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

- 2018 Update -

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Canadian Carbonization Research Association
www.cancarb.ca

CCRA and Geoscience BC

- Canadian Carbonization Research Association (CCRA) is a cooperative industrial research group – coal, steel, cokemaking, CanmetENERGY
- Geoscience BC is a BC government funded group that financially supports joint work on exploration and resource assessment in BC

PRESENTATION OUTLINE

BACKGROUND

CCRA/GEOSCIENCE PROJECT

ROBEN JIG PROCEDURE

RESULTS OF 2017 PROGRAM

CONTINUING WORK

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CLEANING COAL - DENSITY

- **Coking coal is cleaned in processing plants mainly using density separation – (fine particles use flotation).**
- **The differences in density between lighter coal particles and heavier minerals, stones, etc, allows the production of clean low ash coal.**

CLEANING COAL - DENSITY

- **Lab testing and pilot scale processing of raw coal is used to determine the coal processing and clean coal quality properties.**
- **This is done using float and sink baths or in small dense-media pilot plants with froth flotation for the fines.**

FLOAT/SINK – ORGANIC CHEMICALS

- **Traditional method for washing small scale samples is the Float/Sink Method – ASTM D4371**
- **Samples are evaluated from exploration, pit and plant, etc.**
- **Samples are screened into different size ranges similar to processing plants.**

FLOAT/SINK – ORGANIC CHEMICALS

Float/Sink Liquids include the following:

- **Methylene Bromide (SG 2.47)/Bromoform (SG 2.89)**
- **Perchloroethylene (SG 1.62)**
- **VMP Naptha (SG 0.75)**
- **Alternate Liquid: Halocarbon (SG 1.70)**

FLOAT/SINK – ORGANIC CHEMICALS

ADVANTAGES OF FLOAT SINKING

- **Easy to achieve Specific Gravity fractions**
- **Coal readily wets with organic liquids**
- **Inert towards shales**
- **Efficient and repeatable results**

DIS-ADVANTAGES OF FLOAT SINKING

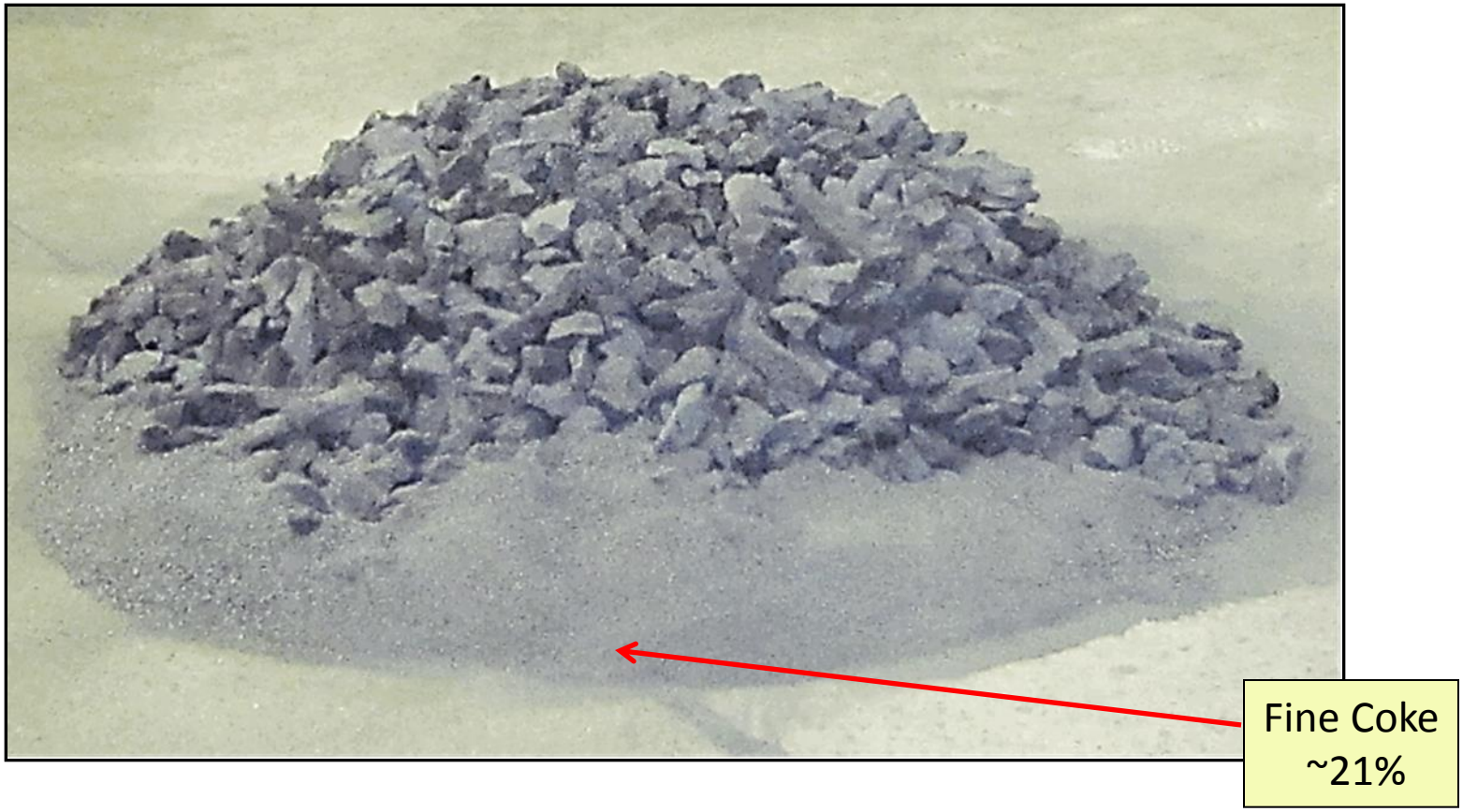
- **Heavy loads/repetition of large samples**
- **Disposal of contamined coal/reject**
- **Expensive: Bromoform ($83/litre), Halocarbon ($240/litre)**
- **Health and Environmental issues**
- **Personal protection equipment and specifically designed work areas.**

FLOAT/SINK – ORGANIC CHEMICALS

DIS-ADVANTAGES

- **Coal quality may be impacted:**
  - **Misplaced material making float/sink results difficult to interpret**
  - **Coking coal quality – thermal softening properties and coking properties can be impacted.**

IMPACT OF PERCHLOROETHYLENE ON COKE



ALTERNATIVES TO ORGANIC CHEMICALS

- **Heavy salts – lab scale**
- **Water based washing**
  - **Lab scale dense-media/flotation**
  - **Pilot scale dense-media/flotation**
  - **Other - i.e. Roben Jig**

ALTERNATIVES TO ORGANIC CHEMICALS

- **Birtley Coal Testing operated a coal washing dense-media pilot plant from the 1970's until the early 2000's, which could produce bulk samples for pilot coke oven testing.**
- **Since the mid 2000's the only alternatives have been much smaller dense-media equipment at Teck, SGS and Hazen.**

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1. **Purchased a Lab Sized Roben Jig and operated at Birtley Coal Testing.**
2. **Tested 4 coals from BC (SEBC & NEBC)**
3. **Each coal float/sink and Jig washed**
4. **Coal analyses: chemical and physical, thermal softening, petrography**
5. **Coking quality: CanmetENERGY sole-heated oven**

ROBEN JIGS

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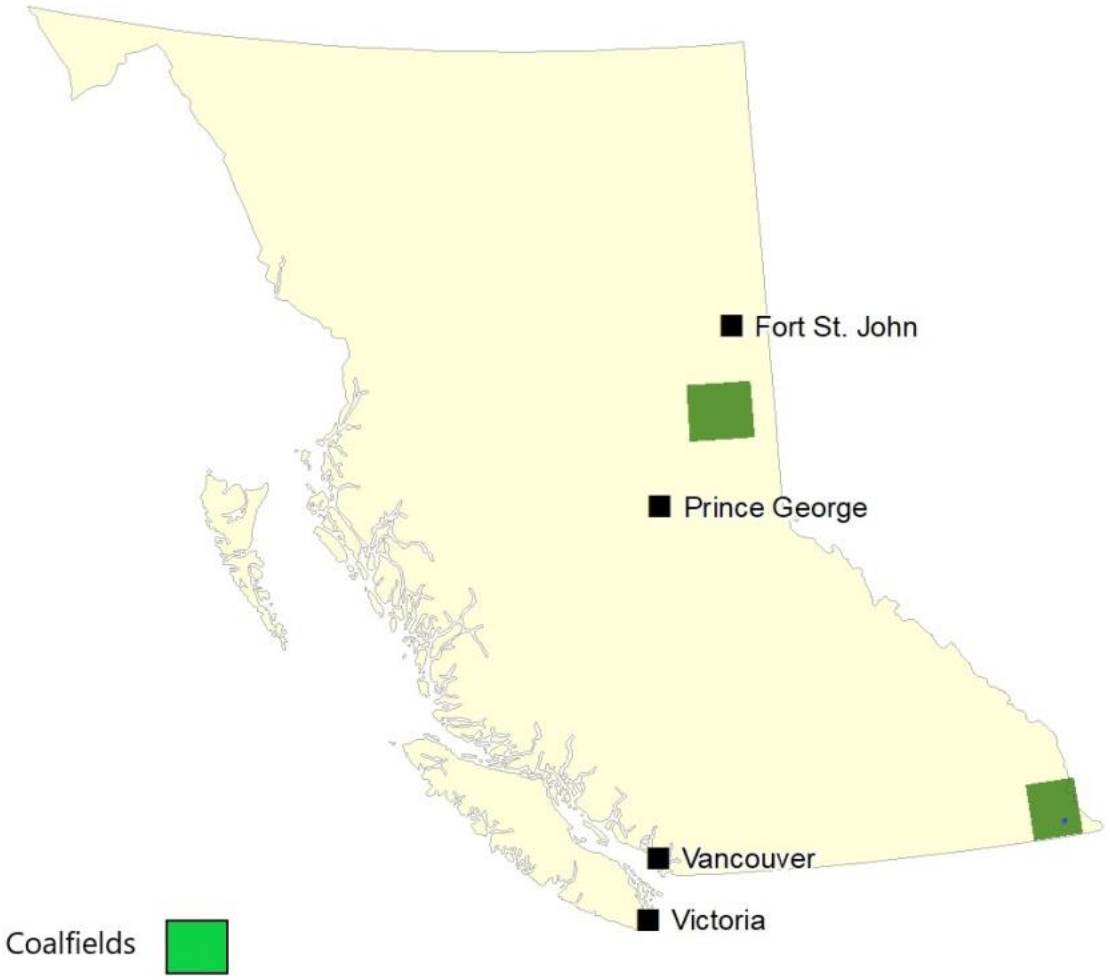
COAL SOURCES - ROBEN JIG PROGRAM



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GOALS FOR 2017 STUDY

1. **Confirm the applicability of the Jig for use in cleaning small mass exploration samples**

2. **Assess Jig methodology**

3. **Spread the word! (publish)**

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LAB TESTS FROM 4 SAMPLES

1. Coal chemical analysis of each fraction: Ash, Volatile Matter, moisture, and selected petrography and FSI
2. Chemical, Physical, Thermal Rheological and Petrographic results of clean coal composites, including detailed Ash elemental composition

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RESULTS – ROBEN JIG STUDY

Samples from Float/Sink and Jig separations were analyzed and compared for:

1. **Density separation characteristics**
2. **Coal proximate (ash, VM), chemical (S, Cl, etc), physical, thermal softening, ash chemistry and petrography**
3. **Clean coal composite coking properties**

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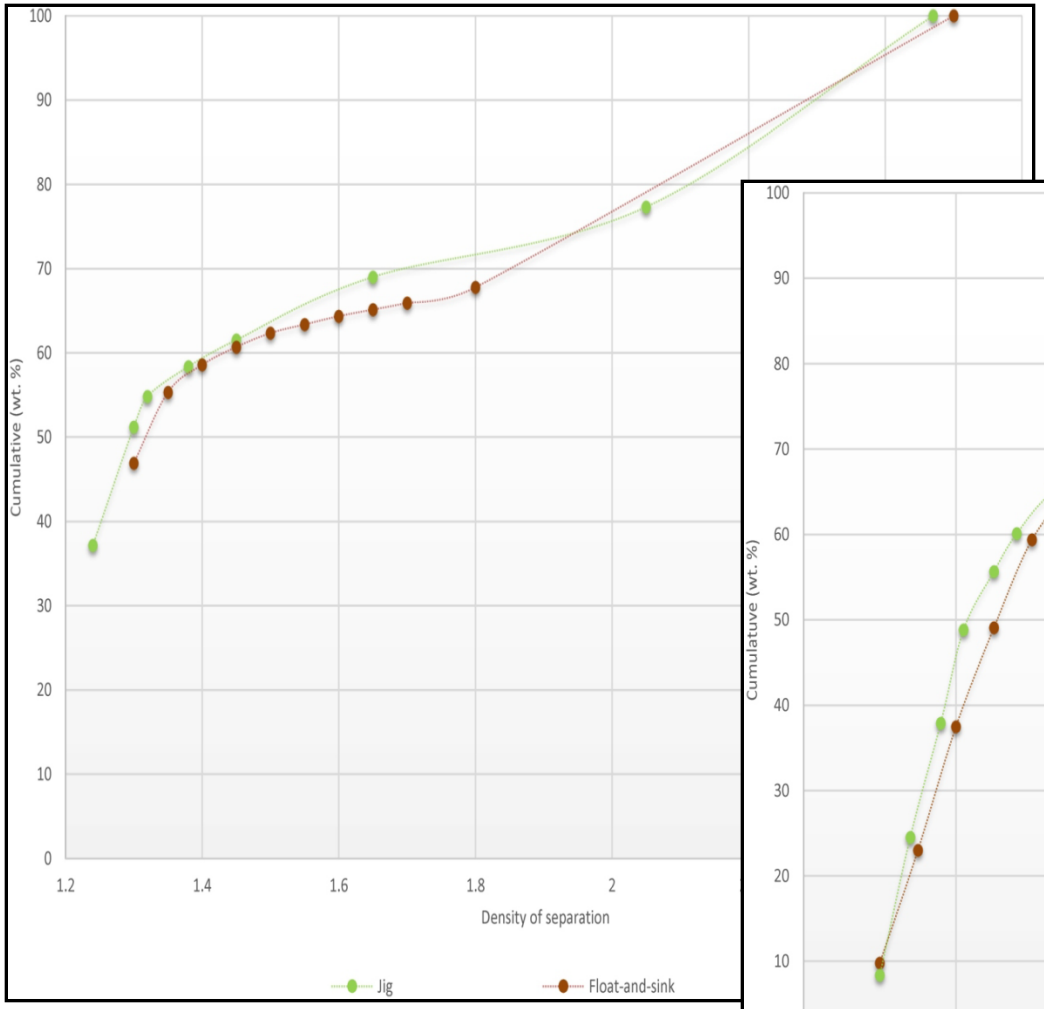
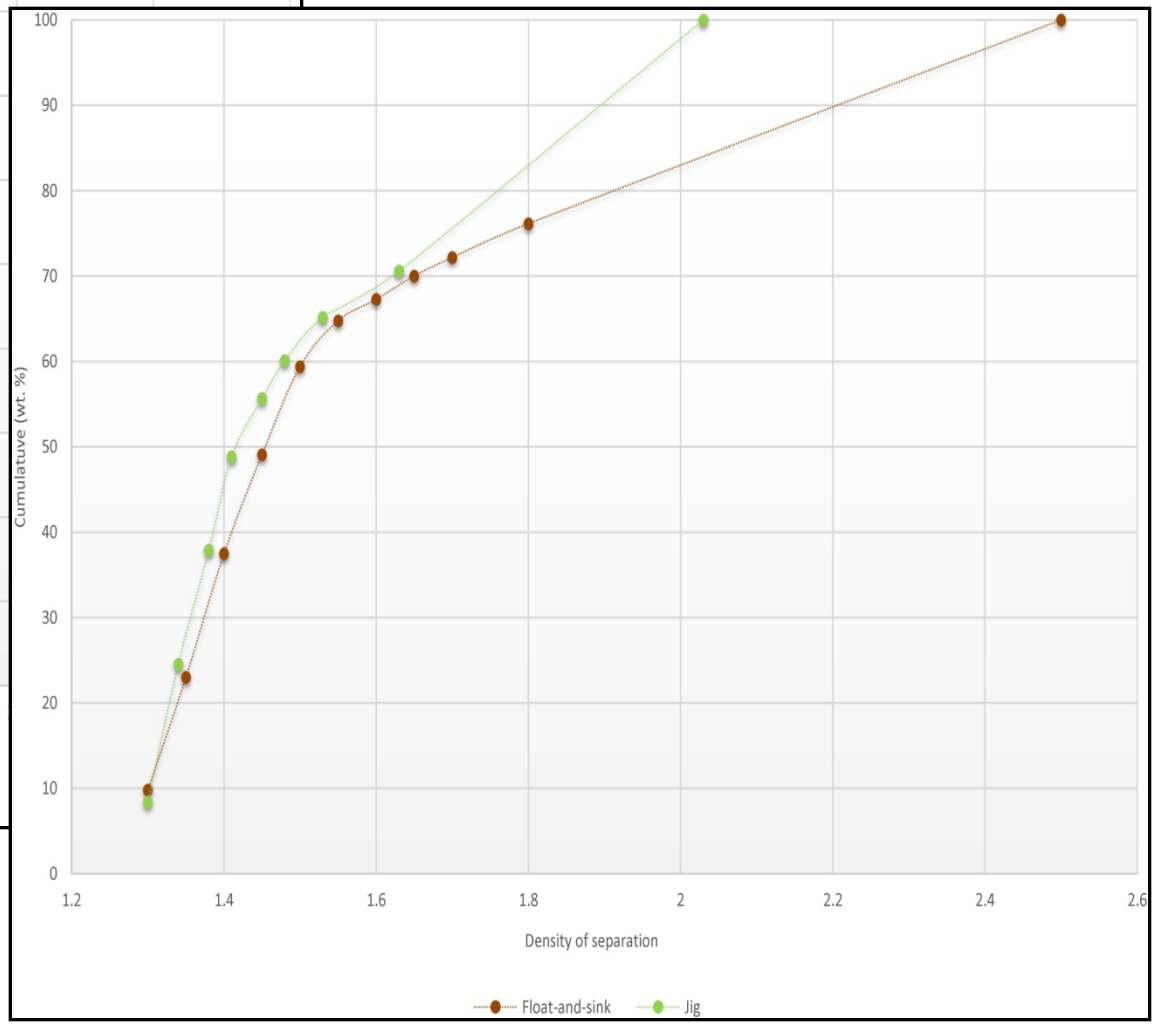
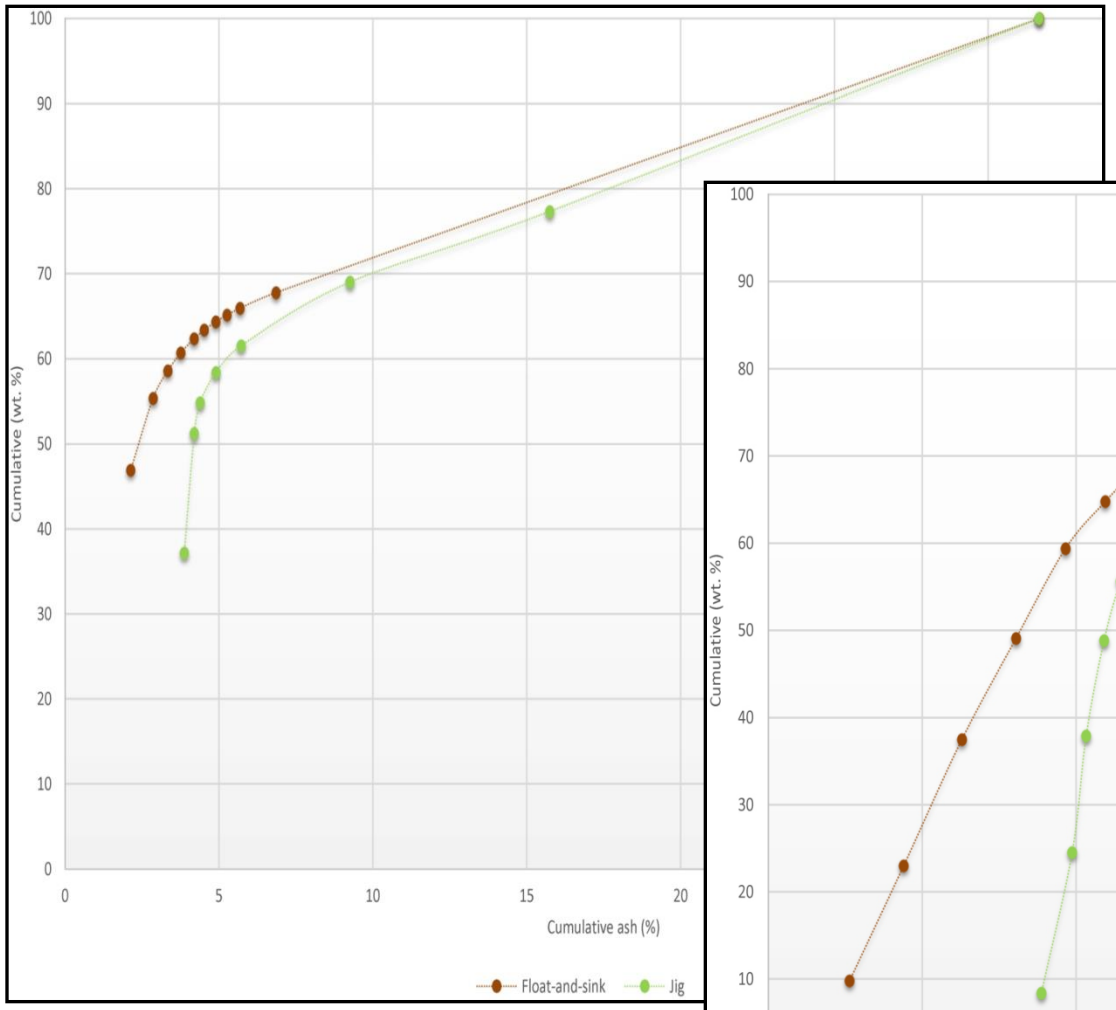
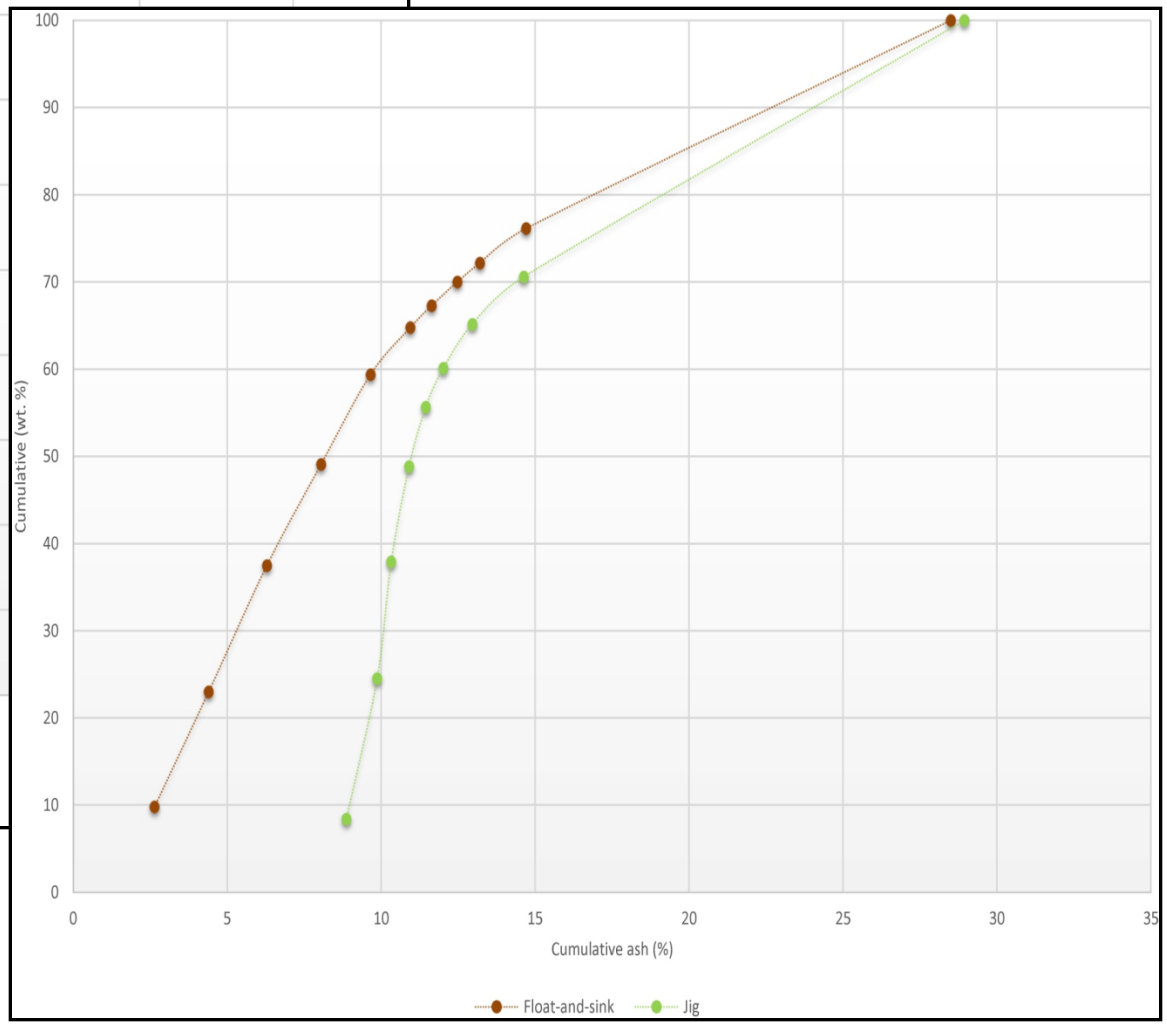
Separation Density and Wt Recovered





Clean Coal Ash and Wt Recovered





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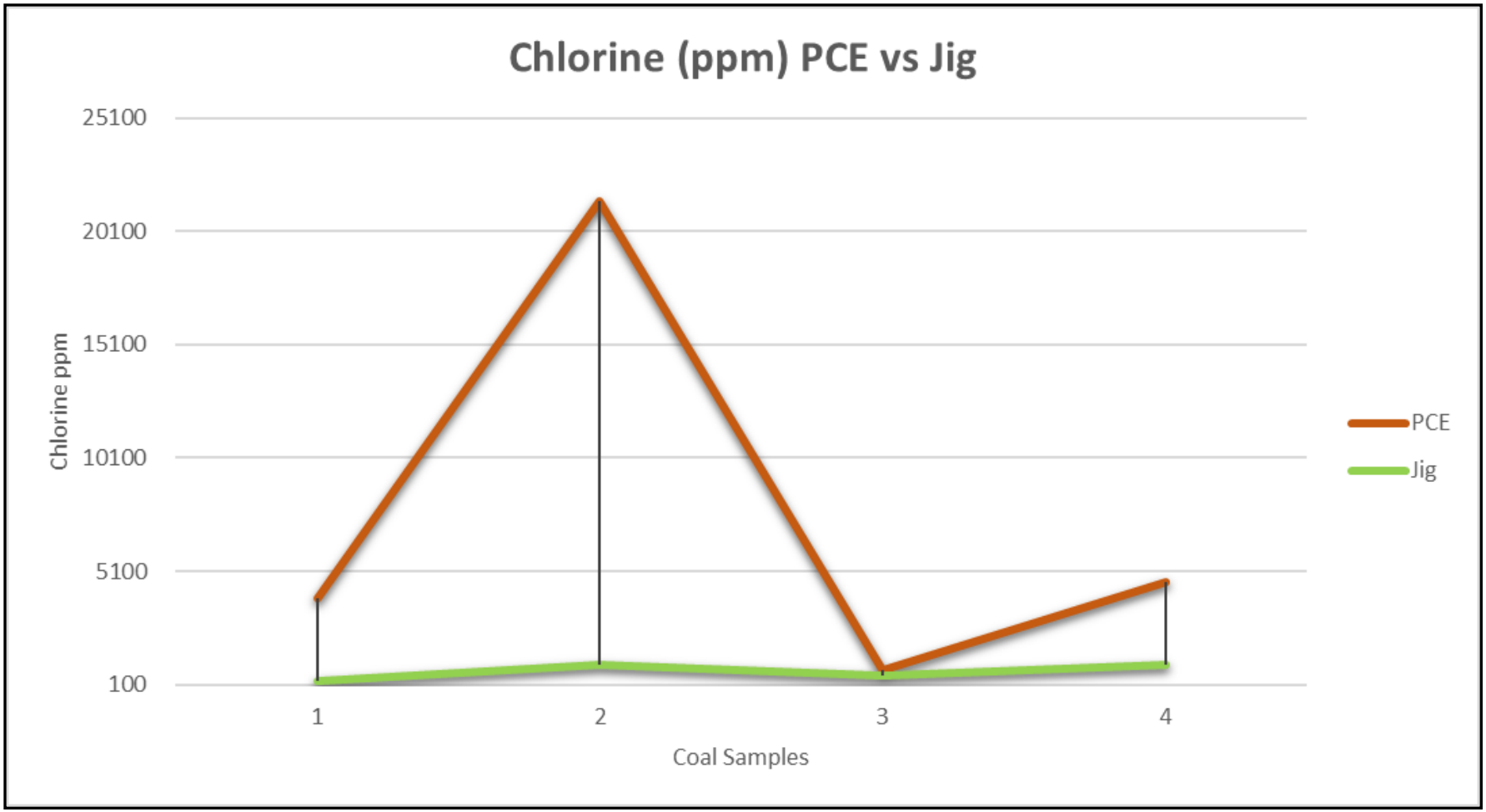
COAL PROXIMATE COMPARISONS

Clean-coal quality	Coal A		Coal B		Coal C		Coal D	
parameter (air-dried basis)	FS	JIG	FS	JIG	FS	JIG	FS	JIG
Moisture (%)	0.99	0.97	2.15	0.56	0.50	0.26	1.05	0.90
Ash (%)	5.74	5.88	8.54	9.70	8.42	8.35	10.95	10.85
Volatile matter (%)	31.76	31.95	23.19	23.52	24.41	24.96	22.14	22.35
Fixed carbon (%)	61.51	61.20	66.12	66.22	66.67	66.43	65.86	65.90

COAL CHEMISTRY AND PHYSICALS

Clean-coal quality parameter (air-dried basis)	Coal A		Coal B		Coal C		Coal D	
	FS	JIG	FS	JIG	FS	JIG	FS	JIG
Sulphur (%)	0.46	0.51	0.41	0.42	0.55	0.56	0.30	0.31
Calorific value (cal/g)	7955	7971	7750	7763	7874	7864	7496	7487
Chlorine (ppm)	3906	271	21450	949	733	472	4600	962
Fluorine (ppm)	224	225	118	115	92	134	93	93
Mercury (ppb)	32	24	38	31	86	85	53	55
Hardgrove grindability index	87	82	147	118	81	80	79	78
Specific gravity (sg)	1.30	1.31	1.37	1.36	1.35	1.34	1.39	1.37

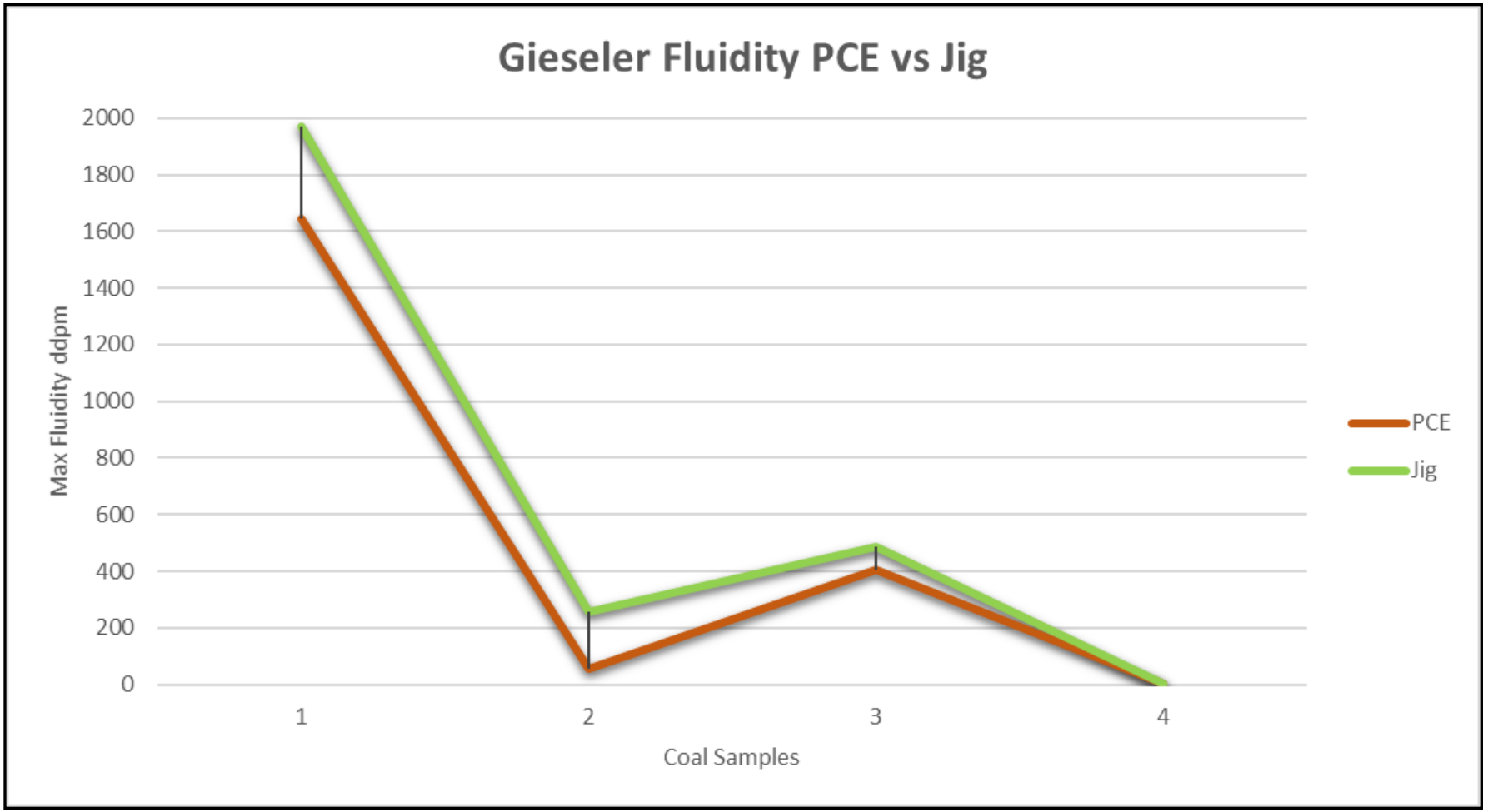
CHLORINE RESULTS



THERMAL RHEOLOGY

Clean-coal quality parameter (air-dried basis)	Coal A		Coal B		Coal C		Coal D	
	FS	JIG	FS	JIG	FS	JIG	FS	JIG
Free swelling index	8.5	8.5	7.75	7.5	8.5	8.5	3.5	4.5
Max fluidity (ddpm)	1647	1972	57	257	405	488	2	4
Ruhr dilatation:								
% contraction	24	27	24	21	23	25	20	16
% dilatation	111	139	3	33	93	103	-	-
% total dilatation	135	166	27	54	116	128	-	-
% SD 2.5	120	154	2	29	86	96	-	-
Caking index (G)	96	98	78	82	93	92	35	46
Sapozhnikov Y index	17.0	17.5	14.5	15.0	18.5	18.0	6.5	7.0

RHEOLOGY RESULTS



CLEAN COAL PETROGRAPHY

Clean-coal quality parameter (air-dried basis)	Coal A		Coal B		Coal C		Coal D	
	FS	JIG	FS	JIG	FS	JIG	FS	JIG
Petrography:								
Vitrinite reflectance (mean max)	0.94	0.94	1.22	1.23	1.20	1.21	1.17	1.17
Maceral analysis:								
Vitrinite (%)	68.7	64	38	46.3	60.6	62.9	41.3	43.4
Semifusinite (%)	9.7	12	24.1	18	13.9	12.8	21.6	20.9
Total reactives (%)	84.4	82.8	62.9	65.1	75.3	76.1	63.5	65.1
Inerts:								
Semifusinite (%)	9.7	12	24.1	18	13.9	12.8	21.6	20.9
Total inerts (%)	15.6	17.2	37.1	34.9	24.7	23.9	36.5	34.9

CONCLUSIONS – FOR F/S VS JIG

1. Coal chemical analysis were very similar for all 4 samples: Ash, Sulfur, Volatile Matter, Fixed Carbon, FSI, ash Base/Acid Ratio
2. Petrographic results very similar
3. The Chlorine content of the F/S samples was higher (one very much higher!)

RESULTS – ROBEN JIG STUDY

Samples from Float/Sink and Jig separations were analyzed and compared for:

1. **Density separation characteristics**
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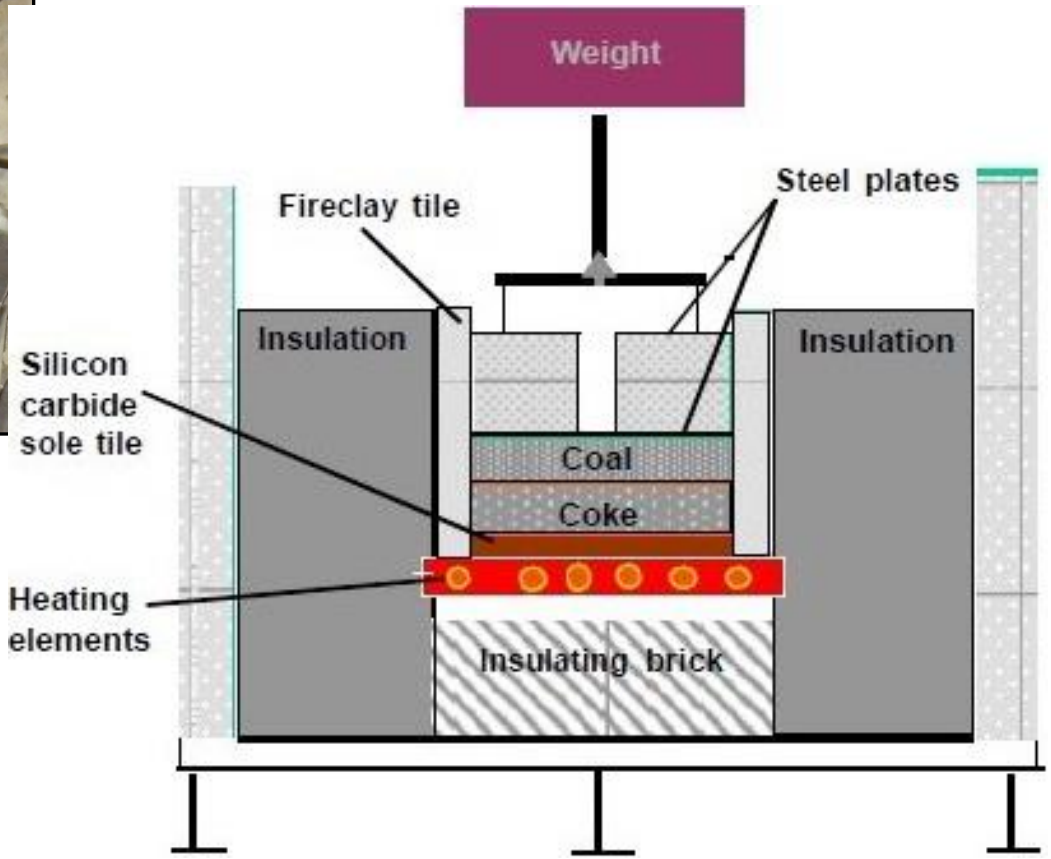
3. **Clean coal composite coking properties**

CanmetENERGY SOLE-HEATED OVEN



SOLE-HEATED OVEN COKE

SOLE-HEATED COKE – CHEMISTRY/PHYSICAL

Description	Unit	Coal A		Coal B		Coal C		Coal D	
		Float-sink	Jig	Float-sink	Jig	Float-sink	Jig	Float-sink	Jig
Index		26152	26153	26164	26165	26209	26210	26240	26241
Coke analyses:									
Proximate analysis (db)									
Ash	%	7.88	8.10	10.89	10.90	10.55	10.40	13.81	13.55
Volatile matter	%	0.71	1.08	0.70	0.86	0.65	0.69	1.07	0.81
Fixed carbon	%	91.41	90.82	88.40	88.24	88.80	88.90	85.12	85.64
Sulphur	%	0.38	0.41	0.30	0.31	0.46	0.45	0.24	0.26
Coke properties:									
Apparent specific gravity		1.051	1.009	1.085	1.096	1.018	1.005	1.157	1.145

SOLE-HEATED COKE – MICROSCOPIC ANALYSIS

Description	Unit	Coal A		Coal B		Coal C		Coal D	
		Float-sink	Jig	Float-sink	Jig	Float-sink	Jig	Float-sink	Jig
Coke textural analysis:									
Reactive textures									
Isotropic	%	0.8	1.4	1.6	0.7	1.3	1.2	1.9	1.4
Very fine mosaic	%	1.2	2.4	0.0	0.0	0.6	0.2	0.5	1.3
Fine mosaic	%	13.3	12.2	0.0	0.3	1.0	0.8	1.3	1.4
Medium mosaic	%	58.8	57.7	2.5	3.1	23.4	13.1	20.5	21.7
Coarse mosaic	%	2.8	1.3	2.6	3.1	8.2	4.1	10.0	6.0
Elongated fine flow	%	6.9	12.8	6.6	4.5	29.3	24.7	8.4	7.2
Elongated medium flow	%	0.4	0.4	50.3	52.1	14.9	30.0	8.0	13.3
Elongated coarse flow	%	0.0	0.0	5.1	3.5	0.7	1.9	2.2	2.6
Domain flat flow	%	0.0	0.0	0.2	0.0	0.1	0.3	0.3	0.6
Domain undulating	%	0.0	0.0	0.8	0.3	0.9	0.1	0.7	1.2
Domain ribbon	%	0.0	0.0	0.0	0.0	0.3	0.0	0.5	0.0
Inert textures									
Fusinite	%	0.2	0.5	1.7	0.8	1.1	1.2	1.3	1.9
Semifusinite	%	15.4	11.1	26.7	31.2	17.5	21.3	43.4	39.8
Unidentifed inerts	%	0.2	0.1	1.9	0.4	0.5	0.9	0.9	1.0
Altered vitrinite	%	0.0	0.0	0.0	0.0	0.2	0.1	0.1	0.6
Total mosaic	%	76.9	75.0	6.7	7.2	34.5	19.4	34.2	31.8
Total flows	%	7.3	13.2	62.0	60.1	44.9	56.6	18.6	23.1
Total domains	%	0.0	0.0	1.0	0.3	1.3	0.4	1.5	1.8
Total coke inerts	%	15.8	11.7	30.3	32.4	19.3	23.5	45.7	43.3
Coke mosaic size index		2.11	2.14	3.07	3.01	2.72	2.85	2.66	2.65
Estimated Ro of coal	%	1.13	1.14	1.42	1.42	1.32	1.37	1.27	1.27

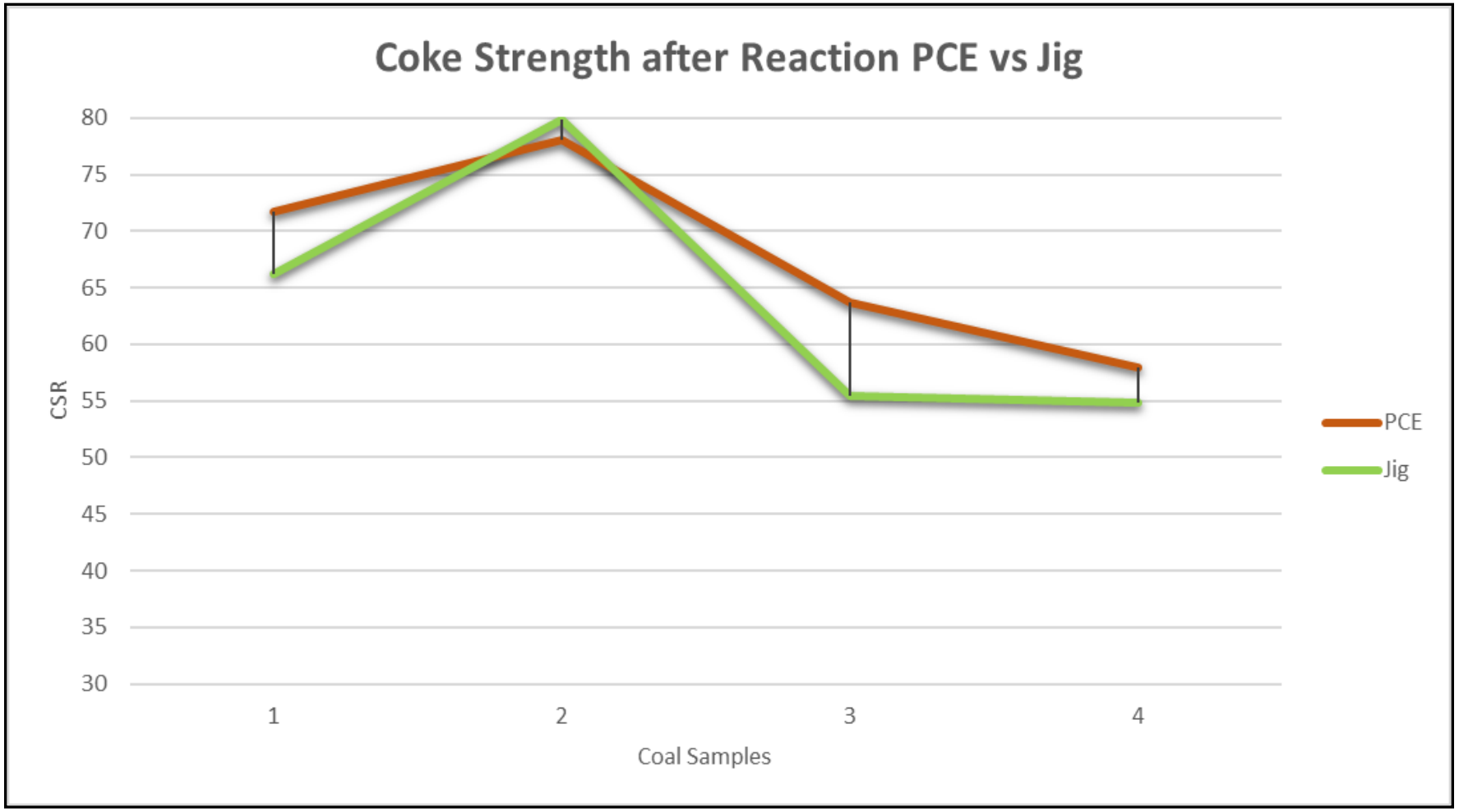
SOLE-HEATED OVEN RESULTS

Description	Units	Coal A		Coal B		Coal C		Coal D	
		Float-sink	Jig	Float-sink	Jig	Float-sink	Jig	Float-sink	Jig
Expansion/contraction value (%)		-20.8	-20.5	-22.3	-17.9	-6.6	-9.4	-19.8	-17.2

SOLE-HEATED COKE – REACTIVITY/CSR

Description	Unit	Coal A		Coal B		Coal C		Coal D	
		Float-sink	Jig	Float-sink	Jig	Float-sink	Jig	Float-sink	Jig
Coke Strength after reaction (CSR)		71.7	66.2	78.1	79.9	63.7	55.5	57.9	54.8
Coke reactivity index (CRI)		17.7	19.2	19.6	17.0	22.7	25.7	33.0	28.6

SOLE HEATED OVEN COKE CSR RESULTS



CSR RESULTS – JIG vs F/S

- **Roben Jig CSRs were expected to be higher than the F/S treated coal since PCE has been know to decrease the CSR of exposed coals.**

CSR RESULTS – JIG vs F/S

- **In addition, the coal base/acid ratio or the total alkaline ash content of the coals were on average the same for the jig vs the F/S samples – implying both coals could have the same CSR, barring other factors.**
- **These results suggest some other factor is impacting the jig clean coal CSR.**

WHY POORER CSR FOR JIG vs F/S?

The Jig is an imperfect separator and higher ash particles can be misplaced to the clean coal – ash composition may be the difference.

There may be tiny rock fragments mixed with the clean coal that results in weaker than expected coke.

WHY POORER CSR FOR JIG vs F/S?

From coke quality perspective, need to fine tune the Jig methodology

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1. 2018 Funding has been received from CCRA and Geoscience BC with support from both Birtley Coal Testing and Teck

2. One coal will be used to fine-tune the Roben Jig methodology – Teck seam sample.

FURTHER WORK – 2018 Update

3. Future work could also include:

- **Test a larger capacity jig**
- **Test other liquids**
- **Determine what happens when coal and perchloroethylene come into contact**

ACKNOWLEDGEMENTS

The authors would like to acknowledge the funding and support for this study from CanmetENERGY, CCRA, Geoscience BC, Glencore Canada, Birtley Coal Testing and Teck Resources.

Thank you for you attention

Questions?