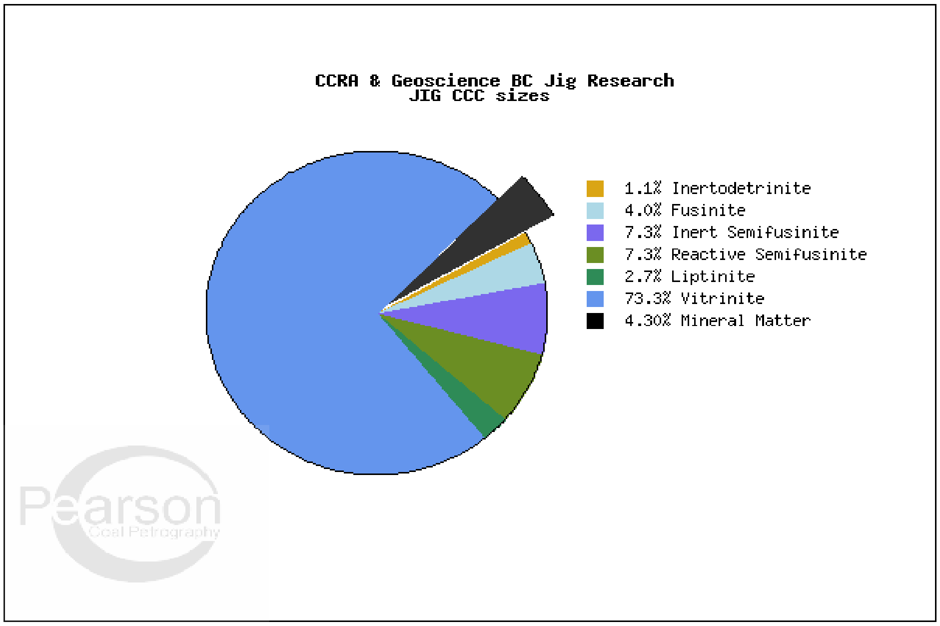
Random Reflectance Graphs



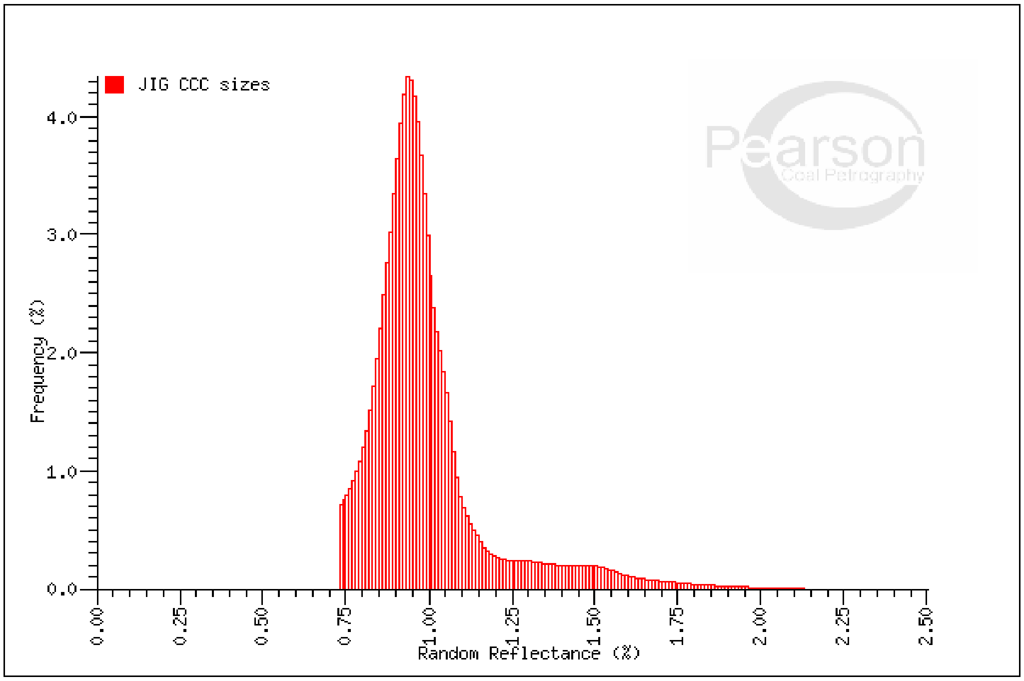
Coke Strength



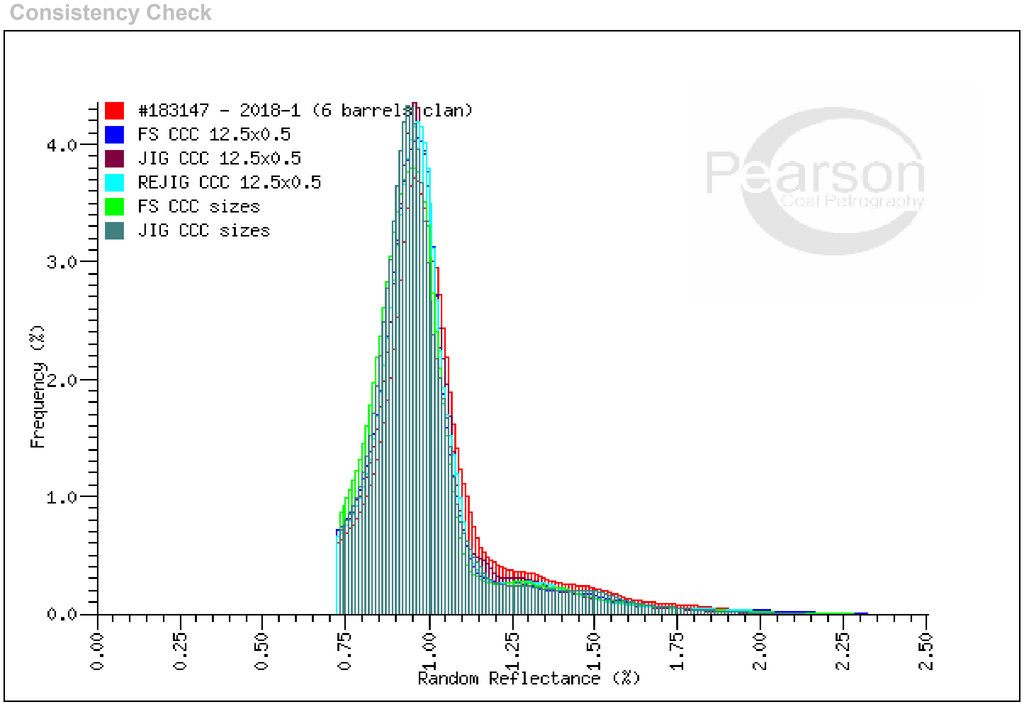
Maceral Distribution



Reflectance Profile



Consistency Check



Appendix D: Coke Analytical Results

CanmetENERGY Carbonization Research
Industrial Innovation Group-Metallurgical Fuels

CCRA 90 Phase 2_Geoscience BC Project_November 15 2018

	Date Received		AUG/10/18	AUG/10/18	AUG/10/18	AUG/10/18	AUG/10/18	AUG/7/18	AUG/7/18
	Weight Received		1-PAIL	1-PAIL	1-PAIL	1-PAIL	1-PAIL	1-PAIL	3-DRUMS
	Project		CCRA 90 - Roben Jig Phase 2	CCRA 90 - Roben Jig Phase 2	CCRA 90 - Roben Jig Phase 2	CCRA 90 - Roben Jig Phase 2	CCRA 90 - Roben Jig Phase 2	CCRA 90 - Roben Jig Phase 2	CCRA 90 - Roben Jig Phase 2
	Coal Index		26774	26775	26776	26777	26778	26798	26800
	Description		100% 12.5X0.5mm REJIG #183148 Sole-Heated Oven	100% SIZES FLOAT SINK #183148 Sole-Heated Oven	100% 12.5X0.5mm JIG #183148 Sole-Heated Oven	100% 12.5X0.5mm FLOAT SINK #183148 Sole-Heated Oven	100% SIZES JIG #183148 Sole-Heated Oven	100% PLANT CLEAN CRUSHED TO 12.5mm Sole-Heated Oven	100% PLANT CLEAN #183147 Sole-Heated Oven
Sole-Heated Oven Test	Expansion/Contraction	%	-9.4	-11.8	-9.2	-11.0	-11.0	-14.5	-11.6
Coke Moisture	Moisture	%	x	x	x	x	x	x	x
Coke Proximate (db)	Ash	%	x	x	x	x	x	x	x
	Volatile Matter	%	x	x	x	x	x	x	x
	Fixed Carbon	%	x	x	x	x	x	x	x
	Sulphur	%	x	x	x	x	x	x	x
Coke Properties	CSR		65.0	65.5	64.3	68.3	70.5	64.2	61.5
	CRI		20.6	21.3	19.2	18.5	17.2	23.0	25.2
	ASG		0.963	0.970	0.989	0.988	0.995	1.012	1.004
Coke Texture	Isotropic	%	2.2	1.3	x	2.0	x	1.5	2.8
	Very Fine Mosaic	%	12.3	11.6	x	5.9	x	8.8	11.4
	Fine Mosaic	%	47.6	52.8	x	33.1	x	36.7	20.0
	Medium Mosaic	%	23.7	19.1	x	45.1	x	33.3	48.3
	Coarse Mosaic	%	1.1	1.8	x	2.5	x	2.1	4.2
	Total Mosaic	%	84.7	85.3	x	86.6	x	80.9	83.9
	Elongated Fine Flow	%	3.1	0.9	x	2.7	x	4.8	3.3
	Rlongated Medium Flow	%	0.3	0.1	x	0.8	x	0.3	1.0
	Elongated Coarse Flow	%	0.0	0.0	x	0.0	x	0.0	0.0
	Total Flow	%	3.4	1.0	x	3.5	x	5.1	4.3
	Domain Flat Flow	%	0.0	0.0	x	0.0	x	0.0	0.1
	Domain Undulating	%	0.0	0.0	x	0.0	x	0.0	0.0
	Domain Ribbon	%	0.0	0.0	x	0.0	x	0.0	0.0
	Total Domain	%	0.0	0.0	x	0.0	x	0.0	0.1
	Fusinite	%	2,3	4.1	x	2.9	x	2.5	1.9
	Semifusinite	%	6.6	7.7	x	4.7	x	8.9	6.1
	Unidentifed Inerts	%	0.8	0.6	x	0.3	x	1.1	0.9
	Altered Vitrinite	%	0.0	0.0	x	0.0	x	0.0	0.0
	Total Inert	%	9.7	12.4	x	7.9	x	12.5	8.9
	Coal Ro Calculated		0.99	0.97	x	1.05	x	1.03	1.05
	Coke Mosaic Index		1.91	1.90	x	2.00	x	1.98	1.97

CCRA 90 Phase 2_Geoscience BC Project_November 15 2018

	Date Received		AUG/7/18
	Weight Received		3-DRUMS
	Project		CCRA 90 - Roben Jig Phase 2
	Coal Index		26799
	Description		100% PLANT CLEAN #183147 C-2733
Sole-Heated Oven Test	Expansion/Contraction	%	-11.6
Coke Moisture	Moisture	%	x
Coke Proximate (db)	Ash	%	x
	Volatile Matter	%	x
	Fixed Carbon	%	x
	Sulphur	%	x
Carbonization Results	Oven Test Number		C-2733
	Test Date		SEP/7/18
	Moisture in Charge	%	3.0
	Net dry charge weight	kg	336.8
	ASTM BD	kg/m3	773.7
	Oven dry BD	kg/m3	815.6
	Coking time	h:min	18:14
	Final Center Temp	oC	1074
	Time to 900 °C	h:min	14:48
	Time to 950 °C	h:min	15:14
	Time to 1000 °C	h:min	15:51
	Time to Max Wall Pressure	h:min	2:45
	Max wall pressure	kPa	4.1
	Max gas pressure	kPa	6.7
	Coke Yield	%	72.4
Sieve Analysis of Coke, cumulative	100 mm sieve	%	0.4
	75 mm sieve	%	7.6
	50 mm sieve	%	51.3
	37.5 mm sieve	%	83.6
	25.0 mm sieve	%	94.3
	19.0 mm sieve	%	95.3
	12.5 mm sieve	%	96.1
	Passing 12.5 mm sieve	%	3.9
	Mean coke size	mm	53.0
ASTM Coke Tumbler Test	Stability		56.3
	Hardness		66.3
JIS Coke Tumbler Test	50 mm sieve 30 rev		21.2
	25 mm sieve 30 rev		90.6
	15 mm sieve 30 rev		93.6
	50 mm sieve 150 rev		8.0
	25 mm sieve 150 rev		79.4
	15 mm sieve 150 rev		85.1
	CSR		58.3
	CRI		27.2
	ASG		0.920
Coke Texture	Isotropic	%	2.7
	Very Fine Mosaic	%	7.4
	Fine Mosaic	%	34.9
	Medium Mosaic	%	32.3
	Coarse Mosaic	%	3.8
	Total Mosaic	%	78.4
	Elongated Fine Flow	%	4.2
	Rlongated Medium Flow	%	0.9
	Elongated Coarse Flow	%	0.0
	Total Flow	%	5.1
	Domain Flat Flow	%	0.0
	Domain Undulating	%	0.0
	Domain Ribbon	%	0.0
	Total Domain	%	0.0
	Fusinite	%	3.5
	Semifusinite	%	9.5
	Unidentifed Inerts	%	0.8
	Altered Vitrinite	%	0.0
	Total Inert	%	13.8
	Coal Ro Calculated		1.04
	Coke Mosaic Index		2.02

Appendix E: 3M Novec Fluids Information

3M™ Novec™ 7000 Engineered Fluid

Introduction

3M™ Novec™ 7000 Engineered Fluid, 1-methoxyheptafluoropropane, is a non-flammable, low global warming potential (GWP) heat transfer fluid capable of reaching -120°C. It is also useful as a direct expansion refrigerant.

For information on other applications, contact your 3M representative or 3M authorized distributor.

Applications

- Semiconductor
  - Ion implanters
  - Dry etchers
  - CVD/PVD tools
  - Electronic Automated Test Equipment (ATE)
- Industrial/Pharmaceutical
  - Chemical reactors
  - Freeze dryers
  - VOC capture
- Fuel cells
- Electronic Cooling
  - Supercomputers
  - Sensitive military electronics
  - High voltage transformers
- Electronics
  - Reliability testing
  - Temperature calibration
- Autocascade refrigeration
  - HCFC-123 replacement
- Medical Lab
  - Histobath working fluid

Benefits

- Low GWP (530, 100-year ITH)
- Excellent dielectric properties
  In event of leakage or other failure, will not damage electronic equipment
- Zero ozone depletion potential (ODP)
- Good materials compatibility
- Low toxicity
- Non-flammable
- Non-corrosive
- Good thermal stability
- Useful at extreme low temperatures
  Viscosity is less than 20 cSt at -120°C

Material Description

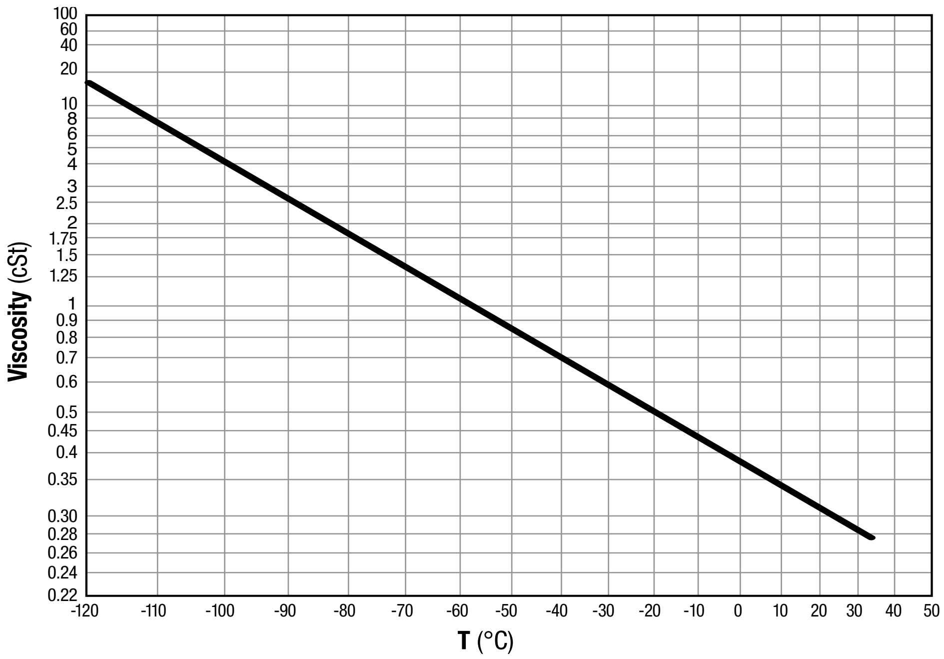
Ingredients	Novec™ 7000 Engineered Fluid
1-methoxyheptafluoropropane ($C_3F_7OCH_3$)	99.5% by weight
Appearance	Clear, colorless
Non-volatile residue (NVR)	25.0 ppm maximum

Typical Physical Properties

Not for specification purposes. All values @ 25°C unless otherwise specified.

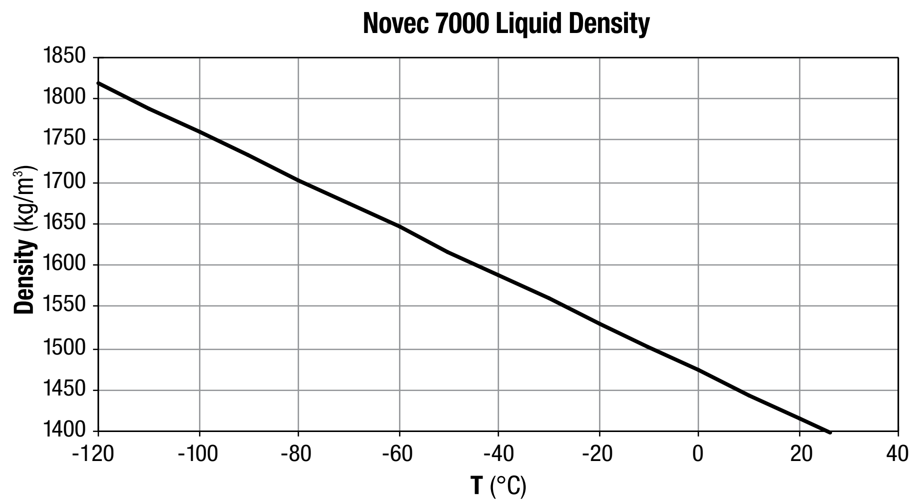
Properties	3M™ Novec™ 7000 Engineered Fluid
Molecular Weight (g/mol)	200
Boiling Point @ 1 atmosphere (°C)	34
Freeze Point (°C)	-122.5
Liquid Density (kg/m³)	1400
Kinematic Viscosity (cSt)	0.32
Kinematic Viscosity @ -80°C (cSt)	2.0
Kinematic Viscosity @ -120°C (cSt)	17
Coefficient of Expansion	0.00219 K^{-1}
Critical Density (kg/m³)	553
Critical Pressure (MPa)	2.48
Critical Temperature (°C)	165°C
Dielectric Constant	7.4
Dielectric Strength (kV)	~40
Flash Point	None
Latent Heat of Vaporization (kJ/kg)	142
Solubility of water in fluid (ppmw)	~60
Solubility of air in fluid (vol %)	~35
Specific Heat ($J \cdot kg^{-1} \cdot K^{-1}$)	1300
Surface Tension (dynes/cm)	12.4
Thermal Conductivity ($W \cdot m^{-1} \cdot K^{-1}$)	0.075
Vapor Pressure (kPa)	64.6
Volume Resistivity (ohm-cm)	108

Novec 7000 Kinematic Viscosity

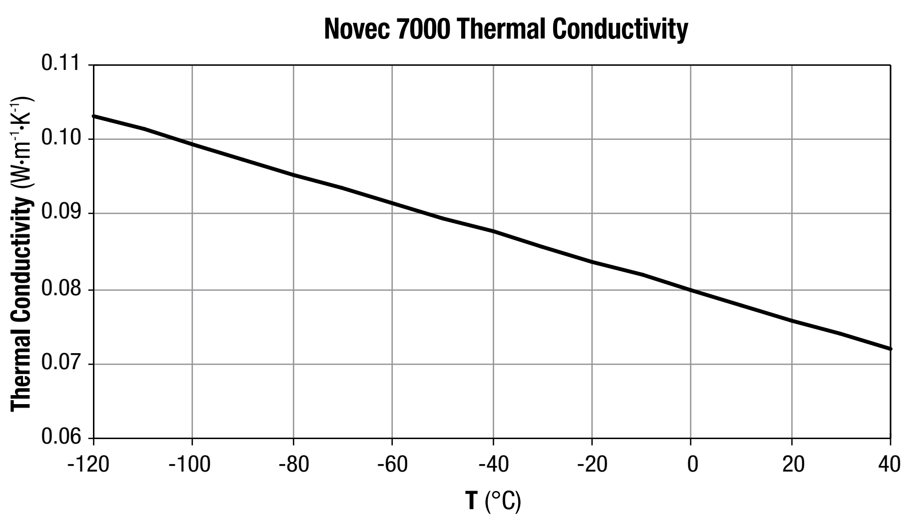


Typical Physical Properties (continued)

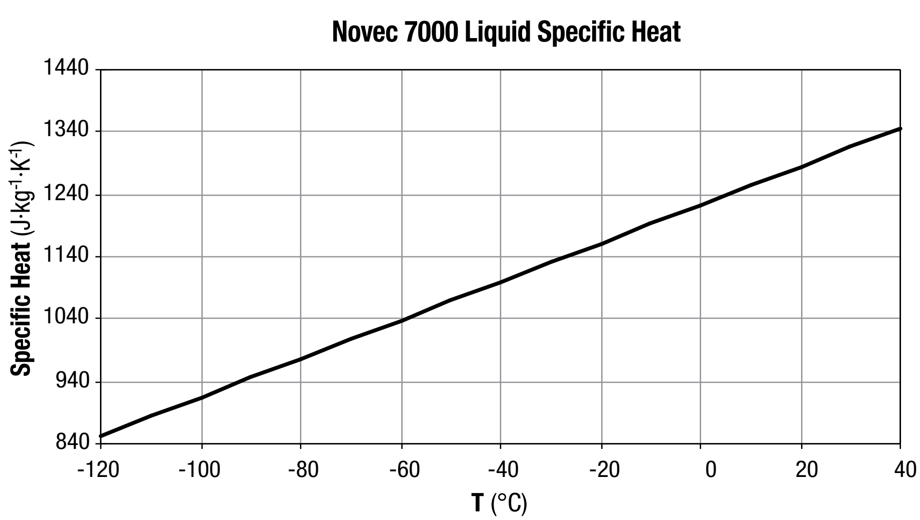
Not for specification purposes. All values @ 25°C unless otherwise specified.



Liquid Density [kg/m^3] = 1472.6 - 2.880·T(°C)



Thermal Conductivity [W·m^{-1}·K^{-1}] = 0.0798 - 0.000196·T(°C)



Liquid Specific Heat [J·kg^{-1}·K^{-1}] = 1223.2 + 3.0803·T (°C)

Novec 7000 Vapor Pressure

$$\ln(P[Pa]) = -3548.6/T[K] + 22.978$$
$$-30°C < T < T_c$$

Toxicity Profile

Not for specification purposes. All values @ 25°C unless otherwise specified.

The toxicological testing completed on 3M™ Novec™ 7000 Engineered Fluid indicates low acute and sub-acute toxicity. A 28-day inhalation study conducted at 1000, 10,000 and 30,000 ppm helped establish an exposure guideline of 250 ppmv for an average 8 hour work day. The No Adverse Effect Level (NOAEL) in this study was 1000 ppm. This data suggests there is a large margin of safety for use of this fluid in relatively non-emissive heat transfer systems.

Toxicological Test Results

Properties	Novec™ 7000 Engineered Fluid
Acute Lethal Concentration (ppmv)	>30,000
8 hr Exposure Guideline (ppmv)	250
Skin Irritation	Negative[1]
Mutagenicity	Negative[1]
Ecotoxicity (water solubility < 2.5 ppb)	Very low aquatic toxicity
Acute Oral Toxicity	LD50 > 2000 mg/kg[1]
28-day Inhalation	NOAEL=1000 ppm

[1] A. Sekiya and S. Misaki, "*The potential of hydrofluoroethers to replace CFCs, HCFCs and PFCs*" J. of Fluorine Chemistry, 101, 2000, pp. 215-221.

Environmental Properties

Properties	Novec™ 7000 Engineered Fluid
Ozone Depletion Potential[1] (ODP)	0.0
Global Warming Potential[2] (GWP)	530
Atmospheric Lifetime (years)	4.9

[1] CFC-11 = 1.0
[2] GWP 100-year integrated time horizon (ITH). IPCC 2013.

Environmental, Health and Safety

Before using this product, please read the current product Safety Data Sheet (available through your 3M sales or technical service representative) and the precautionary statement on the product package. Follow all applicable precautions and directions.

3M™ Novec™ 7000 Engineered Fluid is non-flammable. The fluid is resistant to thermal breakdown and hydrolysis during storage and use. Recommended handling procedures are provided in the Safety Data Sheet, which is available from your local 3M representative upon request.

Materials Compatibility

Novec 7000 fluid is compatible with most metals and hard polymers such as:

Metals	Plastics
Stainless Steel	Polypropylene
Brass	Polyethylene
Copper	Nylon
Aluminum	Polyacetyl
	PEEK
	PTFE

Elastomeric materials should be limited to those compounds that contain the least amount of extractible plasticizer. 3M engineers can suggest appropriate compounds or assist with test procedures.

Heater Selection

The critical heat flux of Novec 7000 fluid is 18 W/cm^2 when boiling from a horizontal 0.5 mm diameter platinum wire in a quiescent pool of saturated fluid. The maximum heat flux obtainable in forced convection applications will be significantly higher, but depends strongly upon the geometry and flow conditions. A safety interlock between the pump and heater is strongly recommended in applications with heat fluxes exceeding 15 W/cm^2.

Regulatory Status

Novec 7000 fluid is available for commercial sale in the United States, China, Malaysia, Singapore and Taiwan and is currently under review by regulatory agencies in Europe, Japan, the Philippines and Korea.

Contact your local 3M representative for an update on the regulatory status of Novec 7000 fluid.

Recycle and Disposal Options

Used Fluid Return Program

3M offers a program for free pickup and return of used 3M specialty fluids in the U.S. A pre-negotiated handling agreement between users and our authorized service provider offers users broad protection against future liability for used 3M product. The fluid return program is covered by independent third-party financial and environmental audits of treatment, storage and disposal facilities. Necessary documentation is provided. A minimum of 30 gallons of used 3M specialty fluid is required for participation in this free program.

For additional information on the 3M Used Fluid Return Program, contact your local 3M representative or call 3M Customer Service at 800.810.8513.

Resources

3M™ Novec™ Engineered Fluids are supported by global sales, technical and customer service resources, with technical service laboratories in the U.S., Europe, Japan, Latin America and Southeast Asia. Users benefit from 3M's broad technology base and continuing attention to product development, performance, safety and environmental issues. For additional technical information on 3M™ Novec™ 7000 Engineered Fluid in the United States or for the name of a local authorized distributor, call 3M Electronics Materials Solutions Division: **800 810 8513.**

The 3M™ Novec™ Brand Family

The Novec brand is the hallmark for a variety of proprietary 3M products. Although each has its own unique formula and performance properties, all Novec products are designed in common to address the need for safe, effective, sustainable solutions in industry-specific applications. These include precision and electronics cleaning, heat transfer, fire protection, protective coatings, immersion cooling, advanced insulation media replacement solutions and several specialty chemical applications.

3M™ Novec™ Engineered Fluids • 3M™ Novec™ Aerosol Cleaners • 3M™ Novec™ 1230 Fire Protection Fluid • 3M™ Novec™ Electronic Grade Coatings • 3M™ Novec™ Electronic Surfactants • 3M™ Novec™ Dielectric Fluids

United States	China	Europe	Japan	Korea	Singapore	Taiwan
3M Electronics Materials Solutions Division 800 810 8513	3M China Ltd. 86 21 6275 3535	3M Belgium N.V. 32 3 250 7521	3M Japan Limited 81 3 6409 3800	3M Korea Limited 82 2 3771 4114	3M Singapore Pte. Ltd. 65 64508888	3M Taiwan Limited 886 2 2704 9011

Regulatory: For regulatory information about this product, contact your 3M representative.

Technical Information: The technical information, recommendations and other statements contained in this document are based upon tests or experience that 3M believes are reliable, but the accuracy or completeness of such information is not guaranteed.

Product Use: Many factors beyond 3M's control and uniquely within user's knowledge and control can affect the use and performance of a 3M product in a particular application. Given the variety of factors that can affect the use and performance of a 3M product, user is solely responsible for evaluating the 3M product and determining whether it is fit for a particular purpose and suitable for user's method of application.

Warranty, Limited Remedy, and Disclaimer: Unless an additional warranty is specifically stated on the applicable 3M product packaging or product literature, 3M warrants that each 3M product meets the applicable 3M product specification at the time 3M ships the product. 3M MAKES NO OTHER WARRANTIES OR CONDITIONS, EXPRESS OR IMPLIED, INCLUDING, BUT NOT LIMITED TO, ANY IMPLIED WARRANTY OR CONDITION OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE OR ANY IMPLIED WARRANTY OR CONDITION ARISING OUT OF A COURSE OF DEALING, CUSTOM OR USAGE OF TRADE. If the 3M product does not conform to this warranty, then the sole and exclusive remedy is, at 3M's option, replacement of the 3M product or refund of the purchase price.

Limitation of Liability: Except where prohibited by law, 3M will not be liable for any loss or damage arising from the 3M product, whether direct, indirect, special, incidental or consequential, regardless of the legal theory asserted, including warranty, contract, negligence or strict liability.

Electronics Materials Solutions Division
3M Center, Building 224-3N-11
St. Paul, MN 55144-1000
www.3M.com/novec
1-800-810-8513

Please recycle. Printed in USA.
Issued: 11/14 10316HB
98-0212-2499-7

Safety Data Sheet

Document Group:	16-2638-1	**Version Number:**	18.00
Issue Date:	05/21/18	**Supercedes Date:**	02/08/18

SECTION 1: Identification

1.1. Product identifier
3M™ Novec™ 7000 Engineered Fluid

Product Identification Numbers
98-0212-2969-9, 98-0212-2970-7, 98-0212-2971-5, 98-0212-3531-6, 98-0212-4900-2

1.2. Recommended use and restrictions on use

Recommended use
For Industrial Use Only. Not Intended for Use as a Medical Device or Drug.

One or more components in this material are approved for specific commercial use(s) under a U.S. EPA TSCA Significant New Use Rule or Consent Order. Approved uses include: heat transfer fluid, refrigerant, aerosol spray cleaner, medium for low temperature immersion baths (e.g., histology baths), deposition coating solvent, vapor degreasing, specialty foam blowing additive, and line flushing for substances requiring special handling (e.g., liquid oxygen).

Novec™ Engineered Fluids are used in a wide variety of applications, including but not limited to precision cleaning of medical devices and as a lubricant deposition solvent for medical devices. When the product is used for applications where the finished device is implanted into the human body, no residual Novec solvent may remain on the parts. It is highly recommended that the supporting test results and protocol be cited during FDA registration.

3M Electronics Markets Materials Division (EMMD) will not knowingly sample, support, or sell its products for incorporation in medical and pharmaceutical products and applications in which the 3M product will be temporarily or permanently implanted into humans or animals. The customer is responsible for evaluating and determining that a 3M EMMD product is suitable and appropriate for its particular use and intended application. The conditions of evaluation, selection, and use of a 3M product can vary widely and affect the use and intended application of a 3M product. Because many of these conditions are uniquely within the user's knowledge and control, it is essential that the user evaluate and determine whether the 3M product is suitable and appropriate for a particular use and intended application, and complies with all local applicable laws, regulations, standards, and guidance.

1.3. Supplier's details

MANUFACTURER:	3M
DIVISION:	Electronics Materials Solutions Division
ADDRESS:	3M Center, St. Paul, MN 55144-1000, USA
Telephone:	1-888-3M HELPS (1-888-364-3577)

1.4. Emergency telephone number

1-800-364-3577 or (651) 737-6501 (24 hours)

SECTION 2: Hazard identification

2.1. Hazard classification
Not classified as hazardous according to OSHA Hazard Communication Standard, 29 CFR 1910.1200.

2.2. Label elements
Signal word
Not applicable.

Symbols
Not applicable.

Pictograms
Not applicable.

SECTION 3: Composition/information on ingredients

Ingredient	C.A.S. No.	% by Wt
Methyl perfluoropropyl ether	375-03-1	> 99.5

SECTION 4: First aid measures

4.1. Description of first aid measures

Inhalation:
Remove person to fresh air. If you are concerned, get medical advice.

Skin Contact:
Wash with soap and water. If signs/symptoms develop, get medical attention.

Eye Contact:
Flush with large amounts of water. Remove contact lenses if easy to do. Continue rinsing. If signs/symptoms persist, get medical attention.

If Swallowed:
No need for first aid is anticipated.

4.2. Most important symptoms and effects, both acute and delayed
See Section 11.1. Information on toxicological effects.

4.3. Indication of any immediate medical attention and special treatment required
Not applicable

SECTION 5: Fire-fighting measures

5.1. Suitable extinguishing media
Non-combustible. Use a fire fighting agent suitable for surrounding fire.

5.2. Special hazards arising from the substance or mixture
Exposure to extreme heat can give rise to thermal decomposition.

Hazardous Decomposition or By-Products

Substance	Condition
Carbon monoxide	During Combustion
Carbon dioxide	During Combustion

5.3. Special protective actions for fire-fighters
When fire fighting conditions are severe and total thermal decomposition of the product is possible, wear full protective clothing, including helmet, self-contained, positive pressure or pressure demand breathing apparatus, bunker coat and pants, bands around arms, waist and legs, face mask, and protective covering for exposed areas of the head.

SECTION 6: Accidental release measures

6.1. Personal precautions, protective equipment and emergency procedures
Ventilate the area with fresh air. For large spill, or spills in confined spaces, provide mechanical ventilation to disperse or exhaust vapors, in accordance with good industrial hygiene practice.

6.2. Environmental precautions
Avoid release to the environment. For larger spills, cover drains and build dikes to prevent entry into sewer systems or bodies of water.

6.3. Methods and material for containment and cleaning up
Contain spill. Working from around the edges of the spill inward, cover with bentonite, vermiculite, or commercially available inorganic absorbent material. Mix in sufficient absorbent until it appears dry. Collect as much of the spilled material as possible. Place in a closed container approved for transportation by appropriate authorities. Collect the resulting residue containing solution. Clean up residue with an appropriate solvent selected by a qualified and authorized person. Ventilate the area with fresh air. Read and follow safety precautions on the solvent label and SDS. Seal the container. Dispose of collected material as soon as possible in accordance with applicable local/regional/national/international regulations.

SECTION 7: Handling and storage

7.1. Precautions for safe handling
Contents may be under pressure, open carefully. Do not breathe thermal decomposition products. For industrial or professional use only. Avoid release to the environment. Avoid contact with oxidizing agents (eg. chlorine, chromic acid etc.)

7.2. Conditions for safe storage including any incompatibilities
Store in a well-ventilated place. Store at temperatures not exceeding 38C/100F Store away from acids. Store away from strong bases. Store away from oxidizing agents.

SECTION 8: Exposure controls/personal protection

8.1. Control parameters

Occupational exposure limits

If a component is disclosed in section 3 but does not appear in the table below, an occupational exposure limit is not available for the component.

Ingredient	C.A.S. No.	Agency	Limit type	Additional Comments
Methyl perfluoropropyl ether	375-03-1	Manufacturer determined	TWA:250 ppm	

ACGIH : American Conference of Governmental Industrial Hygienists
AIHA : American Industrial Hygiene Association
CMRG : Chemical Manufacturer's Recommended Guidelines
OSHA : United States Department of Labor - Occupational Safety and Health Administration

TWA: Time-Weighted-Average
STEL: Short Term Exposure Limit
CEIL: Ceiling

8.2. Exposure controls

8.2.1. Engineering controls

Provide appropriate local exhaust ventilation on open containers. Provide appropriate local exhaust when product is heated. Use general dilution ventilation and/or local exhaust ventilation to control airborne exposures to below relevant Exposure Limits and/or control dust/fume/gas/mist/vapors/spray. If ventilation is not adequate, use respiratory protection equipment.

8.2.2. Personal protective equipment (PPE)

Eye/face protection

Select and use eye/face protection to prevent contact based on the results of an exposure assessment. The following eye/face protection(s) are recommended:
Safety Glasses with side shields

Skin/hand protection
No chemical protective gloves are required.

Respiratory protection

During heating:
Use a positive pressure supplied-air respirator if there is a potential for over exposure from an uncontrolled release, exposure levels are not known, or under any other circumstances where air-purifying respirators may not provide adequate protection.

SECTION 9: Physical and chemical properties

9.1. Information on basic physical and chemical properties

General Physical Form:	Liquid
Specific Physical Form:	Liquid
Odor, Color, Grade:	Colorless liquid with slight ether odor
Odor threshold	*No Data Available*
pH	*Not Applicable*
Melting point	-122.5 ºC
Boiling Point	34 ºC
Flash Point	No flash point
Evaporation rate	*No Data Available*
Flammability (solid, gas)	Not Applicable
Flammable Limits(LEL)	None detected
Flammable Limits(UEL)	None detected
Vapor Pressure	403 mmHg [@ 20 ºC]
Vapor Density	0.51 [@ 25 ºC]
Density	1.41 g/ml
Specific Gravity	1.41 [*Ref Std:*WATER=1]
Solubility in Water	Negligible
Solubility- non-water	*No Data Available*
Partition coefficient: n-octanol/ water	*No Data Available*
Autoignition temperature	415 ºC
Decomposition temperature	*Not Applicable*
Viscosity	0.00047 Pa-s
Hazardous Air Pollutants	*Not Applicable*

Molecular weight	*No Data Available*
Volatile Organic Compounds	*No Data Available*
Percent volatile	100 %
VOC Less H2O & Exempt Solvents	*No Data Available*

SECTION 10: Stability and reactivity

10.1. Reactivity
This material may be reactive with certain agents under certain conditions - see the remaining headings in this section.

10.2. Chemical stability
Stable.

10.3. Possibility of hazardous reactions
Hazardous polymerization will not occur.

10.4. Conditions to avoid
None known.

10.5. Incompatible materials
Strong acids
Strong bases
Strong oxidizing agents

10.6. Hazardous decomposition products

Substance	Condition
Carbonyl Fluoride	At Elevated Temperatures - extreme conditions of heat
Hydrogen Fluoride	At Elevated Temperatures - extreme conditions of heat
Toxic Vapor, Gas, Particulate	At Elevated Temperatures - extreme conditions of heat

Refer to section 5.2 for hazardous decomposition products during combustion.

If the product is exposed to extreme condition of heat from misuse or equipment failure, toxic decomposition products that include hydrogen fluoride and perfluoroisobutylene can occur. Extreme heat arising from situations such as misuse or equipment failure can generate hydrogen fluoride as a decomposition product.

SECTION 11: Toxicological information

The information below may not be consistent with the material classification in Section 2 if specific ingredient classifications are mandated by a competent authority. In addition, toxicological data on ingredients may not be reflected in the material classification and/or the signs and symptoms of exposure, because an ingredient may be present below the threshold for labeling, an ingredient may not be available for exposure, or the data may not be relevant to the material as a whole.

11.1. Information on Toxicological effects

Signs and Symptoms of Exposure

Based on test data and/or information on the components, this material may produce the following health effects:

Inhalation:
No known health effects.

Skin Contact:
Contact with the skin during product use is not expected to result in significant irritation.

Eye Contact:
Contact with the eyes during product use is not expected to result in significant irritation.

Ingestion:
No known health effects.

Toxicological Data
If a component is disclosed in section 3 but does not appear in a table below, either no data are available for that endpoint or the data are not sufficient for classification.

Acute Toxicity

Name	Route	Species	Value
Methyl perfluoropropyl ether	Inhalation-Vapor (4 hours)	Mouse	LC50 820 mg/l
Methyl perfluoropropyl ether	Ingestion	Rat	LD50 > 2,000 mg/kg

ATE = acute toxicity estimate

Skin Corrosion/Irritation

Name	Species	Value
Methyl perfluoropropyl ether	Rabbit	No significant irritation

Serious Eye Damage/Irritation

Name	Species	Value
Methyl perfluoropropyl ether	Rabbit	No significant irritation

Skin Sensitization

Name	Species	Value
Methyl perfluoropropyl ether	Mouse	Not classified

Respiratory Sensitization
For the component/components, either no data are currently available or the data are not sufficient for classification.

Germ Cell Mutagenicity

Name	Route	Value
Methyl perfluoropropyl ether	In Vitro	Not mutagenic

Carcinogenicity
For the component/components, either no data are currently available or the data are not sufficient for classification.

Reproductive Toxicity

Reproductive and/or Developmental Effects
For the component/components, either no data are currently available or the data are not sufficient for classification.

Target Organ(s)

Specific Target Organ Toxicity - single exposure
For the component/components, either no data are currently available or the data are not sufficient for classification.

Specific Target Organ Toxicity - repeated exposure

Name	Route	Target Organ(s)	Value	Species	Test Result	Exposure Duration
Methyl perfluoropropyl ether	Inhalation	kidney and/or bladder	Some positive data exist, but the data are not sufficient for classification	Rat	NOAEL 82 mg/l	30 days
Methyl perfluoropropyl ether	Inhalation	blood | liver | heart | endocrine system | hematopoietic system | nervous system | respiratory system	Not classified	Rat	NOAEL 246 mg/l	30 days

Aspiration Hazard
For the component/components, either no data are currently available or the data are not sufficient for classification.

Please contact the address or phone number listed on the first page of the SDS for additional toxicological information on this material and/or its components.

SECTION 12: Ecological information

Ecotoxicological information

Please contact the address or phone number listed on the first page of the SDS for additional ecotoxicological information on this material and/or its components.

Chemical fate information

Please contact the address or phone number listed on the first page of the SDS for additional chemical fate information on this material and/or its components.

SECTION 13: Disposal considerations

13.1. Disposal methods
Dispose of contents/ container in accordance with the local/regional/national/international regulations.

Dispose of waste product in a permitted industrial waste facility. Combustion products will include HF. Facility must be capable of handling halogenated materials. Combustion products will include halogen acid (HCl/HF/HBr). Facility must be capable of handling halogenated materials. Empty and clean product containers may be disposed as non-hazardous waste. Consult your specific regulations and service providers to determine available options and requirements.

EPA Hazardous Waste Number (RCRA): Not regulated

SECTION 14: Transport Information

For Transport Information, please visit http://3M.com/Transportinfo or call 1-800-364-3577 or 651-737-6501.

SECTION 15: Regulatory information

15.1. US Federal Regulations
Contact 3M for more information.

EPCRA 311/312 Hazard Classifications:

Physical Hazards
Not applicable

Health Hazards
Not applicable

This material contains a chemical which requires export notification under TSCA Section 12[b]:

Ingredient (Category if applicable)	C.A.S. No	Regulation	Status
Methyl perfluoropropyl ether	375-03-1	Toxic Substances Control Act (TSCA) 5 SNUR or Consent Order Chemicals	Applicable

This material contains a chemical regulated by an EPA Significant New Use Rule (TSCA Section 5)

Ingredient (Category if applicable)	C.A.S. No	Reference
Methyl perfluoropropyl ether	375-03-1	40CFR721.8145

15.2. State Regulations
Contact 3M for more information.

15.3. Chemical Inventories
The components of this material are in compliance with the China "Measures on Environmental Management of New Chemical Substance". Certain restrictions may apply. Contact the selling division for additional information.

The components of this material are in compliance with the provisions of the Korean Toxic Chemical Control Law. Certain restrictions may apply. Contact the selling division for additional information.

The components of this material are in compliance with the provisions of Japan Chemical Substance Control Law. Certain restrictions may apply. Contact the selling division for additional information.

The components of this material are in compliance with the provisions of Philippines RA 6969 requirements. Certain restrictions may apply. Contact the selling division for additional information.

The components of this product are in compliance with the chemical notification requirements of TSCA. All required components of this product are listed on the active portion of the TSCA Inventory.

Contact 3M for more information.

15.4. International Regulations
Contact 3M for more information.

This SDS has been prepared to meet the U.S. OSHA Hazard Communication Standard, 29 CFR 1910.1200.

SECTION 16: Other information

NFPA Hazard Classification
Health: 3 **Flammability:** 0 **Instability:** 0 **Special Hazards:** None

National Fire Protection Association (NFPA) hazard ratings are designed for use by emergency response personnel to address the hazards that are presented by short-term, acute exposure to a material under conditions of fire, spill, or similar emergencies. Hazard ratings are primarily based on the inherent physical and toxic properties of the material but also include the toxic properties of combustion or decomposition products that are known to be generated in significant quantities.

The NFPA Health code of 3 is due to emergency situations where the material may thermally decompose and release Hydrogen Fluoride. During normal use conditions, please reference Section 2 and Section 11 of the SDS for additional health hazard information.

HMIS Hazard Classification

Health: 0 **Flammability:** 0 **Physical Hazard:** 0 **Personal Protection:** X - See PPE section.

Hazardous Material Identification System (HMIS® IV) hazard ratings are designed to inform employees of chemical hazards in the workplace. These ratings are based on the inherent properties of the material under expected conditions of normal use and are not intended for use in emergency situations. HMIS® IV ratings are to be used with a fully implemented HMIS® IV program. HMIS® is a registered mark of the American Coatings Association (ACA).

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Conversion to GHS format SDS.

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