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Centre canadien de la technologie des minéraux et de l'énergie

Energy Research Laboratories

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UTILIZATION OF PIPELINEABLE COAL-WATER SLURRIES FOR COMBUSTION

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H. Whaley, K.V. Thambimuthu and J.K. Wong

CPUB

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ABSTRACT

Higher rank coals perform well as transportation coal-water slurries. They require less additives to stabilize and disperse the coal particles in the slurry. However, from the combustion viewpoint, the higher rank coals are more difficult to ignite and burn. Conversely lower rank coals with higher volatility make good combustible coal-water fuel. However, they perform less well as transportation fuels due to their lower thermal loading (i.e. thermal content per unit mass of material being conveyed) and the fact that they require more additives to produce the desired rheological properties.

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UTILISATION EN COMBUSTION
DE SCHLAMMS DE CHARBON-EAU TRANSPORTABLES PAR PIPELINE

par

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RÉSUMÉ

Les charbons de rang élevé dans les schlamms de charbon-eau ont un bon comportement au transport. Pour se stabiliser et se disperser, ces particules de charbon contenues dans les schlamms nécessitent moins d'additifs. Cependant, en matière de combustion, les charbons de rang élevé sont plus difficiles à s'enflammer et à brûler. Par contre les charbons de rang bas à volatilité plus élevée font de bons combustibles de charbon-eau. Leur comportement au transport est toutefois moindre en raison de leur chargement thermique (c'est-à-dire la teneur thermique par unité de masse de matériau tranporté) plus faible et du fait qu'ils nécessitent plus d'additifs pour produire les propriétés rhéologiques souhaitées.

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INTRODUCTION

The use of liquids or fluids to transport coal through pipelines is not new, nor is the application of fuels such as coal-liquids to combustion systems. However, it does appear that there are a number of conflicting areas which preclude slurries from performing well as a transportation liquid and as a coal-water fuel (CWF). Many factors influence the flow of coal-water slurry inside a pipe, either over long distances or simply from the storage tank to the burner. In order to get water and coal particles into a state in which they will pump readily, over long and short distances, store in fuel tanks, atomize well and burn completely in a variety of industrial combustion systems may represent an impossible task. It is intended in this short report to examine those coal properties which lead to good combustion performance as well as those which will give a good transportable slurry and to indicate where these might be incompatible and where it may be possible to arrive at an optimum situation.

COAL SELECTION

The best choice for a pipelineable slurry is a high-rank bituminous coal since it has the highest thermal content, i.e., calorific value, hence maximizes the energy transported per unit weight. It is also clear that high-rank coals require much less additives to stabilize and disperse the coal particles in the slurry due to their low O/C ratio, which relates to surface moisture absorption and porosity as noted below. However, from the combustion viewpoint, the higher rank coals are more difficult to ignite and burn due to low volatility and a high C/H ratio (see Appendix A). The devolatilization products of high-rank coals do not generally tend to support ignition phenomena.

The skeletal structure and apparent densities of candidate coals should be measured mainly to determine porosity. The porosity usually affects the distribution of surface and pore moisture in the CWF, see Fig. 1 and 2, (1).

A higher porosity, and hence a greater concentration of pore moisture would reduce the solids loading and ignition stability of the CWF. Because porosity is often linked to a tendency for increased oxidation, the oxygen content may also serve as an indicator. In addition, the oxygen content increases the amount of chemical additive required to produce a CWF with an acceptable rheology. In most cases, a high oxygen content will also reduce the calorific value of the coal volatiles that are so crucial to the ignition stability of the fuel.

Since it is difficult to delineate natural coals by rank alone, coal selection may be achieved by an evaluation of the following parameters:

a) fixed carbon, hydrogen and carbon to hydrogen ratio,
b) combustible, volatile content,
c) composition and calorific value of the volatiles evolved in an inert atmosphere,
d) higher heating value,
e) inert maceral content, i.e., stable forms of carbon,
f) oxygen content,
g) free swelling index

Coals deemed appropriate in terms of the above criteria and other properties described below should then be evaluated in pilot-scale tests to assess their combustion performance as a generic CWF.

CWF COMBUSTION PROPERTIES

This section describes the fuel properties required for good combustion and minimal ash fouling and erosion in boilers. It does not attempt to evaluate the fuel rheological properties necessary for efficient handling prior to its combustion or for pipelining applications. Fuel atomization behaviour will be discussed when relevant to fuel combustion.

IGNITION STABILITY

Ignition stability of the fuel is the most critical requirement for its efficient combustion in a boiler. For CWF, the moisture content and coal volatility are the most significant fuel selection parameters for good ignition stability. The fuel moisture delays ignition by retarding droplet drying and heating, whereas the coal volatile content and composition determine the onset of fuel ignition and flame propagation at the burner mouth.

Typically, an increased moisture content in the CWF usually dictates a higher volatile content coal and higher calorific value gaseous products (from devolatilization) for stable ignition. For conventional 70% solids CWF, intermediate-rank, bituminous coals with a volatile content >30 wt % are necessary for the stable ignition of CWF. These requirements also vary somewhat with the fuel spray quality, and burner design parameters such as length to diameter ratio of the quarl. Due to the absence of a reliable data base on high moisture generic CWF, it is necessary to evaluate ignition behaviour in pilot-scale combustion tests.

CARBON BURNOUT

The overall fuel carbon conversion efficiency is determined by gas temperature, excess oxygen and residence time available for char burnout in the boiler. For CWF, the moisture reduces the flame temperatures by 100 to 200°C, and this has a great bearing on char burnout. For retrofit applications in an oil-designed boiler, the higher gas volume required for coal combustion and the smaller boiler volume reduce the char residence time. With these negative effects for which little can be done, it is important to select coals with less stable forms of carbon. This selection may be achieved by a petrographic evaluation of candidate coals.

Besides the above parameters, carbon burnout in CWF combustion is also affected by the morphology of the char and ash particles. A recent study has shown that coarse char cenospheres formed in the CWF flame envelope contribute significantly to the unburnt carbon emissions from the boiler (2). This effect was caused by entrainment of the low apparent density chars. It was found that the carbon emissions from the boiler could be improved by coal selection to reduce the free swelling index and by improved fuel atomization (2).

ASH PROPERTIES

The sintering temperatures (or ash fusion temperatures) in an oxidizing and reducing environment are important in determining the slagging and fouling propensity of the ash. High sintering temperatures minimize the tendency to slag on furnace panels, and in forming hard sintered deposits on heat transfer tubes that may be difficult to remove by soot blowing. The sintering temperatures are often determined by the chemical composition of the ash, and increase with the acid oxide ratio, i.e., the fraction of SiO_2/Al_2O_3 and decrease with the base percentage, i.e., the total fraction of Fe_2O_3, CaO, MgO, Na_2O and K_2O. Usually, a minimal tendency for ash slagging and fouling established in a pulverized coal firing environment would be an adequate criterion for safe application as a CWF. However, due to the fundamentally different morphology of the CWF ash (2), pilot-scale combustion tests to evaluate the ash properties are recommended. Where practical, the fuel ash content should be minimized to reduce the risk of erosion damage in the boiler, for improved heat transfer and reduced frequency of operation of soot blowers.

COAL ASSESSMENT

Tables 1 and 2 show the proximate and ultimate analyses of coals which have been formulated into CWF either for pipelining or combustion applications. For comparative purposes the parent coal feedstock for the CBDC Carbogel is also given, since considerable boiler operating experience in Canada exists with this fuel. Table 3 shows the C/H ratio and also the fuel ratio (FC/VM) of the various coals. Coals A and B were selected primarily for transportation purposes and are both from Western Canada. Coals C, D and E were selected for combustion as CWF; C and D are from South America and E is an Eastern US coal. Coals C and A have serious drawbacks due to low calorific value and high oxygen content. In terms of pipelining it is debatable whether either could be considered, since the amount of thermal content per unit weight is much lower due to the high oxidation level. On the other hand coal B is a poor combustion candidate because of its low volatile content, and the volatiles being of high O_2 content means poor ignition stability also.

From the combustion and transportation viewpoints the coals can be provisionally ranked as follows:

	Combustion	Pipeline transportation
1)	D	B
2)	CBDC	CBDC
3)	A	E
4)	E	D
5)	C	C
6)	B	A

Additional analysis involving detailed petrographic examination, porosity free swelling index and composition volatiles are required as are combustion evaluations in pilot-scale equipment and pipeline loop testing before a definite conclusion can be reached.

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Table 1 - Proximate analysis of coals (dry)

Coal type	Ash %	VM %	Fixed carbon %	HHV MJ/kg
A	8.33	34.34	57.33	28.97
B	7.69	28.73	63.58	33.07
C	9.87	38.63	51.50	27.07
D	7.59	36.51	55.90	30.82
E	6.97	37.05	55.98	31.92
CBDC	6.11	37.29	56.61	31.61

Table 2 - Ultimate analysis of coals

Coal type	Carbon %	Hydrogen %	Nitrogen %	Sulphur %	Oxygen %
A	72.10	4.52	1.08	0.26	13.71
B	81.21	4.62	1.17	0.20	5.11
C	65.56	4.87	1.68	1.40	6.29
D	74.77	5.79	1.77	0.77	4.45
E	77.42	5.26	1.82	0.98	5.13
CBDC	76.17	5.90	1.71	2.60	3.27

Table 3 - Miscellaneous coal evaluation parameters

Coal type	A	B	C	D	E	CBDC
C/H ratio	15.95	17.58	13.46	12.91	14.72	12.91
Fuel ratio	1.67	2.21	1.33	1.53	1.51	1.52

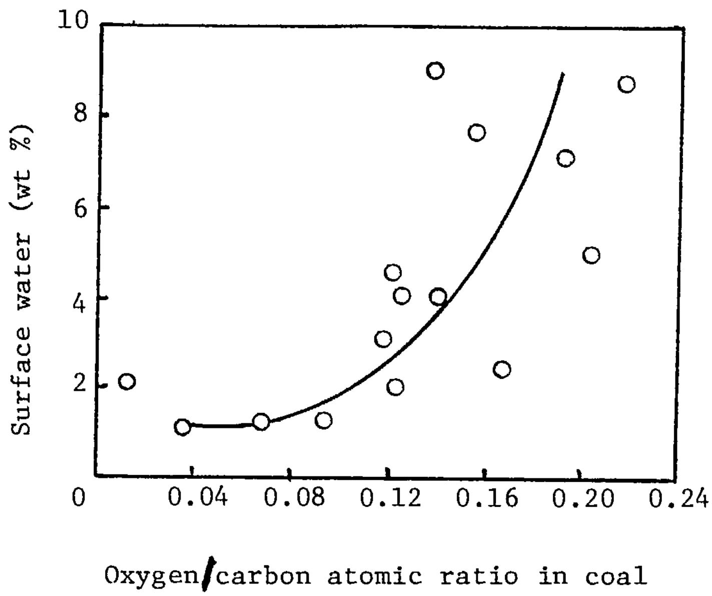

Fig. 1 - Relationship between the O/C atomic ratio and the amount of surface moisture on coal particles

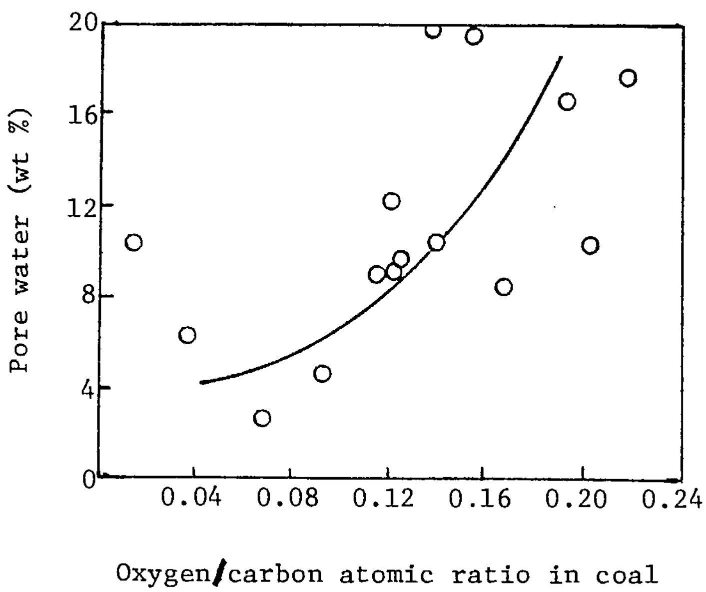

Fig. 2 - Relationship between the O/C atomic ratio and the amount of water absorbed within coal particle pores

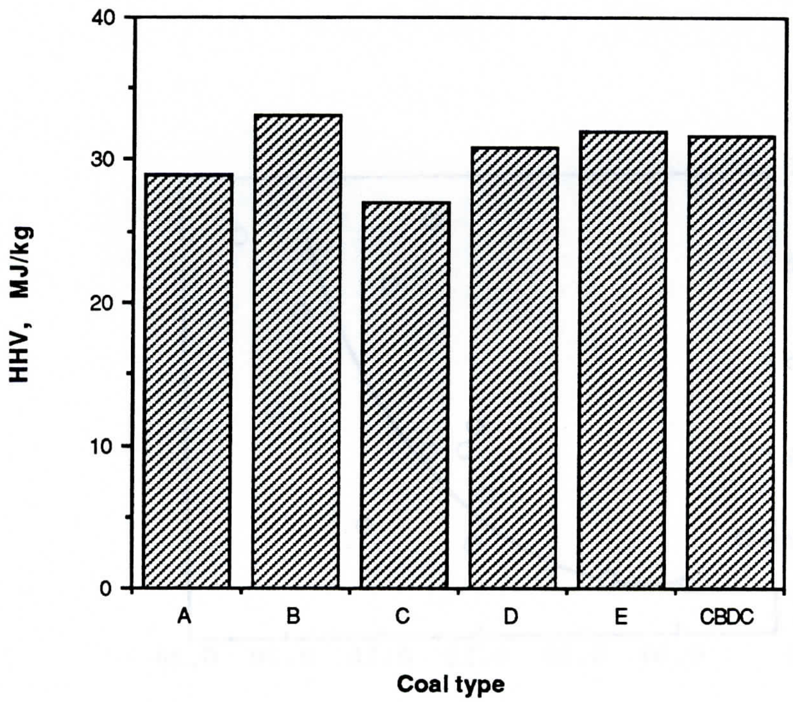

Fig. 3 - Coal heating value

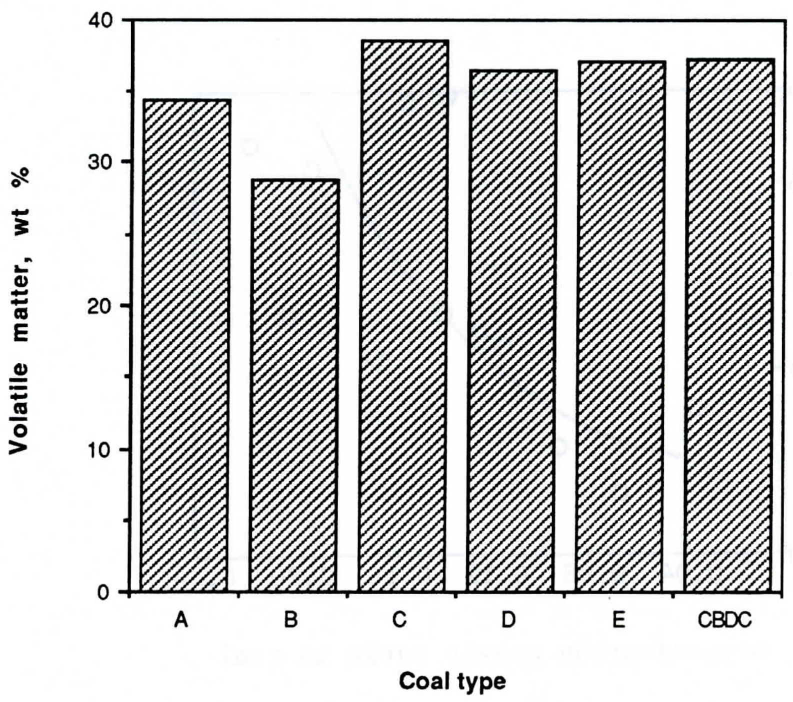

Fig. 4 - Coal volatiles

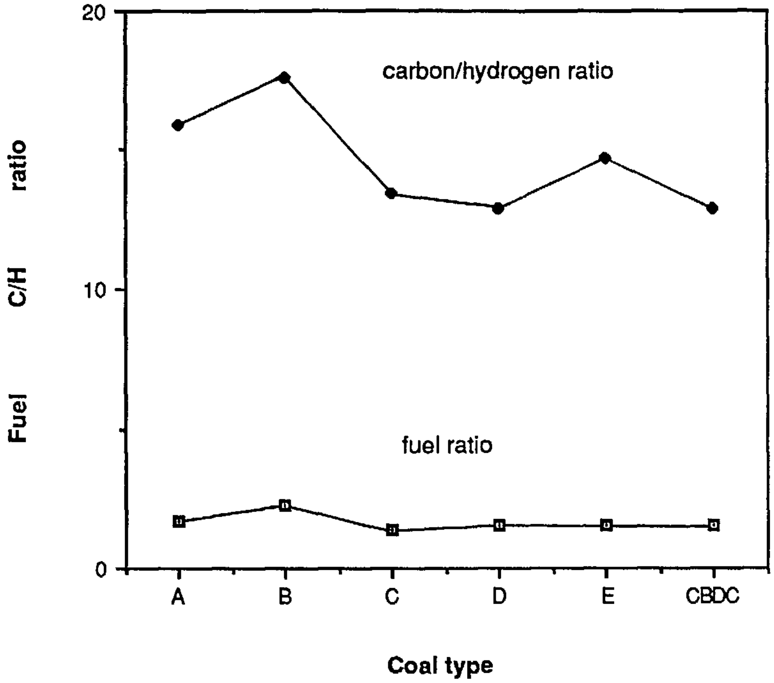

Fig. 5 - Coal fuel and C/H ratio

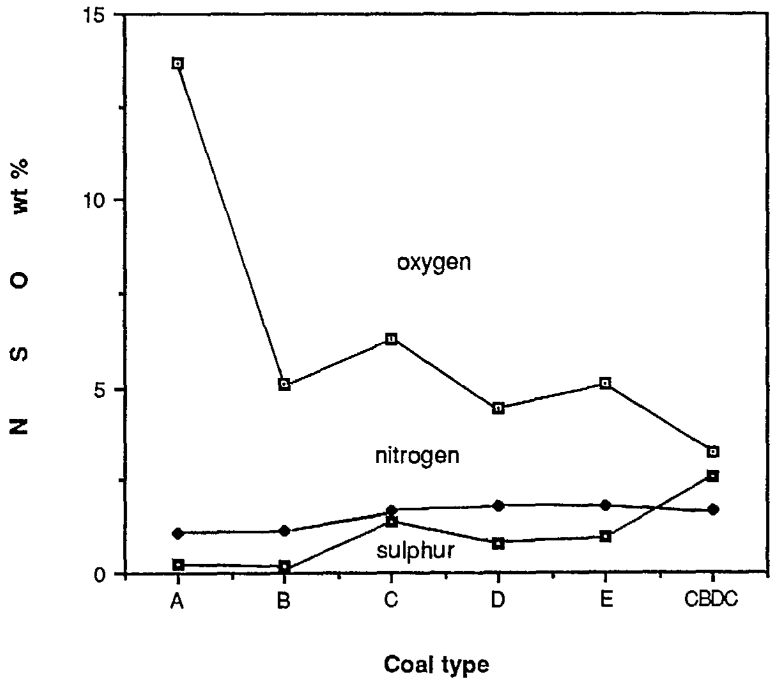

Fig. 6 - Coal N, S, O

APPENDIX A

CLASSIFICATION OF COAL BY RANK

Canada uses the systems and procedures of the American Society for Testing and Materials (ASTM) for sampling, analysing and classifying coals by ranks, as detailed in the Annual Book of ASTM Standards. Basically coals are ranked according to their degree of metamorphism, or progressive alteration, in the natural series from lignite to anthracite.

Classification in the ASTM system is a function of fixed carbon content and calorific value calculated on the mineral-matter-free basis. The high rank coals are classed according to calorific value on the moist basis. The agglomerating characteristics of coals (i.e. their binding and/or swelling qualities when heated in the absence of oxygen) are used to differentiate between certain adjacent groups in the ranking.

VM%*	O_2	FC%*	Class	Group	Calorific value** Btu/lb	Calorific value** MJ/kg
2	Increases ↓	98	Anthracite(1)	Meta Anthracite		
8		92		Anthracite		
14		86		Semianthracite		
22		78	Bituminous(2)	Low-Volatile Bituminous		
31		69		Medium-Volatile Bituminous		
				High-Volatile A Bituminous	14000	32.6
				High-Volatile B Bituminous	13000	30.2
				High-Volatile C Bituminous		
			Subbituminous(4)	Subbituminous A(3)	11500	26.7
				Subbituminous B	10500	24.4
				Subbituminous C	9500	22.1
			Lignite(4)	Lignite A	8300	19.3
				Lignite B	6300	14.7

* Dry, mineral-matter-free basis
** Moist, mineral-matter-free basis
(1) Non-agglomerating; if agglomerating classified as low volatile bituminous
(2) Commonly agglomerating
(3) If agglomerating classified as high volatile C bituminous
(4) Non agglomerating
VM: Volatile matter
FC: Fixed carbon

Source: Energy, Mines and Resources Canada CANMET Report 83-20E