Hydrothermally Treated Coals for Pulverized Coal Injection

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ABSTRACT

HYDROTHERMALLY TREATED COALS FOR PULVERIZED COAL INJECTION

This project is investigating the suitability of hydrothermally dried low-rank coals for pulverized fuel injection into blast furnaces in order to reduce coke consumption. Coal samples from the Beluga coal field and the Usibelli Coal Mine, Alaska, are being used for the study. Crushed coal samples were hydrothermally treated at three temperatures, 275, 300 and 325°C, for residence times ranging from 10 to 120 minutes. Products are being characterized to determine their suitability for pulverized coal injection. Characterization includes proximate and ultimate analyses, vitrinite reflectance and TGA reactivity. A literature survey is being conducted.

I. INTRODUCTION

Injection of pulverized coal into blast furnaces to reduce coke requirements has been investigated in the past and serious trials took place in the 1960s. However, the cost of fitting blast furnaces with pulverized fuel systems and the ready availability of low cost oil at that time, encouraged Japanese steel plants to substitute oil for coke. The shortage of oil during the 1979 oil crisis forced steel industries to take a serious look at replacing oil with pulverized coals. The steel industry soon discovered the advantages of pulverized coal injection (PCI). Large scale conversions to PCI were made both in Japan and Europe.^{1,2,3,4} By 1991, 26 of 33 operating blast furnaces in Japan were equipped with PCI systems, consuming 6 million tons of pulverized coal. Worldwide use of PCI was 13.2 million tons in 1990 and is expected to grow to 25 million tons by 1995. The current practice of pulverized coal injection at the Kakogawa No. 2 blast furnace, operated by Kobe Steel, uses coke (289 kg/t) along with pulverized coal (129 kg/t) and oil (65 kg/t).⁵

Coal injection rates are limited by:^{1,6}

1. Reactivity of injected coal.
2. Chemical composition of injected coal.
3. Particle size of injected coal.
4. Gas distribution in the burden column.
5. Furnace permeability.

A proposed upper limit for pulverized coal injection, which would burn completely in the tuyere combustion zone, is estimated at 180 kg/t when the fuel rate is 500 kg/t. An upper limit for pulverized coal grain size is 0.7 mm.⁷

Calculations based on furnace trials have shown that pulverized coal can replace up to 30-50% of the coke previously used in blast furnaces employing oxygen enriched blast, without impairing productivity or hot metal quality. A pulverized coal injection rate of 150 to 200 kg/t hot metal, with a blast enrichment of 25-27% oxygen, is possible.⁸

The high price of coke has resulted in progressive substitution of coke by low cost pulverized coal. PCI combustion is differentiated from normal coal combustion by:⁹

1. High combustion zone temperatures; 1200 to 2000°C.

2. Short residence times in the presence of oxygen; less than 30 ms.
3. Gasification in the presence of CO₂.

Research conducted at the University of Alaska Fairbanks has shown that hydrothermal treatment of subbituminous 'C' coals can produce a high quality product suited for metallurgical use.¹⁰ The hydrothermally dried product has low moisture, very low sulfur, 0.2%, and is highly reactive. This project addresses the suitability of hydrothermally processed low-rank coals (LRCs) for metallurgical use as pulverized coal for injection into blast furnaces.

The fact that Alaska has over 5 trillion tons of low sulfur coal reserves and that each trillion tons has an energy equivalency of approximately 5,500 years of Alyeska pipeline production (1.5 MM barrels/day) demonstrates the enormous economic potential for Alaska's coal resources. This includes over 4 trillion tons of bituminous and subbituminous coal located in the Northern Alaska basin, north of the Brooks Range. The Usibelli Coal Mine, the only current operating coal mine in Alaska, has an annual production of about 1.5 million tons. Half of this is exported to Korea while the remainder supplies heat and power for interior Alaska. The Beluga coal field, adjacent to Cook Inlet, is readily accessible to ice-free tide water. The field has been extensively drilled and evaluated by Placer Dome Inc. and Diamond Alaska Coal Co.

Coals from Usibelli Coal Mine and the Beluga coal field are of subbituminous 'C' rank and typically have calorific values of 8,000 Btu/lb. The moisture of these coals is about 28%. The combination of high moisture and low heating value has restricted most low-rank coal usage worldwide to mine-mouth power generation, which in turn has limited export sales of Alaskan coal to only 0.75 MM tons per year from Usibelli Coal Mine. This comes at a time when Australian coal exports have topped 100 MM tpy and the steam coal market is expected to more than double in this decade. Alaskan LRCs can participate in the Pacific Rim coal market by suitable upgrading to enhance quality.

While the objective of this project is applied research directed at Alaskan low-rank coal, the larger goal is to increase the available market for our state's and nation's coal resources. The relevance of such research is highlighted by the recent difficulty Usibelli Coal Mine, Inc.

experienced in renegotiating its 1993 coal export contract with KEPCO, a Korean electric utility. Technology and sound engineering management must be applied to enhance the marketability of Alaska's low-rank coals. One potential market for hydrothermally dried, Alaskan, low-rank coals is pulverized coal injection.

II. MIRL'S HYDROTHERMAL DRYING RESEARCH BACKGROUND

Fischer and Schrader first studied hydrothermal treatment of coals in 1921.¹¹ The process involves heating coals to a temperature of 320° to 400°C in the presence of water in an autoclave. Koppleman's process, used in the K-fuels system, treats LRC's at temperatures of 500° to 600°C and high pressure. The process liberates moisture as well as light hydrocarbon gases and liquids. The process developed by University of North Dakota and Bechtel uses temperatures less than 400°C.¹¹ The gases liberated principally consist of CO₂. Some tars are mobilized and these tend to condense on the surfaces of coal particles and in pores.¹⁰

Beginning in 1989, the Mineral Industry Research Laboratory (MIRL), University of Alaska Fairbanks, undertook a preliminary investigation of hydrothermal treatment of Alaskan low-rank coals to 1) determine the quality of the product that can be prepared, and 2) study petrologic changes that accompany hydrothermal treatment that will eventually influence the mechanical properties, surface area and product reactivity. The products obtained during these tests were surprisingly different from conventional, evaporatively dried LRCs. Expected, as well as surprising characteristics are summarized below:¹⁰⁻¹³

1. As expected, the products had low equilibrium moistures and enhanced heating value.
2. Although rank enhancement was expected, vitrinite reflectance increased from 0.25% to over 0.7%, placing the product in a high volatile bituminous range.
3. Improvement in grindability was expected, but surprisingly the HGI increased from 34 for the raw coal up to 115 for the products.

4. Most surprising was the physical property of the product. The coals went through a plastic stage and the resulting products resembled coke produced from coking coal. Beluga coal showed the most thermoplastic behavior upon hydrothermal treatment.

Sectioning of the dried particles showed that the particles were devoid of cracks. The size distribution of cells in the product varied and could be related to petrology. Most significant of all, was that the surface of each particle so fused, that the presence of the inner cell structure is only revealed upon sectioning.¹⁰ The density of the particles varied with the severity of hydrothermal treatment. Some particles have densities as low as 0.75 compared to 1.49 for the raw coal.¹⁰ Of special significance is the fact that although the processed particles are very porous, the fused skin strength of the particle is high and may allow handling without significant degradation.

The high reactivity and porosity of the LRC products, coupled with low ash and sulfur, may make them unique raw materials for numerous metallurgical applications. It is therefore important to characterize the hydrothermally dried low-rank coal products for possible applications, which until now have not been considered for Alaskan coals. Among these alternative applications, pulverized coal injection appears to offer promise, and is the focus of this project.

III. PROJECT PROGRESS: JANUARY THROUGH MARCH 1995

Project progress for the third quarter of the project includes a continuing literature search and review emphasizing coal characteristics required for pulverized coal injection into furnaces (bibliography included in the appendix), and characterization of hydrothermally dried Beluga and Usibelli coals.

Last quarter, 4 X 8 mesh, crushed coal samples from the Beluga coal field and the Usibelli Coal Mine, Alaska, were hydrothermally treated at three temperatures, 275, 300 and 325°C and three residence times, 10, 60 and 120 minutes. Hydrothermal treatment was conducted using a reactor system similar to the one designed by Youtcheff.¹⁴ The system provides excellent

isothermality and accurate residence time measurements. Hydrothermally dried products were filtered and air dried.

To date, the hydrothermally dried products have been characterized using proximate analysis, vitrinite reflectance and TGA reactivity. Tables 1 and 2 (appendix) show the proximate analysis and vitrinite reflectance values completed through the third quarter of the project, and confirm earlier hydrothermal drying studies of Alaskan low-rank coals conducted by MIRL¹³:

1. The degree of upgrading is affected by both process temperature and residence time, but process temperature has a greater influence than residence time on low-rank coal upgrading.
2. The upgrading takes place rapidly. Most occurs in the first 10-20 minutes of residence time and the rate of upgrading decreases thereafter. Significant upgrading can still take place given long enough residence time.
3. Beyond 40-60 minutes, the upgrading response versus residence time tends to level off.
4. Upgrading response increases linearly with increases in process temperature within the temperature range of 275-325°C.
5. Vitrinite reflectance increases significantly from the raw coal to the hydrothermally dried products, indicating significant structural changes, i.e. induced coalification has occurred during the hydrothermal drying process.
6. Small, laboratory scale, tubing reactor hydrothermal drying studies predict pilot plant performance well.

Additionally, hydrothermally dried, Alaskan low-rank coals have many characteristics, which are comparable to those of coals presently being utilized for PCI; Tables 3 and 4 (appendix).

TGA reactivity studies have just been completed using a Perkin-Elmer TGA, Series VII. Char from the raw coals and their hydrothermally dried products were obtained by heating 10 mg of coal in the TGA under a nitrogen atmosphere from room temperature to 1000°C at a scan rate of 20°C/min. Isothermal reactivity of the char was then determined at 1000°C in a gas mixture

consisting of 10.09% CO₂, 2.06% O₂ and 87.85% N₂, which simulates conditions in the raceway of a typical blast furnace during combustion of pulverized coal. The raw TGA data are presently being analyzed and reduced. Examination of the raw data reveals an increase in TGA reactivity for the coal after hydrothermal treatment.

Additionally, during the third quarter, letters soliciting participation in this project continue to be sent to Japan and Korea, after consultation with persons knowledgeable concerning appropriate contacts there.

IV. FUTURE PROJECT RESEARCH GOALS

The hydrothermally dried coal products will be characterized using ultimate analysis. Data analysis will continue, and a summary of the test data will be forwarded to PCI users in Japan to obtain their input relating to the most suitable hydrothermally treated coal for PCI applications.

V. SUMMARY

In summary, progress on the project to date is on schedule as defined by the original proposal. Hydrothermal drying relationships have been defined, that should enable rapid progress, via process modeling, for this study. The next technical progress report (April-June 1995) will include the complete characterization data for hydrothermally dried coal products.

The special attributes of Alaska's low-rank coals, i.e., extremely low sulfur content, low ash and a possibility of preparing coal suitable for PCI by varying hydrothermal treatment temperatures and residence times, may offer an exciting new product for iron ore reduction, both in blast furnaces and for the direct reduction of beach sands in rotary kilns.

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VII. APPENDIX

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Table 1. Proximate Analysis and Vitrinite Reflectance of
Hydrothermally Treated, 4x8 mesh Usibelli Coal.

Process Temp/ Residence Time (C/min)	Test #	Moisture (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Heating Value, Btu/lb	Vitrinite Reflect., % R(max), Oil
Raw Coal	1	6.54	5.83	46.59	41.04	10496	0.30
	2	32.38	4.22	33.71	29.69	7594	
	2		6.24	49.85	43.91	11230	
	3			53.17	46.83	11978	
275/10 U-14	1	5.15	6.14	44.44	44.27	10680	0.42
	2	15.77	5.45	39.46	39.31	9484	
	2		6.47	46.85	46.67	11260	
	3			50.10	49.90	12039	
275/10 U-36	1	4.62	6.23	46.50	42.65	10933	
	2	16.19	5.47	40.86	37.48	9607	
	2		6.53	48.75	44.72	11463	
	3			52.16	47.84	12264	
275/60 U-33	1	4.31	6.40	44.33	44.96	11148	
	2	14.98	5.69	39.39	39.95	9905	
	2		6.69	46.33	46.99	11650	
	3			49.65	50.35	12485	
275/60 U-18	1	4.55	6.37	44.41	44.67	11229	0.54
	2	14.13	5.73	39.95	40.19	10102	
	2		6.67	46.53	46.80	11764	
	3			49.85	50.15	12606	
275/120 U-17	1	3.63	6.48	43.92	45.97	11493	0.54
	2	12.42	5.89	39.91	41.78	10445	
	2		6.72	45.57	47.70	11926	
	3			48.86	51.14	12786	
275/120 U-31	1	3.91	6.55	43.94	45.60	11444	0.59
	2	14.04	5.86	39.31	40.79	10238	
	2		6.82	45.73	47.46	11910	
	3			49.07	50.93	12781	

Table 1. (continued)

Process Temp/ Residence Time (C/min)	Test #	Moisture (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Heating Value, Btu/lb	Vitrinite Reflect., % R(max), Oil
300/10	U-34		4.32	6.30	44.68	44.70	11203
		1	14.34	5.64	40.00	40.02	10030
		2		6.58	46.70	46.72	11709
		3			49.99	50.01	12534
300/10	U-16		4.11	6.71	44.37	44.81	11221
		1	13.95	6.02	39.82	40.21	10070
		2		7.00	46.27	46.73	11702
		3			49.75	50.25	12582
300/60	U-15		2.79	6.73	43.42	47.06	11740
		1	11.28	6.14	39.63	42.95	10715
		2		6.92	44.67	48.41	12077
		3			47.99	52.01	12975
300/60	U-20		3.13	6.63	42.82	47.42	11789
		1	9.93	6.16	39.81	44.09	10961
		2		6.84	44.20	48.95	12170
		3			47.45	52.55	13064
300/120	U-11		2.75	6.85	41.03	49.37	11932
		1	9.07	6.40	38.36	46.16	11157
		2		7.04	42.19	50.77	12269
		3			45.39	54.61	13199
300/120	U-35		2.69	6.64	42.29	48.38	11904
		1	9.78	6.16	39.21	44.86	11037
		2		6.82	43.46	49.72	12233
		3			46.64	53.36	13129

Table 1. (continued)

Process Temp/ Residence Time (C/min)	Test #	Moisture (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Heating Value, Btu/lb	Vitrinite Reflect., % R(max), Oil
325/10	U-19		4.07	6.97	43.15	45.81	11527
		1	11.60	6.42	39.76	42.21	10622
		2		7.27	44.98	47.75	12016
		3			48.50	51.50	12958
325/10	U-30		3.62	6.64	43.25	46.49	11564
		1	13.45	5.96	38.84	41.75	10385
		2		6.89	44.87	48.24	11998
		3			48.19	51.81	12886
325/60	U-10		2.88	6.89	40.17	50.06	11986
		1	9.27	6.44	37.53	46.77	11197
		2		7.09	41.36	51.54	12341
		3			44.52	55.48	13284
325/60	U-12		2.49	7.74	39.28	50.49	11929
		1	8.61	7.25	36.81	47.32	11180
		2		7.94	40.28	51.78	12234
		3			43.76	56.24	13288
325/120	U-13		2.00	7.35	38.34	52.31	12191
		1	7.58	6.93	36.16	49.33	11497
		2		7.50	39.12	53.38	12440
		3			42.29	57.71	13448
325/120	U-32		2.04	7.43	39.76	50.77	12204
		1	8.96	6.91	36.95	47.18	11342
		2		7.58	40.59	51.83	12458
		3			43.92	56.08	13481

LEGEND:

- = As Determined Basis
- 1 = Equilibrium Moisture Basis
- 2 = Dry, Moisture Free Basis
- 3 = Dry, Ash Free Basis

Table 2. Proximate Analysis and Vitrinite Reflectance of
Hydrothermally Treated, 4x8 mesh Beluga Coal.

Process Temp/ Residence Time (C/min)	Test #	Moisture (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Heating Value, Btu/lb	Vitrinite Reflect., % R(max), Oil
Raw Coal		4.79	9.84	45.05	40.32	10310	0.32
	1	19.28	8.34	38.19	34.18	8741	
	2		10.34	47.32	42.35	10829	
	3			52.77	47.23	12077	
275/10 B-2		2.77	11.72	41.14	44.37	10814	
	1	10.96	10.73	37.67	40.63	9903	
	2		12.05	42.31	45.63	11122	
	3			48.11	51.89	12646	
275/10 B23		3.50	10.80	42.78	42.92	10626	
	1	13.16	9.72	38.50	38.62	9562	
	2		11.19	44.33	44.48	11011	
	3			49.92	50.08	12399	
275/60 B-28		3.02	10.86	40.80	45.32	10828	0.64
	1	11.96	9.86	37.04	41.14	9830	
	2		11.20	42.07	46.73	11165	
	3			47.38	52.62	12573	
275/60 B-1		2.96	9.52	42.57	44.95	10780	
	1	13.50	8.49	37.95	40.07	9609	
	2		9.81	43.87	46.32	11109	
	3			48.64	51.36	12317	
275/120 B-7		2.19	11.76	41.90	44.15	10868	0.63
	1	10.14	10.80	38.49	40.56	9985	
	2		12.02	42.84	45.14	11111	
	3			48.69	51.31	12630	
275/120 B-24		2.77	11.97	40.01	45.25	10818	0.64
	1	11.50	10.90	36.42	41.19	9847	
	2		12.31	41.15	46.54	11126	
	3			46.93	53.07	12688	

Process Temp/ Residence Time (C/min)	Test #		Moisture (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Heating Value, Btu/lb	Vitrinite Reflect., % R(max), Oil
300/10	B-9		2.11	12.79	41.84	43.26	10607	
		1	11.04	11.62	38.02	39.31	9639	
		2		13.07	42.74	44.19	10836	
		3			49.17	50.83	12464	
300/10	B-25		3.05	13.09	40.36	43.50	10530	
		1	12.90	11.76	36.26	39.08	9460	
		2		13.50	41.63	44.87	10861	
		3			48.13	51.87	12557	
300/60	B-8		1.97	12.64	39.48	45.91	10940	0.84
		1	10.10	11.59	36.21	42.10	10033	
		2		12.89	40.27	46.83	11160	
		3			46.23	53.77	12812	
300/60	B-22		2.61	13.65	38.27	45.47	10925	
		1	9.37	12.70	35.61	42.31	10167	
		2		14.02	39.30	46.69	11218	
		3			45.70	54.30	13046	
300/120	B-4		2.06	11.26	39.97	46.71	11339	
		1	9.41	10.41	36.97	43.20	10488	0.75
		2		11.50	40.81	47.69	11577	
		3			46.11	53.89	13081	
300/120	B-27		2.26	15.02	36.96	45.76	10768	
		1	9.88	13.85	34.08	42.19	9929	0.75
		2		15.37	37.81	46.82	11017	
		3			44.68	55.32	13017	

Process Temp/ Residence Time (C/min)	Test #		Moisture (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Heating Value, Btu/lb	Vitrinite Reflect., % R(max), Oil
325/10	B-5		2.47	11.04	40.80	45.69	11077	
		1	10.32	10.15	37.52	42.01	10185	
		2		11.32	41.83	46.85	11358	
		3			47.17	52.83	12807	
325/10	B-26		2.81	13.33	39.62	44.24	10624	
		1	11.15	12.19	36.22	40.44	9712	
		2		13.72	40.77	45.52	10931	
		3			47.25	52.75	12669	
325/60	B-3		1.79	12.44	37.73	48.04	11282	
		1	10.04	11.39	34.56	44.00	10334	0.94
		2		12.67	38.42	48.92	11488	
		3			43.99	56.01	13154	
325/60	B-29		2.14	12.73	36.77	48.36	11333	
		1	9.54	11.77	33.99	44.70	10476	
		2		13.01	37.57	49.42	11581	
		3			43.19	56.81	13313	
325/120	B-6		1.80	16.60	35.44	46.16	10924	
		1	8.34	15.49	33.08	43.09	10196	0.86
		2		16.90	36.09	47.01	11124	
		3			43.43	56.57	13387	
325/120	B-21		1.58	14.62	36.31	47.49	11237	
		1	8.34	13.62	33.82	44.23	10465	0.87
		2		14.85	36.89	48.25	11417	
		3			43.33	56.67	13409	

LEGEND:

- = As Determined Basis
- 1 = Equilibrium Moisture Basis
- 2 = Dry, Moisture Free Basis
- 3 = Dry, Ash Free Basis

TABLE 3. CHARACTERISTICS OF COALS USED FOR INJECTION AT TATA STEEL⁹

Parameter	South Black Water	West Bokaro
Proximate Analysis (db), %		
Ash	9-10	17-18
VM	24-26	26-28
Ultimate Analysis (Typical), %		
Ash	10.1	18.30
C	77.72	71.47
H	4.22	4.24
N	1.75	1.63
O	5.73	3.75
S	0.48	0.61
Alkalis (Na ₂ O + K ₂ O), %	0.25-0.27	0.25-0.35
Initial Ash Fusion Temp., °C	1170	1250
HGI	55-65	60-70
Calorific Value, kcal/kg	7250	6820
Tar Yield, kg/t	31.5	39.85

Table 4. Main characteristics of injected coals.³

Coal number	Volatile matter (d.b.)	Ash (d.b.)	S (d.b.)	HGI	Ultimate analysis				Replacement factor (%) Coke/Coal	Moisture			
					C (d.b.)	H (d.b.)	N (d.b.)	O (d.b.)		Total	Inherent	Evaporated	Pulverized coal
1	36.6	3.7	0.97	51	81.1	5.3	1.3	7.7	91.20	7.7	2.3	6.0	1.5
2	32.6	5.8	0.88	62	81.2	5.1	1.4	5.6	93.41	5.7	1.4	4.7	0.9
3	31.8	6.3	0.88	62	81.6	5.1	1.5	4.6	94.98	6.5	1.0	5.8	0.7
4	34.7	6.3	0.67	61	78.3	5.1	1.2	8.5	87.22	8.3	2.6	6.0	1.8
5	33.0	4.7	0.73	56	83.0	5.0	1.4	5.3	95.82	4.8	1.3	3.9	0.9
6	32.5	7.5	0.62	46	77.8	4.8	1.6	7.7	86.62	6.6	2.6	4.9	1.7
7	32.5	5.7	0.75	59	81.3	5.2	1.4	5.7	93.93	5.0	1.2	4.2	0.8
8	35.5	6.3	0.74	45	77.7	5.0	1.5	8.8	85.73	5.6	2.7	3.8	1.8
9	33.8	5.7	0.66	48	80.4	4.7	1.4	7.1	89.48	8.7	2.1	6.0	2.2
10	31.3	8.5	1.07	75	78.7	5.2	1.5	5.0	88.35	10.2	1.2	6.0	3.7
11	30.5	5.4	0.79	60	82.6	5.1	1.4	4.7	95.99	5.3	1.1	4.6	0.7
12	17.5	5.6	0.79	100	84.9	4.4	1.4	2.9	97.84	8.5	0.7	6.0	2.0
13	33.9	5.7	0.88	58	82.1	5.1	1.3	4.9	95.43	6.5	1.0	5.8	0.7
14	31.6	6.1	0.94	61	82.3	4.8	1.3	4.6	95.29	4.6	1.2	3.8	0.8
15	33.3	5.5	0.78	62	82.2	5.1	1.3	5.1	95.34	6.0	1.2	5.2	0.8
16	39.3	5.9	0.64	54	78.0	5.0	1.3	9.3	82.79	11.4	7.1	6.0	4.9
17	33.8	9.2	0.67	57	76.8	5.4	1.3	6.6	87.78	7.3	2.4	5.7	1.6
18	32.7	10.8	0.54	55	73.6	4.4	1.5	9.2	79.52	8.8	3.6	6.0	2.4
19	24.4	8.3	0.87	80	81.8	4.7	1.5	2.8	93.62	9.7	1.2	6.0	3.2
20	30.7	8.0	0.62	58	77.7	4.4	0.7	8.6	84.40	8.9	4.8	5.7	3.2
21	30.7	8.6	0.54	50	76.4	4.1	0.7	9.7	78.69	12.6	7.1	6.0	6.1

Evaporated moisture = total moisture - 2/3 inherent moisture (maximum = 6 %)

Pulverized coal moisture = total moisture - evaporated moisture.

Replacement factor coke/coal = 2 % C + 2.5 % H + 0.9 % ash

Pulverized coal moisture : 86 %

(d.b. = dry basis, sur sec).