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WASHABILITY CHARACTERISTICS OF BRITISH COLUMBIA COALS

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KEYWORDS: Coal geology, coal quality, washability, sink-and-float tests, degree of washing, washability number, mineral matter, lithotypes.

INTRODUCTION

As part of the British Columbia Geological Survey Branch's Coal Quality Project, washability characteristics of coals from all parts of the province are being compiled (*see* manuscript 5-1, this volume, for descriptions of other ongoing coal quality studies). The interpretation of these data will provide insight into the geological basis of washability, and hopefully provide practical information which will aid in the assessment and exploitation of our coal resources.

Coals described in this paper are from the Peace River coalfield of northeastern British Columbia. They occur in the Gates Formation of the Lower Cretaceous Fort St. John Group.

BACKGROUND

Washability is an essential factor in any coal seam or property evaluation. Washability provides practical information on those characteristics of coal that affect recovery, beneficiation and final use. It often determines the economic feasibility of a coal deposit.

In an assessment of any coal it is necessary to categorize it according to its rank, type and grade. Rank and type are related to the organic matter composing the coal, whereas grade refers to the quality of coal in terms of size and ash content. Washability analyses are carried out to determine how much coal, of what quality (in terms of grade), can be produced at a given specific gravity, or what the separation gravity should be to achieve desired coal quality.

Washability characteristics of a coal provide information to the design of the coal preparation processes. Most of the coal upgrading processes rely on gravity separation methods. This is because there is a significant difference in specific gravity between coal organic material (at any given rank of coal) and its associated mineral matter (specific gravity for macerals is 1.1 to 1.45, and for mineral matter is 2.0 to 5.0). Depending on the association between the coal macerals and mineral matter, the process of separating high-ash particles from low-ash particles may be easy or difficult. In general, the density of unliberated coal particles is proportional to the content of mineral matter.

Washability curves are constructed from sink-and-float analysis of a representative coal sample, carried out under ideal conditions, and are characterized by ash content and yield at a given density of separation. They are the best possible prediction of theoretical results for the gravity-based coal preparation processes.

MINERAL MATTER

The type and mode of occurrence of mineral matter in coal is particularly important to washability. The amount of inorganic matter associated with macerals has direct influence on the density of composite coal particles, while the type of minerals, and their association with the coal macerals, will have direct impact on the ease of gravity separation.

The mineral matter in coal occurs as inorganic matter from the original plant material, detrital particles and authigenic deposits associated with the first stage of coalification, or as deposits associated with the second stage of coalification after consolidation of the coal (Stach *et al.*, 1982, pages 153-171). The minerals which have formed together with the coal, or authigenically, are referred to as syngenetic, whereas the minerals formed later are commonly called epigenetic. The syngenetic minerals tend to be fine grained and are intimately intergrown with the coal, whereas epigenetic minerals occur in the cracks and fissures of macerals.

Minerals deposited in cleats and fissures are easier to remove by means of crushing and washing operations. Liberation of this type of mineral matter is relatively easy and results in good density separation between clean coal and shale particles, with very small amounts of middlings.

Syngenetic minerals occur either as finely disseminated mineral particles or in the form of larger species intimately intergrown with coal macerals. In western Canadian coals, pyrite occurs predominately in the latter form, whereas

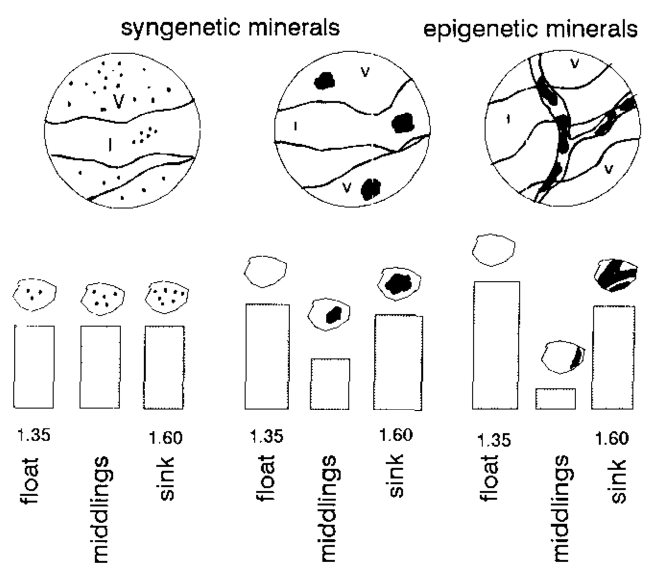

Figure 5-2-1. Types of mineral matter association and its effect on the washability. Adapted from Falcon and Falcon (1983).

TABLE 5-2-1
COAL INORGANIC IMPURITIES

Type	Origin	Examples	Physical Separation
Strongly chemically bonded elements	From coal-forming organic tissue material	Organic sulphur, nitrogen	No
Adsorbed and weakly bonded groups	Ash-forming components in pure water, adsorbed on the coal surface	Various salts	Very limited
Mineral matter			
a. Epiclastic	Minerals washed or blown into the sea during its formation	Clays, quartz	Partly separable by physical methods
b. Syngenetic	Incorporated into coal from the very earliest peat-accumulation stage	Pyrite, siderite, some clay minerals	Intimately intergrown with coal macerals
c. Epigenetic	Stage subsequent to syngenetic; migration of the mineral-forming solutions through coal fractures	Carbonates, pyrite, kaolinite	Vein type mineralization; epigenetic minerals concentrated along cleats, preferentially exposed during breakage; separable by physical methods

clays are found in both forms. Coals with fine syngenetic minerals will produce relatively equal amounts of light-density clean coal, middlings and high-density rejects when subjected to gravity separation. In this case liberation of the mineral matter can only be achieved by fine grinding.

Coarser syngenetic minerals display much better washability characteristics. Better washing characteristics are mainly due to greater degree of liberation of coarse minerals from coal. Figure 5-2-1 shows the type of mineral association and its effect on the washability. Table 5-2-1 presents the types of mineral phases in coal and their relation to physical separation.

Lithotypes

Another factor which contributes to the washability is the lithotype composition of the seam. Lithotypes are defined as the macroscopic bands of different types of coal in a given seam (ICCP Handbook of Coal Petrology, 1963; Stach *et al.*, 1982, page 376). The formation of various lithotypes is mainly a result of diverse enviromental conditions at the time of deposition and subsequently differing rates of subsidence of a swamp. The composition of lithotypes is strongly dependent on the maceral make-up as well as their association with different proportions of mineral matter (*e.g.* Diessel, 1965). It is also known that different lithotypes are characterized by different density and hardness (Falcon and Falcon, 1987; Hower, 1988; Hower and Lineberry 1988; Hower *et al.*, 1987; Hsiech, 1976 in Hower *et al.*, 1987), the latter measured as the Hardgrove Grindability Index (HGI). It is expected that lithotype composition for a given rank of coal will influence the process of liberation of minerals as well as the density separation and washability characteristics.

Among lithotypes from the same coal, durain is the toughest and the hardest and would concentrate in the largest size fractions, whereas vitrain tends to be brittle and reports to the fines. Fusain is the most friable and concentrates in the dust, unless it is mineralized, in which case it will report to the coarse coal. Clarain is more resistant than vitrain and its hardness will depend on the thickness of liptinite bands or inherent mineral matter (Hower, 1988) For any sized run-of-mine or bulk composite sample, different lithotypes will be found in different size fractions (Stach *et al.*, 1982, page 415). Since the washability tests are performed on different sizes, it is important to realize that washability will be controlled to some extent by the lithology of the seam.

Lithotypes also vary in density. Vitrain has the lowest density, unless contaminated with mineral matter, fusain is the next lightest, while clarain and durain, depending on their maceral and mineral composition, are the heaviest (Falcon and Falcon, 1987). Size fractions containing an abundance of one or the other lithotype will tend to have different washing characteristics as the washability depends on density. Figure 5-2-2 illustrates the effect of the microlithotype composition on washing characteristics (Falcon and Falcon, 1983). Microlithotypes form bands of lithotypes on the macroscopic scale.

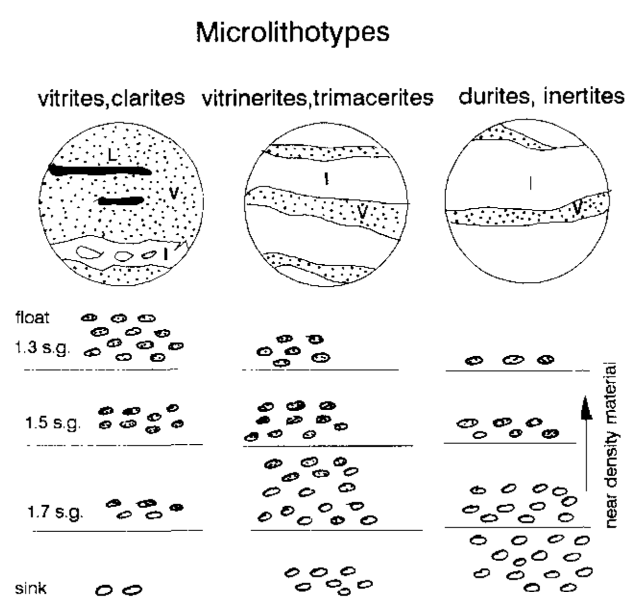

Figure 5-2-2. The effect of the microlithotype composition on the washability. Adapted from Falcon and Falcon (1983).

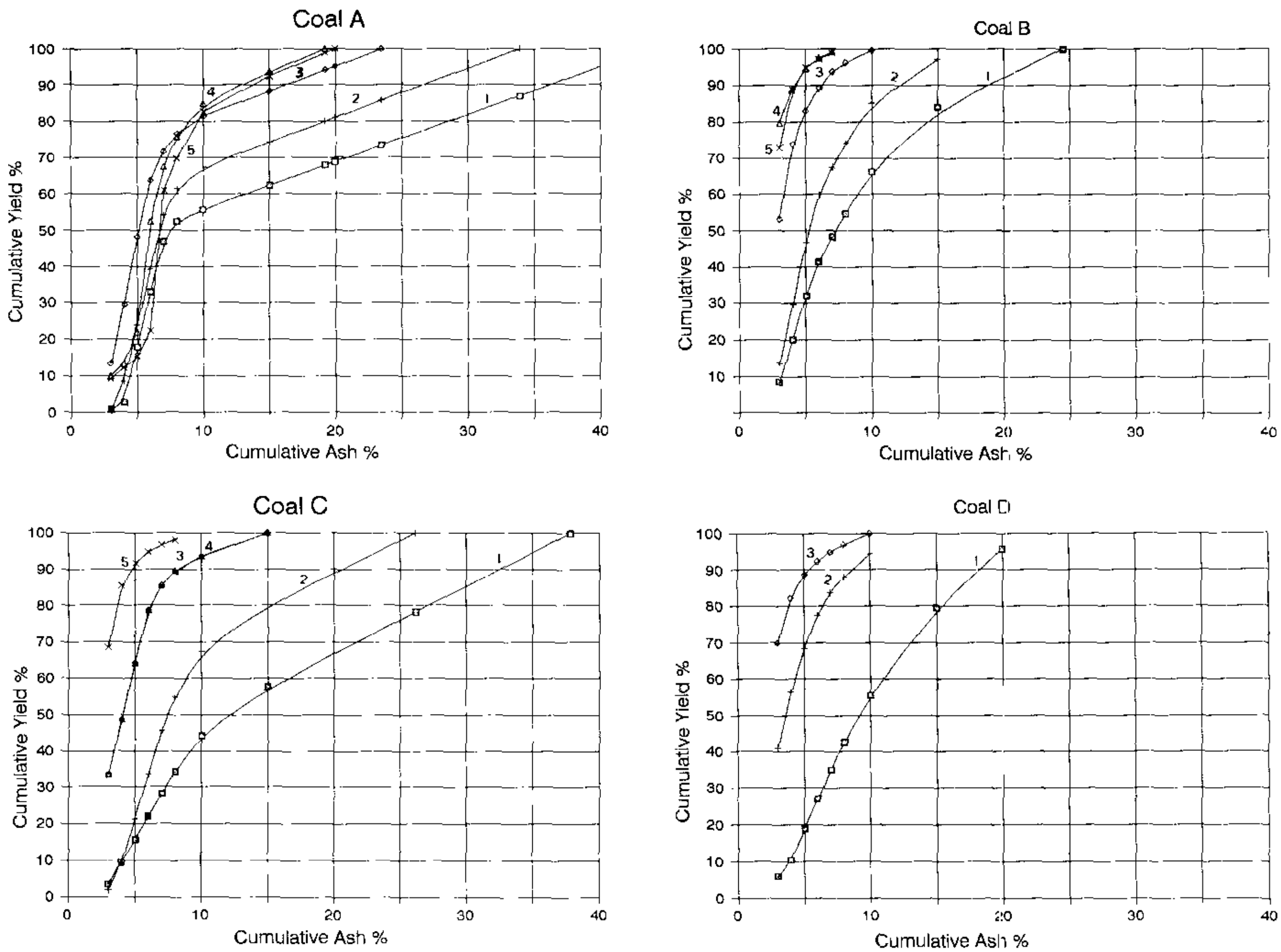

Figure 5-2-3. Plots of cumulative ash per cent versus cumulative yield per cent for different size fractions from four different British Columbia coals, referred to as A, B, C and D. For coals A, B and C size fraction 1 = 50-19 millimetres, 2 = 19-6.3 millimetres, 3 = 6.3-0.6 millimetres, 4 = 0.6 – 0.3, and 5 = 0.3-0.15 millimetre. For coal D size fraction 1 = 75-12.5 millimetre, 2 = 12.5-0.5 millimetres, and 3 = 0.5-0.15 millimetre.

Plots of ash in clean coal versus yield, for four different British Columbia coals, are presented in Figure 5-2-3. Washability improves as the particle size decreases. One reason for the better washing characteristics of fines is the fact that as the size is decreased, the liberation of mineral matter increases and gravity separation becomes more efficient. When the size becomes too fine, however, gravity separation itself becomes less ideal as the very fine coal or mineral (clay) particles remain suspended in the separating medium. Better washability of finer sizes can also be attributed to the increased presence of vitrain in the fines, vitrain being a natural concentration of light and low-ash vitrinite particles. It is important to be aware of the segregation of lithotypes and their liberation characteristics when comparing washability of different seams.

OBJECTIVES

The objectives of this coal quality study are to compile and study the washability characteristics of coals from different coalfields within the province.

Washability data from across the province are already available in the Ministry's collection of coal exploration assessment reports. Most of the washability results are in the form of sink-and-float analyses. These are usually carried out either on core or bulk samples representing individual seams. In accordance with ASTM D 437-84 methodology, sink-and-float tests are carried out on coarse and fine fractions separately. Frequently the analyses on the bulk samples are done on several size fractions, for more accurate predictions. All results reported in this paper are based on assessment report data.

Comparison of the washability of different coal seams and the coal regions of the province will be very useful in assessing coal quality. Coal washability data will be compiled in the form of an in-house catalogue, containing all possible washability parameters. Lithotype composition and the mineral matter studies will be merged with the washability evaluation. Publications arising out of washability data compilation and interpretation will honour the confidential nature of the data.

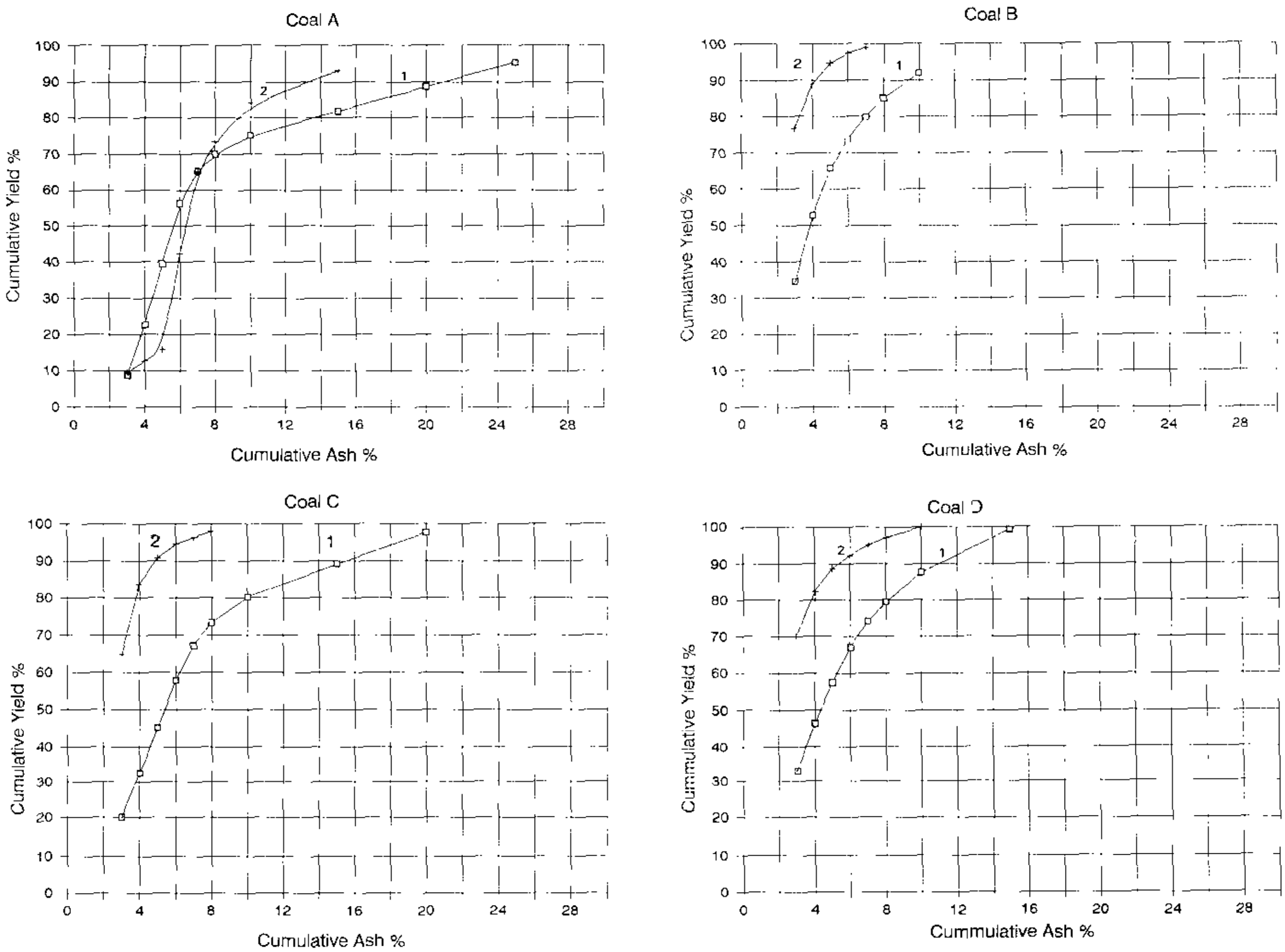

Figure 5-2-4. Cumulative clean coal curves for coarse and fine fractions from coals A, B, C and D: For coals A, B and C size fraction 1 = 50-0.6 millimetres (coarse) and 2 = 0.6-0.15 millimetre (fine). For coal D size fraction 1 = 75-0.5 millimetres (coarse) and 2 = 0.5-0.15 millimetre (fine).

At this time a number of washability curves have been constructed for four different properties from the Peace River coalfield. Each of the properties has washability data on four or five different seams. The form of the data is not uniform, as different size ranges have been used for sink-and-float analysis for different properties. For the purpose of comparison, data have to be converted into a more uniform format.

A computer program in BASIC was used to obtain washability calculations from sink-and-float tests. The set of washability curves for compiled data was plotted using in-house software.

To discuss and compare washing characteristics of different coal seams, sets of washability data for each of the samples are used. For carrying out the comparison between seams the following criteria have been applied:

- The washability data on separate size fractions have been combined into two size ranges, coarse and fine (upper limit for coarse is 150 millimetres and the lower limit is 0.5 to 0.6 millimetre, whereas the range for fines is 0.5 to 0.15 millimetre);
- Only bulk samples are studied, being the most representative of a seam.

For the comparison of different coalfields or regions the same criteria as above apply. As well, samples must be statistically representative of the region or coalfield.

METHODS

To compare washing characteristics of British Columbia coals, a number of parameters are used; yield and quality of clean coal and rejects at density of separation, near-gravity material, and densimetric distributions, together with the new washability measures such as degree of washing and washability number.

WASHABILITY CURVES

The most frequently used way of expressing concentration results is either by recovery of a valuable component, or by yield of concentrate, accompanied by the grade of the concentrate. However, a concentration process, as in the case of sink-and-float separation, is not carried out to completion, but stopped when an optimum concentration has been reached. Points given by yield and grade (ash content) at each step of density separation are used to construct washability curves.

The **primary curve** is obtained by plotting incremental ash content at each separation density versus incremental yield on the cumulative yield scale. The **clean coal curve** is obtained by plotting cumulative ash content at any given density versus cumulative yield. The **cumulative sink curve** predicts ash content of the sinks at any yield of clean coal. The fourth curve is the **cumulative density distribution,** which is plotted as density versus yield. The last curve is the curve of **near-gravity material.** It indicates the amount of material within ±0.1 specific gravity of separation. For a full discussion of washability curves refer to Leonard (1979), Laskowski and Walters (1987).

Washability data are usually obtained for several different size fractions within a coal sample, and then combined to plot the total curves for coarse and fine fractions separately.

Yield of Clean Coal and Quality of Rejects

The clean-coal curve, as derived from sink-and-float analysis, predicts the theoretical yield of clean coal product at any given ash content. For example, if the clean coal product has to meet market requirements of 10 per cent ash, then the yield of this product can be obtained from the curve. The higher the yield at the lowest ash content, the better the quality of the cleaned coal.

Figure 5-2-4 represents four different seams with different washability characteristics. Cumulative ash per cent of the floats, versus cumulative yield per cent, are plotted

TABLE 5-2-2
THE QUALITY OF CLEAN COAL AND REJECTS

Coarse

Clean Coal Ash %	CC yield %	Ash % reject	CC ash %	CC yield %	Ash % reject
Coal A				**Coal B**	
5	39.5	30.06	5	65.78	23.66
10	75.1	81.94	10	92.04	64.32
15	81.87	82.44			
Coal C				**Coal D**	
5	45.23	23.82	5	57.38	23.36
10	80.27	65.15	10	87.64	48.65
15	89.19	68.39	15	99.35	76.25

Fines

Clean Coal Ash %	CC yield %	Ash % reject	CC ash %	CC yield %	Ash % reject
Coal A				**Coal B**	
5	15.87	18.52	5	94.76	40.93
10	84.07	61.24			
15	93.22	76.06			
Coal C				**Coal D**	
5	90.88	46.06	5	88.64	44.12
			10	90.93	75.73

separately for coarse and fine fractions. If there were economic reasons for imposing strict limits on the yield of clean coal for these seams, as for instance 50 per cent yield at 5 per cent ash or 80 per cent yield at 10 per cent ash, it would be not feasible to process some of the seams.

From a theoretical point of view, reject is the coal which has higher ash content than feed sample as a result of the concentration process. The quality of the rejects is usually measured by ash content. The ash content of rejects can also be used as a measure of efficiency of the coal preparation. If, for example, the ash content of rejects is not sufficiently higher than ash of the feed sample, this is an indication of the loss of combustibles into the discard. Either the process of separation has not been efficient or liberation has not been adequate. Additional grinding would be required to liberate interlocked coal particles.

Table 5-2-2 shows the relationship between yield of clean coal at selected levels of ash and quality of rejects among four British Columbia coals.Industrial experience is that a reject ash content of about 65 per cent or more is expected for satisfactory recovery of combustibles from coal.

Predicting the Ease of Washing

The "ease" of washing is a term to describe the way in which a given coal will respond to gravity separation. The difference in density between clean-coal particles and liberated mineral matter is sufficient to achieve complete separation. In this case, there will always be an intermediate density at which complete separation of two distinctly different components will occur. The difficulty in washing will be encountered with the particles of composite nature. Density distribution within the bulk sample may give some indication of the "ease" of washing. Density distributions of four coals are presented in Figure 5-2-5. All four samples contain high amounts of low-density material (1.3-1.4 relative density), very little of middlings (1.4-1.6 relative density) and varying amounts of high-density mineral matter particles. Therefore, coals A and C will be the easiest to wash, with samples B and D being somewhat more difficult. It is also interesting to notice that coal A has less of the 1.3 specific gravity material as compared to the others. This is in very good agreement with lithotype composition of this particular seam, which is known to be low in vitrain bands.

The shape of the primary curve and the yield of the clean-coal curve are other indications of whether a coal is easy or difficult to clean. The greater the change in shape of the primary or clean-coal curve in the range of low ash content, the more difficult it is to clean the coal (*see* Figure 5-2-4). When comparing a number of washability curves, it is difficult to assess the ease of washing by just comparing the shape of the different curves. A comparison of the yields of clean coal at selected ash levels and the quality of their sinks is more appropriate. The low ash content of the sinks at low separation densities indicates the presence of middlings, but this is not quantitative information on the ease of washing (*see* Table 5-2-2).

The quantitive measure of the ease of washing is the near-density material (0.1 relative density) curve. The greater the

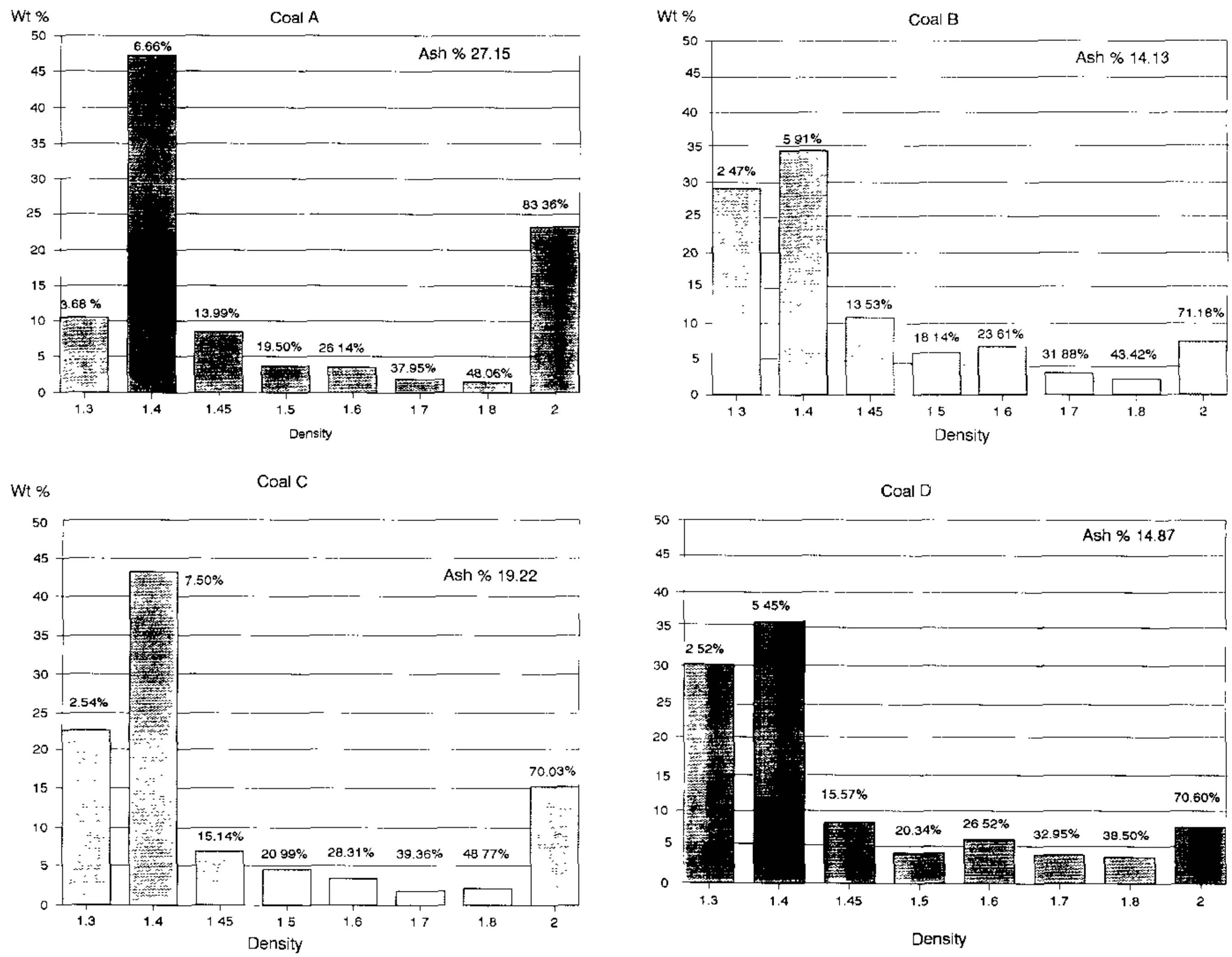

Figure 5-2-5. Density distribution for coals A, B, C and D. Total sample ash is given in the top right-hand corners, while ash contents for each density fraction are above the bars.

yield of the 0.1 fraction the more difficult it will be to carry out the separation at this relative density. The more the near-gravity material curve approximates the shape of a letter L, the easier it is to obtain good gravity separation. A sharp change in the shape of the curve indicates the presence of two different types of material: clean, low ash and heavy, mineral matter particles. This provides a basis for easy separation.

Figure 5-2-6 compares the near-gravity material curves for the four coals under discussion. For coals B, C and D, fine fractions have less near-density material than the coarse fractions, at any given density of separation. This confirms that fine size fractions are easier to wash because of the greater liberation of coal from mineral matter. Coal A is an exception; the fines have more near-density material, which may indicate the presence of clays. In this case separation becomes less efficient and this is reflected in a decrease of the ease of washing.

It is important to determine the amount of near-density material at the cut points required for good quality, clean coals.

Degree of Washing as a New Parameter of Washability

Washability takes into account a number of parameters such as ash, yield of floats and rejects, amount of near-gravity material and densimetric distribution.

As discussed by several authors (Sarkar and Das, 1974; Sanders and Brooks, 1986) it is useful to have a parameter which includes most of the variables. The degree of cleaning, or degree of washing, has been introduced to supplement the washability parameters. The degree of washing is expressed as:

$$N = w(a-b)/a$$

where: a = the ash content of the feed

b = the ash content of the clean coal at a given density of separation

w = the yield of clean coal at a given density of separation.

The degree of washing N values, calculated as above and plotted as a function of density of coarse and fine fractions are presented in Figure 5-2-7. For each coal there is an

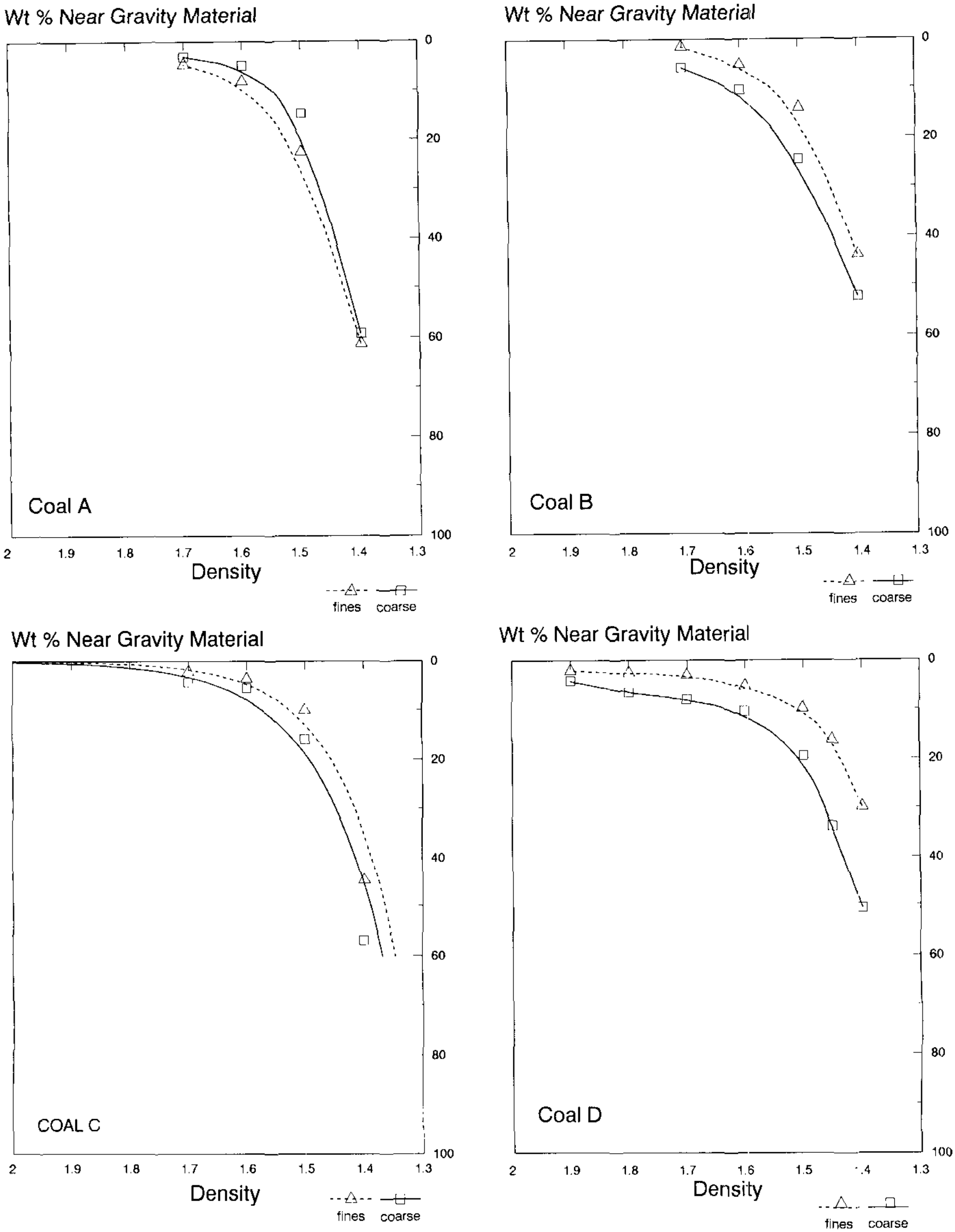

Figure 5-2-6. Near-gravity material (0.1 r.d.) curves for coals A, B, C and D.

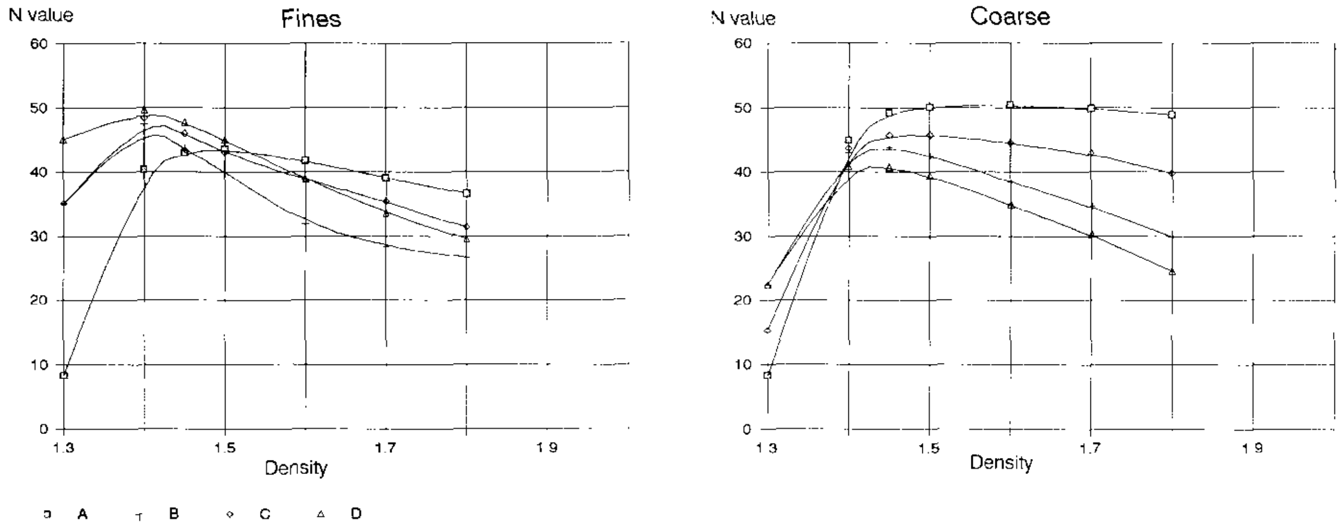

Figure 5-2-7. Degree of washing plots (N value versus separation density) for coals A, B, C and D.

optimum N value which is equivalent to the maximum of ash rejection at a given density. Ash rejection is proportional to the recovery of the combustibles from a given coal. The higher the rejection of ash the better the recovery of combustibles. For the coarse fractions the degree of washing (N), and therefore ease of washing increases in order D, B, C and A, whereas for the fines, the order is A, B, C and D.

The shape of the N-value curve indicates a change in ash rejection ability of a given coal for a different density of separation. For instance, the coarse fraction of coal A shows very little change in the N value over the range of densities increasing from 1.45 specific gravity. This means that ash rejection does not change in intermediate densities, because there is very little middlings, and most of the material is either in the low-density fraction or in rejects.

For other samples, the N values change with increase in density. As the amount of middlings is increased, the ability to reject the ash is reduced. N values for fines are much higher in the low-density ranges than in the case of the coarse fractions. This is indicative of much better ash rejection in fines for light coal material, except for Sample A.

The ash rejection value is the parameter which can more precisely quantify the "ease" of washing.

For a better comparative measure, the N optimum value can be further developed (Sanders and Brooks, 1986). The "washability number" is calculated as:

$$W = (N_{opt}/b_{opt})10$$

where a_{opt} = ash content corresponding to the fraction at N_{opt}.

The washability number indicates differences in the ease of washing, taking into account conditions for the maximum ash reduction and the ash content of the product at the optimum. However, optimal conditions will not always satisfy the economic side of the processing, therefore the washability number should only be considered as an additional indicator of washing ease. It must also be used in conjunction with all the other parameters of the washability data, to confirm its validity. Table 5-2-3 presents the calculated washability numbers and other washability parameters which correspond to the optimum cut points.

TABLE 5-2-3
WASHING CHARACTERISTICS OF OPTIMUM DEGREE OF WASHING

Coarse

Coal	Cut Point Relative Density	Yield %	Ash %	Ash % in Rejects	Nopt Value	Wn Washability Number
A	1.60	68.63	7.64	68.92	50.45	66
B	1.40	73.14	5.92	31.63	43.07	73
C	1.50	69.49	7.29	46.11	45.86	63
D	1.40	73.42	6.89	33.16	40.82	59

Fines

Coal	Cut Point Relative Density	Yield %	Ash %	Ash % in Rejects	Nopt Value	Wn Washability Number
A	1.50	77.98	8.59	48.56	43.69	51
B	1.40	87.77	3.83	26.83	47.50	124
C	1.40	87.89	4.46	36.01	48.42	109
D	1.40	81.90	3.96	29.51	29.8	75

SUMMARY AND CONCLUSIONS

The comparison between washability of coals or coal seams should always be considered on a much broader scale than just comparing the washability numbers derived from the sink-and-float analyses. The following factors should always be taken into account:

- mineral matter type and its mode of occurrence as the most important factor in the washability;
- lithology of a particular seam;
- the parameters such as optimum degree of washing and washability number, highlighting relative washing difficulties in relation to the optimal ash rejection, are recommended as a supplementary measure to the traditional washability parameters.

FUTURE PLANS

The compilation of the available washability data from coal seams across the province will continue. Washability curves will be obtained for a representative suite of coal seams in the province. The available computer programs will be used to obtain all possible combinations of washability parameters, and to find relationships between them. Values such as yield and quality of rejects at preselected ash levels will be calculated and compared. Degree of washing, together with the other measures of "ease" of cleaning, such as amount of near-gravity material, density distributions, and the "washability" number, will be used to compare different coals.

The washability data will be entered into in-house, catalogue-type files, where all washability parameters will be included. The computer software will be set up to maintain all possible washability information as active files. The system will be computerized for calculations and display of different washability parameters as needed.

As the new Alpern Classification System is being developed and approved (Alpern *et al.*, 1989) a further aim of this study is to compare British Columbia coals with coals from elsewhere.

The mineral matter content and its mode of occurrence significantly affects washability characteristics of any given coal, therefore it will be necessary to study mineral matter in conjunction with the washability. For the same reason, lithotype data will also be considered in conjunction with washability evaluations.

ACKNOWLEDGMENTS

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REFERENCES

Alpern, B., Lemos de Sousa, M.J. and Flores, D. (1989): A Progress Report on the Alpern Coal Classification; *International Journal of Coal Geology*, Volume 13, pages 1-19.

Diessel, C.F.K. (1965): Correlation of Macro and Micropetrography of Some New South Wales Coals; *Proceedings of 8th Commonwealth Mining and Metallurgical Congress*, Volume 6, pages 669-677.

Falcon, L.M. and Falcon, R.M.S. (1983): The Application of Coal Petrography to Certain Beneficiation Techniques on South African Coal; *Geological Society of South Africa*, Special Publication 7, pages 137-148.

Falcon, L.M. and Falcon R.M.S. (1987): The Petrographic Composition of Southern African Coals in Relation to Friability, Hardness and Abrasive Indices; *Journal of the South African Institute of Mining and Metallurgy*, Volume 87, No. 10, pages 323-336.

Hower, J.C. (1988): Additivity of Hardgrove Grindability: a Case Study; *Journal of Coal Quality*, Volume 7, pages 68-70.

Hower, J.C., Graese, A.M.and Klapheke, J.G. (1987): Influence of Microlithotype Composition on Hardgrove Grindability for Selected Eastern Kentucky Coals; *International Journal of Coal Geology*, Volume 7, pages 227-244.

Hower, J.C. and Lineberry, G.T. (1988): The Interaction of Coal Lithology and Coal Cutting on the Breakage Characteristics of Selected Kentucky Coals; *Journal of Coal Quality*, Volume 7, pages 88-95.

International Committee for Coal Petrology (1963): International Handbook of Coal Petrology, 2nd Edition; *Centre Nationale de la Recherche Scientifique*, Paris.

Laskowski, J.S. and Walters, A.D.(1987): Coal Preparation; *in* Encyclopedia of Physical Science and Technology, Volume 3, *Academic Press*, pages 37-61.

Leonard, J.W. (1979): Coal Preparation; 4th *American Institute of Mechanical Engineers*, New York.

Sanders, G.J. and Brooks, G.F. (1986): Preparation of the "Gondwana" Coals. 1. Washability Characteristics; *Coal Preparation*, Volume 3, pages 105-132.

Sarkar, G.G. and Das, H.P. (1974): A World Pattern of the Optimum Ash Levels on Cleans from the Washability Data of Typical Coal Seams; *Fuel*, Volume 53, page 74.

Stach, E., Mackowsky, M.-Th., Teichmuller, M., Taylor, G.H., Chandra, D. and Teichmuller, R. (1982): Stach's Textbook of Coal Petrology, 3rd Edition; *Gerbruder Borntraeger*, Berlin, Stuttgart.

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