CONTRIBUTION TO SUSTAINABILITY IN CEMENT AND COAL PRODUCTION

Southwest British Columbia, Canada

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Executive Summary

This Geofile aims to enhance the sustainable development of coal and cement raw materials in British Columbia. The main objectives of this study are to confirm the chemical composition of the Quinsam coal mine rejects, find out if the rejects from the Quinsam coal mine washing plant have a favorable chemical composition for use as a raw material in cement making and demonstrate how the use of these rejects could benefit coal and cement producers, the environment, and our society.

The rejects from Quinsam coal mine's washing plant represent a valuable raw material for cement making. The inorganic components of the rejects have appropriate Al_2O_3 - CaO - SiO_2 proportions and low Na_2O and K_2O content (ideal for cement making). Assuming nearly complete combustion within the conventional cement kiln, the organic components of coal rejects would burn, supplying between 6MJ and 12.5MJ of energy per kg of the feed. The use of these rejects (low grade coal) could extend the life of the mine, reduce or eliminate the problems associated with the waste disposal and represent substantial savings for cement producers. The results of this conceptual study are positive; however, detailed work is needed to quantify the benefits. Such work would be most efficiently accomplished in direct collaboration with cement and coal producers.

Although this research was specific to the Quinsam Coal Mine, the same principles can be applied to other coal operations and deposits where alumina-rich clays or shales with low concentrations of alkali elements are associated with coal.

Introduction

Cement is one of the key materials used in modern economy. Canada's cement production for 2006 is estimated at over 1.7 billion dollars (Anonymous, 2006). Coal is also very important for Canada. British Columbia alone produces over 2 billion dollars worth of coal (Schroeter et al., 2007).

This project is technical in nature and it introduces the public to concepts of cement making and coal processing. It also aims to enhance the sustainable development of coal and cement raw materials. The unpublished precursor of this document was presented at the 2007 Vancouver Island Science Fair held at the University of Victoria and subsequently at the Canada-Wide Science Fair which was held in Truro, Nova Scotia. The current version contains a more detailed list of references and identifies aspects that should be addressed before test firing of rejects in the kiln takes place. It shares common ground with a recent review covering supplementary cementitious materials and their potential role in reducing cement production related greenhouse gas emissions in British Columbia (Simandl and Simandl, 2008). It appears that Hillsborough Resources Limited, the owner of the Quinsam mine, studied the feasibility to produce metakaolin from coal-associated clays (Hillsborough Resources Limited, 2007). Technical, economic and environmental merits of both of these different approaches should be objectively compared.

Cement Background

Portland cement's main constituents are lime, silica, alumina and iron. Raw materials for cement production are limestone, shale and/or clay and silica sand (Table 1). During the calcining process, a ground mixture of raw materials passes through the kiln where it is exposed to gas temperatures up to 2000°C and heated to 1500°C (Fig.1). The resulting material is cement clinker. Gypsum is added at a later stage to the ground clinker to regulate the setting time of concrete. The engineering details are covered in books on cement making and are behind the scope of this document. The recent trends in the cement industry with the emphasis on blended cements are covered by Simandl and Simandl (2008).

Table 1. Cement Ingredients

Raw materials	Quantity	Main constituent
limestone ($CaCO_3$)	1.5 - 1.8 tonnes	lime (CaO)
clay; shale	0.4 tonne	alumina (Al_2O_3)
silica sand	minor	silica (SiO_2)
iron ore	minor	iron
slag and fly ash*	approx. 25%	silica, alumina, iron,
gypsum ($CaSO_4$ $2H_2O$) **	minor, 4-7%	

*cementitious materials

**controls cement settling time

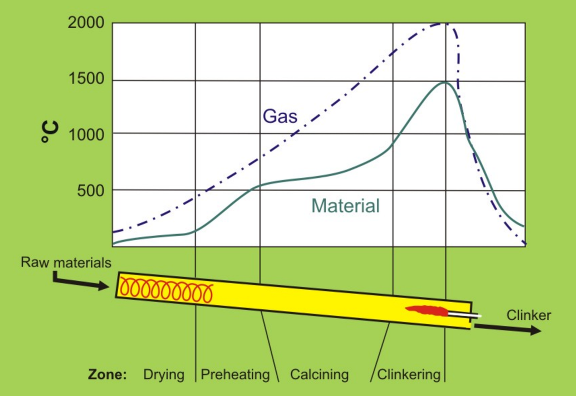


Fig. 1 Temperatures of gas and material within specific kiln zones. From Bye (1983) and Manning (1995).

British Columbia has 3 cement plants. Two of them are located on the Frazer River (Figs. 2 and 3a, b). These two plants account for more than 90% of BC's cement production. They require reliable, low-cost sources of high-alumina raw materials with low Na_2O and K_2O content.

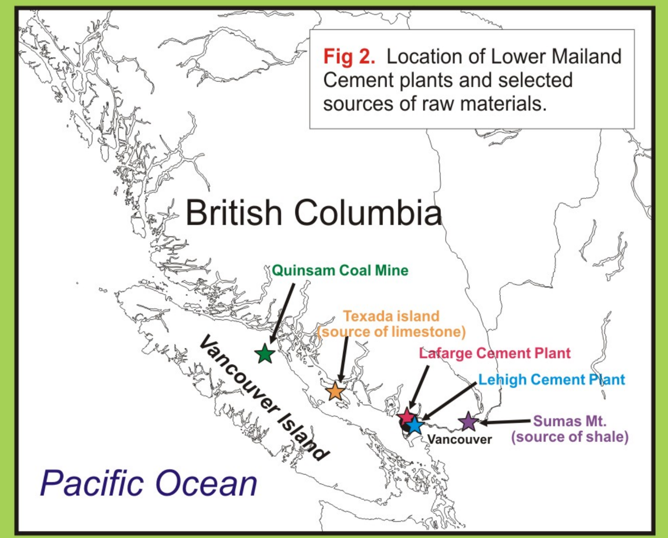


Fig 2. Location of Lower Mailand Cement plants and selected sources of raw materials.

Fig. 3a Lafarge Cement Plant in Richmond; view from the preheater. The plant is strategically located near a major highway, watterway and railway.

Fig. 3b Cement kiln at the Lafarge Canada Plant in Richmond. Mr. Caude Brûlé and the author are shown for scale.

Coal

Coal is a carbon-rich sedimentary rock formed by the decay of organic material underneath a cover of younger sediments. It is the most common fossil fuel used in cement making. Mined coal contains finely disintegrated minerals and chunks of waste rock. Raw coal is upgraded to "clean coal" by heavy media separation (Fig. 4, 4a, 4b, 4c, 4d), but not all impurities can be separated. Such impurities are left behind once coal is burned (***ash***). Typical analysis of ash derived from Quinsam coal is given.

Table 2. Average Chemistry of Ash present in Quinsam coal from Ryan (1995)

SiO_2 (%)	Al_2O_3 (%)	CaO (%)	TiO_2 (%)	Fe_2O_3 (%)	MgO (%)	Na_2O (%)	K_2O (%)	P_2O_5 (%)	SO_3 (%)
27.3	27.8	22.2	1.93	8.45	0.6	0.3	0.03	1.4	9.3

Al_2O_3, SiO_2 and CaO are the major components of the Ash present in Quinsam Coal.

Quinsam coal mine, located on Fig. 2, is the ideal source of coal for cement plants in the Vancouver area. In 2006, it produced 765 000 tonnes of raw coal. After coal washing, 520 000 tonnes of clean coal were shipped (Northcote, 2007) and 245 000 tonnes of rejects were disposed at the site.

COAL WASHING

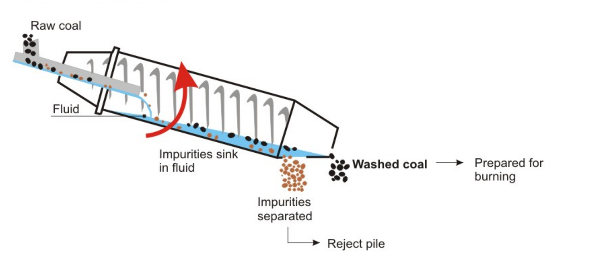


Fig. 4 This technique involves feeding the coal into turning barrels containing a fluid of a higher density than the coal. The coal floats, while unwanted materials (impurities) sink and are removed from the fuel mix.

Modified from Anonymous (2005).

Fig. 4a Quinsam Coal Processing Plant.

Fig. 4b Magnetite is used as a heavy media to separate coal from waste.

Fig. 4c Magnetite is recovered by magnetic separation and recycled.

Fig. 4d High-grade coal from Quinsam Coal Mine.

Methods

Five representative samples of coal rejects, each weighing between 10 and 20 kg were collected from the washing plant dump and settling pond (Fig. 6a, b). A sample of raw coal and two of claystone (host rock) were collected from the underground mine. All of the samples are composite to make them as representative as possible (Fig. 7). They were dried overnight at 40°C, split, crushed and then analyzed for major elements by ACME Laboratories in Vancouver by ICP-emission spectrometry following a lithium metaborate/tetrabortate fusion and dilute nitric digestion. Loss on ignition (LOI) was determined after combustion at 1000°C. Total carbon and sulphur analysis was done by Leco method. Because the samples were dried overnight before sample preparation, no direct data is available on the in situ sample humidity. The water content that can be deduced from available analyses therefore corresponds largely to water contained in crystal latice.

Fig. 6a Reject pile at Quinsam Coal Mine.

Fig. 6b Settling pond at Quinsam Coal Mine.

Fig. 7 Some of samples collected from the Quinsam Coal Mine.

Data

Sample descriptions and the results of the chemical analysis are presented in Table 3. Coarse rejects consist typically of angular to subrounded rock fragments that are typically less than 15 cm in longest dimension. Fine rejects from the setling pond are typically subangular and less than 2 mm in size. Sample 7a is a duplicate of sample 7. The ash content for each sample was calculated by subtracting the Loss on Ignition (LOI) from 100%.

Table 3. Chemical composition of coal, claystone and coal washing plant rejects

Field No.	Sample Description	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	Cr_2O_3	LOI	$C_{(tot)}$	CO_2	$S_{(tot)}$	SUM	ASH
		%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Q#1	Organic-rich claystone	41.3	27.7	1.17	8.45	0.98	0.17	0.11	2.62	0.07	0.11	0.041	16.6	3.1	2.95	0.2	99.4	83.4
Q#2	Coal	3.18	2.78	9.18	0.32	<.01	0.02	<.04	0.2	0.03	0.01	<.001	84.2	64.9	6.93	0.36	99.9	15.8
Q#5	Claystone (Clay layer above rider seam, underground)	44.6	19.9	2.75	11.7	1.76	0.5	0.44	1.85	0.16	0.1	0.026	16.2	4.93	3.89	1.56	100	83.8
Q#7	Coarse reject (dump)	32.8	19.8	3.51	9.29	1.2	0.4	0.11	2	0.07	0.16	0.027	30.6	17	4.69	0.61	100	69.4
Q#7a	Coarse reject (dump) duplicate	35.7	21	2.82	9.93	1.18	0.35	0.09	2.19	0.1	0.14	0.027	26.5	12.7	4.73	0.24	100	73.5
Q#8	Coarse reject (dump)	34.7	18	5.83	7.34	1.18	0.77	0.19	1.47	0.11	0.1	0.019	30.2	17.1	5.24	0.34	100	69.8
Q#9	Coarse reject (dump)	27.2	15.5	6.29	4.83	0.66	0.22	0.1	1.42	0.08	0.05	0.019	43.6	27.5	5.61	0.45	100	56.4
Q#10	Fine rejects (settling pond) away from washing plant discharge pipe Fraction <1.5mm, 50% coal, 50% clay	33.5	11.8	4.4	6.16	1.59	1.39	0.52	0.96	0.09	0.08	0.014	39.5	30.1	1.22	0.22	100	60.5
Q#11	Fine reject, (settling pond) near discharge pipe, 70% coal, 30% clay, calcite (?)	26.5	17.4	7.51	7.27	0.48	0.17	0.08	1.63	0.05	0.05	0.021	38.8	24.8	5.9	0.22	100	61.2

Discussion

The inorganic component of Quinsam rejects has a ideal chemical composition for cement making. The organic component of the rejects represent a valuable source of energy that can be recovered during the calcining process. Both of these aspects are covered in detail bellow.

Suitability for cement making- Major oxides

The suitability of raw materials for cement making can be demonstrated using a well established ternary SiO_2 - CaO - Al_2O_3 diagram (Fig. 8a).

The two main materials in cement making are limestone (source of CaO) and shale (source of Al_2O_3 and SiO_2). These materials are blended in such a way that the final composition of the blend falls within the red triangle to meet industry specifications. C_2S, C_3S and C_3A are abbreviations for stable minerals in cement clinker. C_2S is dicalcium silicate (belite), C_3S is tricalcium silicate (alite) and C_3A is tricalcium aluminate. In the cement industry, C stands for CaO, S for SiO_2 and A for Al_2O_3.

Samples from Quinsam plot close to the typical shale composition (Fig. 8b). The blending line connecting each of these samples to typical limestone intercepts the red triangle, as illustrated using sample Q10. The Quinsam samples have nearly ideal proportions of Al_2O_3, SiO_2 and CaO for cement making. The Quinsam samples also have low Na_2O and K_2O content. This is particularly suitable for cement making because it reduces the danger of alkali-silica reaction which may result in premature cement deterioration. In low alkali cements the total alkali content equivalent (calculated as wt% Na_2O + 62/94 K_2O) should be less than 0.6%.

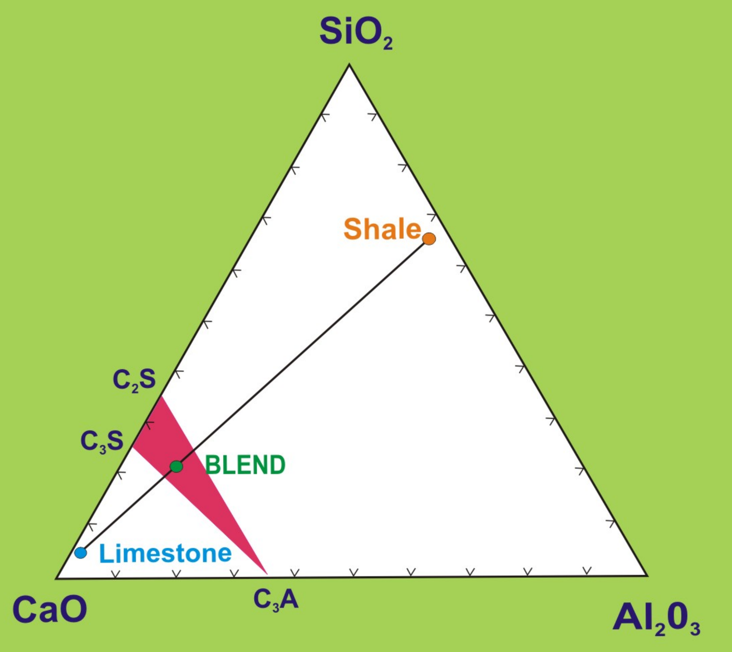


Figure 8a **Raw Materials for cement blend -** The line connecting limestone and shale is called the blending line. Any blend of limestone and shale will plot along this line. The red triangle represents the ideal composition of cement blend. (Modified from: *Manning, 1995*).

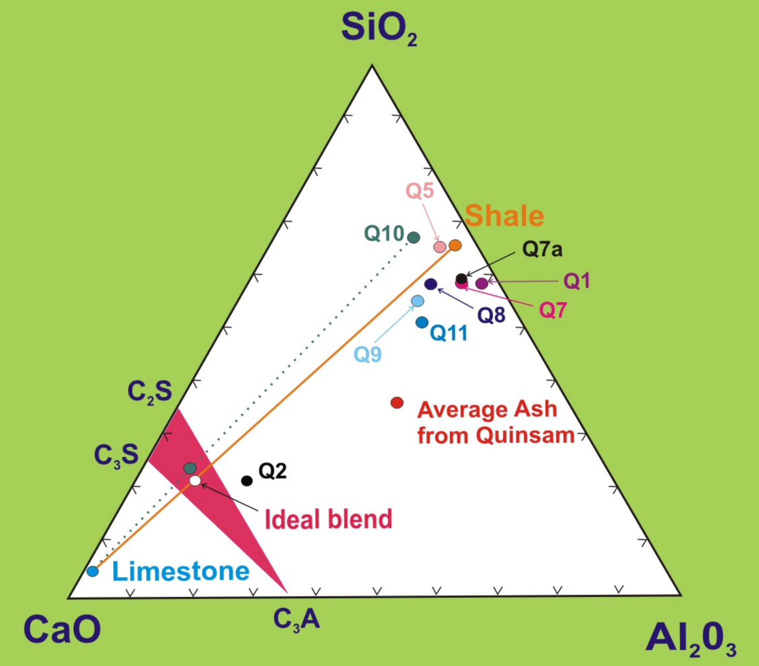
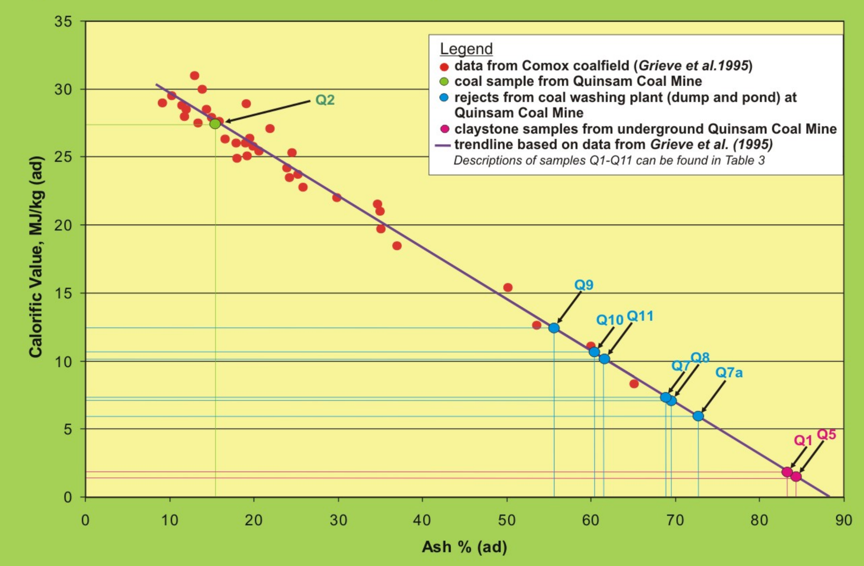


Figure 8b **Composition of samples from Quinsam Coal Mine.** See Table 3 for description of samples Q1 to Q11. Average composition of ash from Quinsam as reported by *Ryan (1995)*.

Energetic value of Quinsam rejects

Fig. 9 **Calorific value vs. Ash - Samples from Comox Coal Basin**



Grieve et al. (1995) established the relation between the ash content and calorific value for air-dried coal in the Comox Basin (Fig. 9). Then trend line derived from Grieve's data using the Linear Regression method (Fig. 9) shows that one kg of Quinsam coal (sample Q2) will provide approximately 26.5 MJ of energy and 150 g of quality high alumina material. Rejects will provide between 6 MJ and 12.5 MJ per kg, but each kg of rejects represents between 560g and 730g of high alumina raw material. This projection represents optimum conditions. It is valid as long as combustion is complete (it assumes that the intimate textural relationship between the alumina and coal components of the coal rejects does not negatively affect the kinetics of the coal combustion). Fine rejects, extracted from the settling pond (as collected), have high moisture content, which may be reduced by dewatering and sun-drying before transport. Coarse rejects are expected to have lower moisture content (as collected), but more energy would be spent during milling to reduce particle size to -350 mesh.

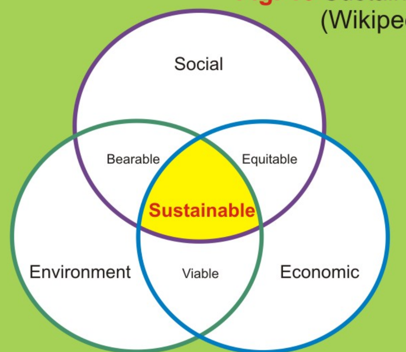
Conclusion

The coal rejects from the Quinsam Mine have an ideal chemical composition for cement making. Cement plants may use the Quinsam Mine rejects as high-alumina raw material for cement making. The organic component of the rejects will ignite, resulting in energy savings. The inorganic components will reduce the need for high alumina raw materials, which are currently in short supply. Environmental problems associated with coal disposal will be solved and local population will benefit of lower cost of construction material. As illustrated by Fig. 10, this project would qualify as a perfect example of sustainable development in terms of its environmental, social and economic components.

This conceptual study should be supported by more detailed work. Systematic sampling of coarse and fine rejects should be carried out to establish the homogeneity and tonnage of coarse and fine grained rejects. Rejects should be considered in terms of ultimate and proximate analysis, moisture, major and trace elements, particle size, and grindability prior to any kiln test run. Sun-drying of fine rejects should be considered and possibly incorporated as part of evaluation procedure. Calorific values estimated in this study correspond to air-dryed samples. Calorific values of coal rejects rejects as collected would be lesser.

The concept highlighted in this document may be applied worldwide; however, in some coal fields the sulphur content can be correlated with the ash content of the coal. In such cases, only the cement plants equipped with modern desulphurization equipment (scrubbers) designed to exceed current environmental standards and capable of handling higher sulphur content of raw materials on a routine basis should be permitted to burn current coal rejects or lower grade coal.

Fig. 10 Sustainability concept (Wikipedia, 2007)



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