Paper Number:
DOE/MC/30097-97/C0833

CONF-9510439--1

Title:
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Contract Number:
DE-FC21-93MC30097

Conference:
24th Biennial Conference of the Institute for Briquetting and Agglomeration

Conference Location:
Philadelphia, Pennsylvania

Conference Dates:
October 31-November 2, 1995

Conference Sponsor:
Institute for Briquetting and Agglomeration

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UPGRADING SELECTED CZECH COALS FOR HOME AND INDUSTRIAL HEATING

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1. ABSTRACT

The Czech Republic has large coal reserves, particularly brown coal and lignite, and to a lesser extent, bituminous coal. Concurrent with the recent political changes, there has been a reassessment of the role of coal for electrical and heating energy in the future economy, owing to the large dependence on brown coal and lignite and the implementation of more stringent environmental regulations. These coals have a relatively high sulfur content, typically 1–3 wt%, and ash content, leading to significant SO_2 and other gaseous and particulate emissions. Some of the bituminous coals also exhibit high ash content.

Against this background, the Energy & Environmental Research Center, on behalf of the U.S. Agency for International Development and the U.S. Department of Energy Office of Fossil Energy, undertook a project on upgrading Czech coals to achieve desired fuel properties. The purpose of the project was to assist the city of Ústí nad Labem in Northern Bohemia in developing cost-effective alternatives for reducing environmental emissions from district and home heating systems.

Three coals were selected, namely Bílina and Nástup lignites from Northern Bohemia and Ostrava bituminous coal from Moravia, for a limited technical investigation to assess their potential for upgrading. All coals were analyzed for ash and sulfur content, forms of sulfur, and ash composition. Bílina and Nástup lignites were subjected to wet and dry physical cleaning methods to reduce the ash and sulfur content. Physically cleaned Bílina lignite and raw Ostrava bituminous coal were carbonized to reduce volatile matter content. Selected physically cleaned and carbonized coals were tableted with a starch binder and calcium carbonate, the latter being added for sulfur capture. Following analysis of the tableted coal products, the latter were evaluated for their potential application as district and home heating fuels.

Fuels prepared from raw Ostrava bituminous coal and Bílina lignite cleaned by the float–sink method would be acceptable for steam-raising in commercial and energy installation applications. Tableted fuels prepared from Ostrava bituminous coal and a carbonized, magnetically cleaned Bílina product would be suitable as smokeless fuels for home heating because of their reduced sulfur and volatile matter contents. The Bílina lignite-derived fuels containing the sulfur capture agent have an emission-effective sulfur content similar to that of the Ostrava fuels.

The results of this project indicate the opportunities for reducing sulfur dioxide, smoke, and particulate emissions in Northern Bohemia, especially around Ústí nad Labem, by the proper cleaning treatment, briquetting, and utilization of Czech indigenous coals. However, further development at

pilot and demonstration scales is required, along with an economic evaluation of the fuel preparation and fuel combustion systems for heating.

2. INTRODUCTION

The Czech Republic, as of 1993, had over 4700 million metric tons of recoverable coal reserves, about 83% of which was brown coal and lignite, and the balance consisting of hard or bituminous coal (1). Minable reserves of lignite and hard coal will last for at least 30 and 50 years respectively, especially since there has been a contraction in the Czech coal industry recently. However, a strong incentive to use indigenous sources of fuels exists in the country. Figure 1 depicts the various coal regions and types of coal in the Czech Republic.

A substantial amount of the brown coal and lignite has high ash and sulfur content, the coal quality varying with the region. Brown coal from the Most region in Northern Bohemia has an ash content ranging from 18–36 wt% and a sulfur content ranging from 0.4 to 3.5 wt%. In comparison, the bituminous coal from Ostrava in the Moravia region of the eastern Czech Republic, has an ash content of 8–40 wt% and a sulfur content of 0.4–0.9 wt%.

Ústí nad Labem, an industrial city of 121,000 people in Northern Bohemia, is typical of a Czech city which is dependent on coal. It, along with other cities in Poland and the former East Germany, has contributed to the high pollution levels of the "Black Triangle." A critical concern of Ústí nad Labem is the substantial pollution attributable to emissions from sulfur dioxide (SO_2), nitrogen oxides (NO_x), and particulates from large district heating systems as well as from small residential coal-fired stoves. Average concentrations of SO_2 exceeding 100 mg m^{-3} and of particulates at typically 75 mg m^{-3} have been reported (2).

In the early 1990s, domestic heating in the Czech Republic used some 7.4 million tons/yr of raw lignite and 600,000 tons/yr of lignite briquettes, as well as 640,000 tons/yr of bituminous coal. The briquettes were produced at the one remaining briquette plant located at Sokolov (3).

New environmental regulations for coal-burning units without desulfurizing devices were effected on January 1, 1994, and January 1, 1995. Essentially the amount of sulfur per lower heating value (g/MJ) is used as a control parameter in two ways: the average amount of sulfur in supplies of individual producers during a 3-month period and the maximum amount of sulfur in any fuel. The regulations are defined for three levels of installations: >5-MW installed heating capacity (commercial), >50-kW installed heating capacity (commercial), and up to 50-kW installed heating capacity (households) (4).

Although the production of lignite and hard coal in the Czech Republic is declining, upgrading or beneficiating the coal is a potential option for improving the efficiency of coal use as well as meeting the environmental requirements. The upgrading or beneficiation of lower-quality coals may involve one or more techniques for the removal or reduction of mineral species, moisture, or derived combustion products (e.g., SO_2). These techniques include dry physical cleaning (e.g., magnetic separation of minerals); wet physical cleaning (e.g., water washing), oil agglomeration, ion exchange, hot-water drying, or thermal pretreatment for moisture reduction; and briquetting. Depending on the

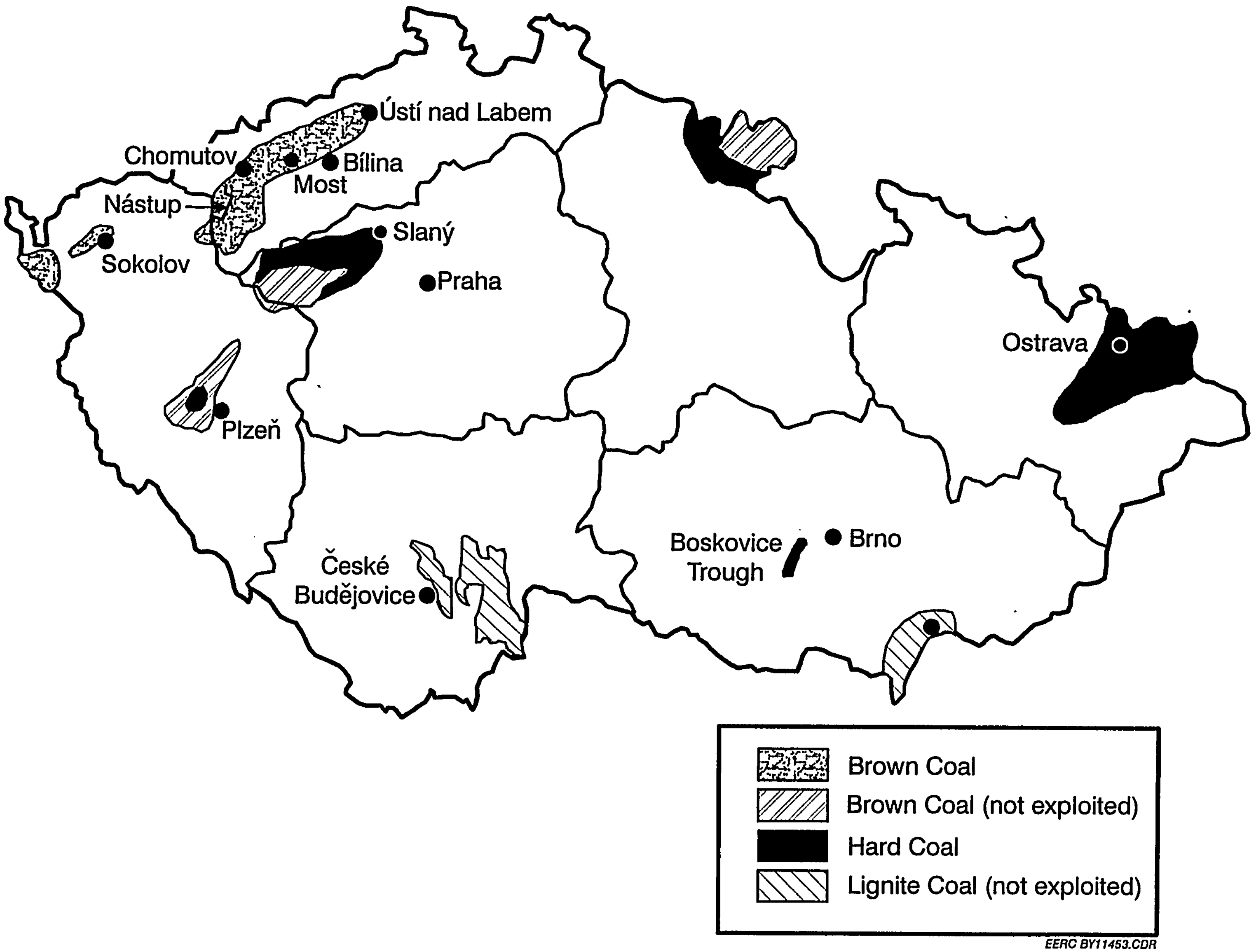

Figure 1. Coal Regions in the Czech Republic (adapted from U.S. Environmental Protection Agency [5]).

type of coal, coal-cleaning costs, including the cost of the disposal of wastes, can be high. However, beneficiation can lead to improved consistency of feedstock quality, enhanced heating value of the fuel, and reduced mineral content, resulting in less wear and corrosion of the boiler plant as well as lower emissions and reduced transport, handling, and storage costs for a specific plant output (6).

The purpose of this paper is to report the preliminary upgrading tests for three Czech coals: two lignites and one bituminous coal. Physical cleaning, carbonization, tableting, and combustion tests and their results are described. The primary aim of the work was to produce acceptable briquette tablets that complied with the new environmental regulations for sulfur levels and show the potential for developing home and/or district heating and commercial/industrial briquetted fuels based on upgraded feedstocks. This paper is based on a more detailed report compiled by the authors (7) for the Office of Fossil Energy, U.S. Department of Energy (DOE).

3. EXPERIMENTAL

3.1 COAL PREPARATION AND ANALYSES

Three coals from producing mines in the Czech Republic were received at the Energy & Environmental Research Center (EERC). The coals included Bílina and Nástup lignites from Northern Bohemia and Ostrava bituminous coal from Moravia. Four samples of the Bílina lignite were received representing different locations in the same seam.

The coal samples were each divided into four roughly equal fractions using a laboratory splitter; one-half of the split sample was directed to testing, one-quarter was submitted for analyses, and one quarter was placed in reserve. Proximate and ultimate analyses, heating value, and ash chemistry of the samples were undertaken.

The test coals were prepared to a specified size range for wet and dry physical cleaning and carbonization. Briefly, the as-received (ar) coals were sieved at 1/4 in., with the oversized fraction crushed with a laboratory jaw mill until 100% of the coal passed 1/4 in. The crushed Bílina and Nástup lignites were bottom-sized at 20 mesh and the yield of the two fractions, 1/4 × 20 mesh and −20 mesh, determined. The Ostrava bituminous coal was not subjected to bottom sizing. Short proximate analysis (moisture, ash, sulfur, and heating value) was undertaken on the −20-mesh fractions, but they were not tested further.

3.2 COAL BENEFICIATION

Two methods of physical cleaning were investigated for reducing the ash content and sulfur content of the sized Bílina and Nástup lignites. Firstly, a density-based method was used whereby the "clean" coal is separated from impurities (e.g., minerals) by flotation as a result of charging the feed coal to a liquid which has a density intermediate to that of the fractions to be separated. Wet physical cleaning usually implies that an aqueous medium is used, but in the bench-scale procedure described below, an organic liquid medium was used.

Rare earth magnetic separation (REMS) was the second physical cleaning method for the reduction of sulfur and mineral matter. Under REMS, pure coal which is diamagnetic is repulsed while pyrite and most other coal minerals which are paramagnetic are attracted by magnetic forces. This test is done under dry conditions affording a significant advantage, if effective, over the wet physical cleaning method.

3.3 WET PHYSICAL CLEANING

Float–sink washability testing was performed, simulating the ideal wet physical cleaning process, on weighed Bílina and Nástup lignite fractions (1/4 × 20 mesh) added to a separation vessel containing Certigrav true specific gravity solution. Following settling, the suspended clean coal (float) and settled impurities (sink) fractions were recovered, with the resulting sink fraction subjected to further treatment at a higher specific gravity. Consecutive separations were performed at specific gravities of 1.3, 1.4, and 1.6, thus producing three float fractions and one sink fraction. All float and sink fractions were treated to remove trace Certigrav solution and weighed, after which short proximate analysis was performed on each fraction.

3.4 DRY PHYSICAL CLEANING

Selected fractions, 1/4 in. × 6 mesh and 6 mesh × 20 mesh, of the Nástup and Bílina lignites, were tested by laboratory-scale REMS at ERIEZ Magnetics (Erie, Pennsylvania). The narrower size fractions, aiding better separation, were weighed prior to feeding to the REMS system using a 100-ft/min linear belt speed. All magnetic and nonmagnetic product fractions were weighed, with the nonmagnetic fraction subjected to short proximate analysis.

3.5 CARBONIZATION

Carbonization was used to produce low-volatile content feedstocks from selected coal samples for home heating fuel preparation. Briefly, the Bílina dry physically cleaned products from the 1/4-in. × 6-mesh and 6-mesh × 20-mesh fractions were combined in proportion to their dry physical yields and carbonized. The 1/4 × 0-in. fraction of the raw Ostrava coal was also carbonized. Carbonization took place at 650°C in an inert atmosphere in an electrically heated Lindbergh furnace. Replicate carbonization tests were performed to provide enough char for briquette tablet preparation. The yield of carbonized product or char was determined, following which a representative sample was analyzed for total sulfur content.

3.6 COAL AND CHAR TABLETING

The Bílina lignite wet physically cleaned product of 1.3 specific gravity, the carbonized Bílina lignite product from dry physical cleaning, the raw Ostrava bituminous coal, and the Ostrava carbonization product were tableted for testing as potential district and/or home heating fuels. The coal and char samples were stage-crushed to 1-mm (18-mesh) top size in a laboratory hammer mill. The crushed feedstocks were wetted with deionized water to assist dispersion of the pregelatinized binder at 4 wt% (moisture-free feedstock basis) and pulverized limestone. The latter was added only in the case of Bílina lignite samples to enhance sulfur capture. The heating fuel feedstocks were densified into 1¼-in. diameter × ½-in. thick cylindrical briquette tablets using a hydraulic press. Densification occurred at a pressure of 8100 psig with a hold time at pressure of 3 seconds. The "green" tablets were allowed to air dry to facilitate binder setting and strength development. Representative air-dried tablets were tested for proximate and ultimate analysis, heating value, compressive strength, and apparent density.

3.7 TABLET COMBUSTION

Combustion testing of the briquette tablets prepared by the above method was performed using a DuPont model 951 thermogravimetric analyzer (TGA) with continuous combustion gas analysis undertaken by a Bomem model B100 Fourier transform infrared (FT-IR) spectrometer. Combustion was initiated by charging the tablets to the TGA furnace preheated to approximately 1000°C (1800°F). Air was supplied for combustion at a rate of approximately 200 mL/min. The mass loss was continually monitored until the sample was completely burned. The effluent gas from the TGA was analyzed for CO_2, CO, total hydrocarbons (HC), SO_2, and NO_x.

4.0 RESULTS AND DISCUSSION

4.1 COAL PREPARATION AND ANALYSES

The analysis data (proximate, ultimate, and ash composition, sulfur forms, and heating value) are presented in Table 1 for the Bílina and Nástup lignites and the Ostrava bituminous coal. Of the six coal samples, the Ostrava bituminous coal had the lowest sulfur content (0.4 wt%) and the lowest ash content (5.9 wt%) and a heating value of 14,600 Btu/lb (34.0 MJ/kg), all values reported on a moisture-free (mf) basis. The Bílina and Nástup lignites, by comparison, had sulfur contents ranging from 1.0 to 1.7 wt%, ash contents ranging from 6.4 to 18.8 wt%, and heating values ranging from 10,000 to 12,000 Btu/lb (23.2 to 27.9 MJ/kg). The moisture contents of the lignites ranged from 30 to 39 wt%. The Nástup lignite exhibited the lowest quality among the lignites.

The Bílina lignites were essentially identical in all analysis categories except for forms of sulfur where the pyritic sulfur (as a percentage of total sulfur) ranged from 15 wt% in the Bílina 3 up to 40 wt% in the Bílina 2. Bílina lignites 1, 2, and 4, and the Nástup lignite were selected for wet physical cleaning tests; the comparatively high pyritic sulfur contents of these coals indicated high potential for sulfur reduction. The Bílina 4 lignite was selected for dry physical cleaning tests. The Bílina 3 lignite was excluded from beneficiation evaluations because of its low pyritic sulfur content (15 wt% of total sulfur). The Ostrava bituminous coal, also excluded from beneficiation tests because of its inherently low ash and sulfur contents, was selected for carbonization tests only.

4.2 COAL BENEFICIATION

4.2.1 Wet Physical Cleaning

Float–sink test results indicated that the Bílina 1, 2, and 4 lignites, sized to ¼ in. × 20 mesh, were amenable to substantial ash and sulfur reductions by wet density-based physical cleaning, and each sample exhibited similar properties at each separation specific gravity tested. Analyses data and mass and Btu recovery values for the Bílina 4 lignite, presented in Table 2, are representative of float–sink results for the three tested Bílina lignites.

TABLE 1

Analysis Results of Six Czech Republic Sample Coals

Analysis	Bílina 1	Bílina 2	Bílina 3	Bílina 4	Nástup	Ostrava
Coal Type	Lignite	Lignite	Lignite	Lignite	Lignite	Bituminous
Moisture, wt% ar[1]	31.3	29.8	29.7	29.7	38.7	13.6
Proximate, wt% mf[2]						
Volatile Matter	47.2	47.5	48.1	48.3	44.9	31.8
Fixed Carbon	46.4	44.5	45.0	43.9	36.3	62.3
Ash	6.4	8.1	7.0	7.8	18.8	5.9
Ultimate, wt% mf						
Hydrogen	5.3	5.6	5.7	5.8	4.5	4.7
Carbon	68.1	67.1	68.3	67.2	56.7	84.0
Nitrogen	1.1	1.1	1.0	1.0	1.3	1.2
Sulfur	1.02	1.23	0.95	1.14	1.74	0.44
Oxygen	18.1	17.0	17.1	17.1	17.0	3.8
Ash	6.4	8.1	7.0	7.8	18.8	5.9
Sulfur Forms, wt% mf						
Organic	0.68	0.76	0.80	0.67	1.03	0.29
Pyritic	0.30	0.53	0.15	0.44	0.59	0.10
Sulfate	0.02	0.05	0.02	0.08	0.12	0.01
Heating Value, Btu/lb mf	12,100	11,910	12,180	12,120	10,070	14,570
Ash XRFA[3], wt% as oxide						
Silicon	34.7	36.5	37.0	37.1	49.8	43.9
Aluminum	24.4	23.6	24.2	24.5	10.9	29.3
Iron	10.8	11.4	9.0	9.6	14.6	11.5
Titanium	1.1	1.1	1.3	1.3	0.4	1.0
Phosphorus	0.8	0.6	0.5	0.7	0.8	0.1
Calcium	8.4	7.7	8.0	7.8	7.4	3.2
Magnesium	4.2	3.9	4.0	4.2	2.6	3.2
Sodium	1.5	1.4	1.6	1.3	0.6	0.9
Potassium	1.0	1.1	1.1	1.1	0.4	1.6
Sulfur	13.1	12.6	13.3	12.4	12.5	5.3

[1] As-received.
[2] Moisture-free.
[3] X-ray fluorescence analysis.

TABLE 2

Fractional Washability Results for Czech Republic Coals

Coal Sample	Coal Yield, wt%	Btu Yields, % mf	Heating Value, Btu/lb mf	Ash, wt% mf	Sulfur, wt% mf
Bílina Lignite, No. 4 Sample					
1.3 Float	89.2	92.3	12,580	3.9	0.69
1.4 Float	7.0	6.1	10,620	18.5	1.62
1.4 Sink	3.8	1.6	4,940	54.0	7.86
Nástup Lignite					
1.3 Float	73.6	88.8	11,280	9.2	1.79
1.4 Float	3.6	3.6	9,480	22.4	3.15
1.6 Float	2.8	2.1	7,020	40.3	2.48
1.6 Sink	20.0	5.5	2,560	74.4	1.49

At Btu yields between 90% and 93%, clean coal fractions were produced with ash and sulfur contents averaging 42 and 36 wt% lower, respectively, than values for the feed fractions. The average ash reduction is more substantial when compared to the average raw coal ash content. Further, because of a modest improvement in the heating value, the average theoretical sulfur emission value (0.55 lb S/MMBtu), is 41% lower for the clean Bílina lignite relative to the raw coal. The ash chemistry analysis for the Bílina lignite 1.3 specific gravity float product indicated that silicon-bearing minerals were reduced while the typically organically associated species, such as calcium, magnesium, and sodium, were concentrated. The calcium concentration was doubled as a consequence of float–sink testing.

Float–sink test results indicated that the Nástup lignite, sized to ¼ in. × 20 mesh, was also amenable to substantial ash reduction by wet density-based physical cleaning. At a Btu recovery of almost 90%, an ash reduction of approximately 50 wt% was attained. However, wet physical cleaning for sulfur reduction was not effective at the size studied. A rather substantial improvement in the Nástup lignite heating value, from approximately 10,100 Btu/lb (23.5 MJ/kg) to over 11,000 Btu/lb (25.6 MJ/kg) at almost 90% Btu yield, produced a 8% reduction in the theoretical sulfur emission value for the raw coal (1.73 lb S/MMBtu).

4.2.2 Dry Physical Cleaning

Analyses data and mass recovery values for the REMS clean coal (diamagnetic) fractions for the Bílina 4 and Nástup lignites are presented in Table 3. Preliminary results indicated that the Bílina lignite was amenable to ash and sulfur reductions via REMS. At a coal recovery of almost 95 wt%, the sulfur content of the clean coal was 27 wt% lower than the values for the head fraction and raw coal. Further, the heating value and ash and sulfur contents for the combined fraction closely paralleled washability data. Optimization with this coal may produce REMS yield and coal quality results near those obtained from wet gravity-based methods.

TABLE 3

Magnetic Beneficiation Results for Bílina and Nástup Lignites

Coal Sample	Coal Yield, wt%	Heating Value, Btu/lb mf	Ash, wt% mf	Sulfur, wt% mf
Bílina Lignite (No. 4 Sample)				
-¼ in. × 6 mesh	97.8	12,300	5.9	0.86
-6 mesh × 20 mesh	90.3	12,410	5.2	0.73
Combined	94.5	12,350	5.6	0.80
Nástup Lignite				
-¼ in. × 6 mesh	93.1	9270	24.5	1.70
-6 mesh × 20 mesh	80.4	9860	19.5	1.76
Combined	87.7	9500	22.6	1.72

Preliminary results with the Nástup lignite indicate poor performance using REMS at a size of ¼ in. × 20 mesh; however, insufficient testing was done to completely assess the suitability of REMS for treating Nástup lignite.

4.2.3 Carbonization

The yields of char produced by carbonization of the Bílina lignite dry physical cleaning product and the Ostrava bituminous coal were determined to be approximately 39 and 75 wt%, respectively. The sulfur contents of the char products were lower than the carbonization feedstocks, indicating that sulfur was liberated in gaseous form. The sulfur content of the Bílina lignite dry physical cleaning char product was 0.62 wt% mf, which compared to 0.80 wt% mf for the Bílina lignite dry physical cleaning product and 1.1 wt% mf for the raw Bílina lignite. Sulfur liberation was substantial as the char product contained only 43% of the precarbonization feed coal sulfur. The sulfur contents of the Ostrava bituminous coal and carbonization product char were 0.44 wt% and 0.40 wt%, respectively, indicating that approximately 20 wt% of the sulfur was liberated by carbonization.

4.3 COAL AND COAL CHAR TABLETING

Analysis data for the briquette tablet products prepared from the Ostrava bituminous coal, the Bílina lignite wet physical cleaning product, the carbonized Ostrava bituminous coal, and the Bílina dry physical cleaning char product are presented in Table 4. Preliminary results show that the sulfur contents of all four tablet fuels fall well under the new quality standards in the Czech Republic. These standards regulate the maximum sulfur content for lignite and hard coals, briquettes, and liquid fuels utilized in household, business, or energy installations that are not equipped with sulfur emission abatement devices. For example, the maximum sulfur levels for indigenous lignite utilized for household or business activities are 1.07 and 1.65 g/MJ, respectively. Similarly, the maximum sulfur levels for indigenous hard coal utilized for household or business activities are both 0.78 g/MJ, respectively (4).

The sulfur contents for tablet fuels prepared from the Ostrava bituminous coal, the Bílina wet physical cleaning product, the carbonized Ostrava bituminous coal, and the Bílina dry physical cleaning char product were determined to be 0.13, 0.25, 0.14, and 0.23 g/MJ (lower heating value), respectively. These values compare to an allowable maximum of 0.60 g/MJ for indigenous briquettes prepared for residential heat or steam raising, thus qualifying all four fuels for application as district heating fuel. Further, adding calcium carbonate during tablet preparation produced molar calcium-to-sulfur ratios of 2.7 in the Bílina wet physical cleaning product fuel and 3.1 in the carbonized Bílina dry physical cleaning product fuel, thus theoretically reducing the emissions-effective sulfur content below 0.25 and 0.23 g/MJ, respectively.

TABLE 4

Analysis Results of Four Tableted Heating Fuels

Coal: Treatment:	Ostrava None	Bílina 4 Float–Sink	Ostrava Carboniz.	Bílina 4 REMS/Carboniz.
Moisture, wt%	1.0	6.2	1.5	2.2
Proximate, wt% mf[1]				
Volatile Matter	29.9	52.7	11.8	15.5
Fixed Carbon	64.3	40.3	80.8	72.9
Ash	5.8	7.0	7.4	11.6
Ultimate, wt% mf				
Hydrogen	4.8	4.8	1.7	1.5
Carbon	83.0	66.0	85.7	79.4
Nitrogen	1.2	0.9	1.3	1.2
Sulfur	0.43	0.61	0.38	0.56
Oxygen	4.8	20.7	3.5	5.8
Ash	5.8	7.0	7.4	11.6
Heating Value, Btu/lb mf	14,320	11,500	13,320	12,390
Ash XRFA, wt% as oxide				
Silicon	43.9	18.9	43.1	30.7
Aluminum	29.3	13.7	26.2	21.4
Iron	11.5	1.9	12.0	4.2
Titanium	1.0	0.6	1.0	1.1
Phosphorus	0.1	0.4	0.1	0.5
Calcium	3.2	41.5	5.6	26.2
Magnesium	3.2	4.4	3.4	3.2
Sodium	0.9	1.2	1.5	1.6
Potassium	1.6	0.6	1.4	0.8
Sulfur	5.3	16.8	5.7	10.4
Apparent Density, lb/ft^3	69	53	65	64
Compressive Strength, lb/in^2	290	80	220	90

[1]Moisture-free.

The weight percentages of volatile matter in the briquette tablet fuels prepared from the carbonized Ostrava bituminous coal and the carbonized Bílina dry physical cleaning product were determined to be 11.8 and 15.5, respectively. Volatile matter content of the carbonized Ostrava bituminous coal easily met the arbitrary, but long-established, limit of 15 wt% to qualify as a smokeless fuel for home heating application. Although marginally above this value, the volatile matter content of the Bílina dry physical cleaning char product fuel can easily be brought into specification as a home heating fuel through slight modifications to the carbonization conditions (e.g., temperature, residence time).

Preliminary strength analysis indicates that the briquette tablets have good strength, ranging from 80 to 290 $lb/in.^2$, and were higher for the Ostrava bituminous coal-based fuels. Carbonization had the apparent positive effect of increasing the density and compressive strength of the Bílina lignite, presumably by the destruction of pore volume. The opposite effect was observed upon carbonization of the Ostrava bituminous coal.

Positive attributes of the prepared densified fuel relative to their parent coal include lower as-fired moisture content and higher as-fired heating value and convenience in handling. The former attribute would reduce the size of live or active storage and reduce the size and power requirements for conveyors, augers, and feeding devices on district heating systems. Further, the chemical homogeneity and size uniformity of briquette tablet (or aggregated) fuels would enhance predictability in operation of heat or steam-raising stoves and boilers. Similarly, for domestic or home heating applications, the time between fuel charges to the heating appliance would be reduced. The handling of combustion residues will be reduced for both applications, and with the proper selection of densification system and parameters, binders, and waterproofing agent, the fuel will be stable toward weathering and dust generation.

4.4 TABLET COMBUSTION

The TGA combustion (mass loss) profiles for the four fuels are presented in Figure 2. Preliminary TGA combustion tests indicated that there were no difficulties burning the four fuels. All four fuels exhibited an initial devolatilization stage during which the mass loss agreed quite well with the mass percentage of moisture plus volatile matter, as determined by proximate analysis. The rate of devolatilization was more rapid with the wet physical cleaning product of the Bílina lignite and the raw Ostrava bituminous coal. The Bílina lignite wet physical cleaning tablet fuel exhibited the fastest burnout rate after devolatilization, indicating a highly reactive char relative to the other fuels after the devolatilization stage. The carbonized Ostrava bituminous coal and carbonized Bílina dry physical cleaning product exhibited similar reactivity, with burnout rates slightly less than that of the raw Ostrava bituminous coal.

Preliminary results of gas analysis by FT-IR spectroscopy indicate that SO_2 and NO_x were below detectable limits of 10 and 50 ppm, respectively. Dilution caused by the high combustion air rate inhibited the measurement of the amounts of SO_2 and NO_x. FT-IR spectrometric analysis also indicated that the carbonized fuel tablets had the lowest HC emissions relative to the noncarbonized fuel tablets. The initial HC emission levels were nearly proportional to the volatile matter content of each as-fired fuel.

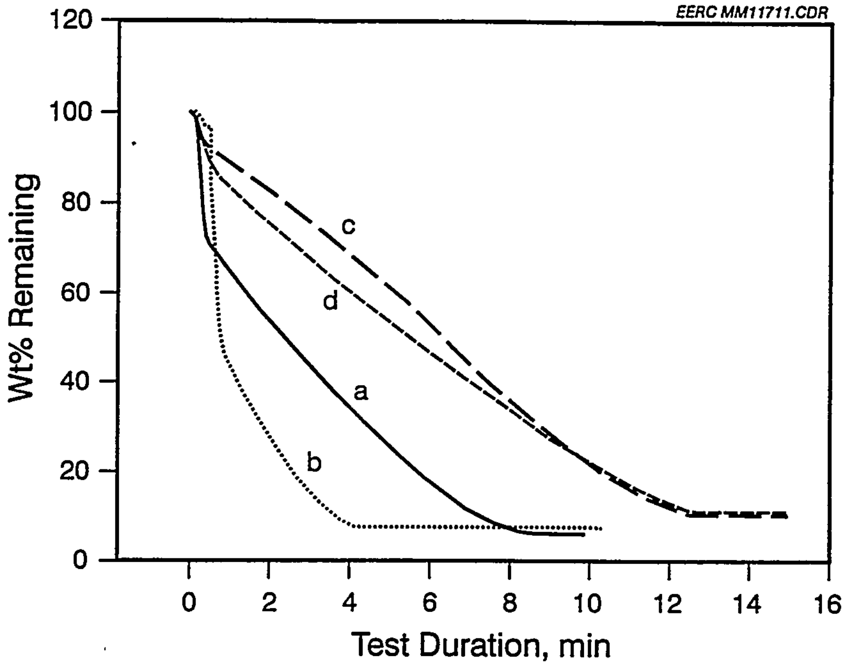

Figure 2. TGA combustion profiles for tableted Czech Republic coals: a) raw Ostrava bituminous, b) float–sink-cleaned Bílina No. 4 lignite, c) carbonized Ostrava bituminous coal, d) and REMS cleaned/carbonized Bílina No. 4 lignite.

5.0 CONCLUDING REMARKS

Coal mining output in the Czech Republic has declined significantly over recent years. In 1993, over 18 million tons of hard (black) coal and almost 67 million tons of brown coal were mined (1). For residential use, the black coal containing relatively low sulfur (0.6 wt%) would need to be carbonized, preferably under mild conditions to reduce the tarry vapors and soot formation during combustion as a home heating fuel. Briquetting of the carbonized product, char, would at the same time increase the convenience and acceptability of this solid fuel.

The production of clean energy from brown coal and lignite is a major concern for the Czech Republic given this large fuel resource with not only high moisture but relatively high sulfur content. Mild gasification of these coals followed by briquetting is one option. Alternatively, the coal can be briquetted with binders and other additives to reduce emissions and improve heating values (i.e., efficiency). A case in point is a new German briquetting process that blends lignite with a waste lime product from a calcium carbide plant's anthracite fines, dries the mixture to at least 19 wt% moisture, and briquettes the blend in a stamping press (8).

Preliminary testing at the EERC has shown that beneficiation technologies based on the float–sink principle can effectively reduce the sulfur and ash content of Bílina lignite, a significant coal reserve in the North Bohemia region of the Czech Republic. Further, dry beneficiation via REMS can also produce appreciable reduction in sulfur; optimization of this process with the Bílina lignite may allow product yields and sulfur reduction to approach those values derived from wet gravity-based separations. Nástup lignite, also mined in the North Bohemia region, is not amenable to sulfur reduction at the 1/4- × 20-mesh fraction via conventional wet gravity-based methods or REMS.

Given the new quality standards introduced in 1994–1995 in the Czech Republic for the allowable maximum sulfur content (0.60 g/MJ) of indigenous fuel briquettes, briquette tablet fuels prepared here from raw Ostrava bituminous coal from Moravia and a float–sink-cleaned Bílina lignite would qualify as fuels for steam raising in commercial and industrial boiler installations. Further, briquette tablet fuels prepared from carbonized Ostrava bituminous coal and carbonized Bílina REMS product would qualify as smokeless fuels for home heating applications by virtue of their sulfur content and volatile matter content. Both Bílina lignite-derived fuels when briquetted with calcium carbonate would exhibit, on combustion, potentially lower sulfur dioxide emissions and compare favorably with those from the low-sulfur-content Ostrava fuels.

Hence, through beneficiation, carbonization, and briquetting technologies, suitable fuels could be produced from Bílina and Ostrava coals for use in home and district heating as well for commercial and industrial boilers in cities like Ústí nad Labem. However, pilot- and demonstration-scale beneficiation and combustion testing need to be undertaken for optimization of the fuel properties and heating equipment and characterization of the emissions. In addition, an economic evaluation comparing the cost benefits of fuel upgrading to other methods of achieving emission reduction is required before implementing the discussed upgrading technologies.

6.0 ACKNOWLEDGMENTS

The authors express their appreciation and thanks to Dr. Z. Krivsky, North Bohemia Economic Association, for supplying information and for his helpful discussions and comments. Thanks are also due to Mr. William Fedarko, U.S. DOE, for his encouragement and support, and to Mr. Richard Merwin of ERIEZ Magnetics for undertaking the REMS tests. The EERC gratefully acknowledges the sponsorship of the U.S. Agency for International Development for the program monitored by the DOE Office of Fossil Energy.

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