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EMISSIONS REDUCTIONS IN COAL-FIRED HOME HEATING STOVES THROUGH USE OF BRIQUETTES

Quarterly Report:
for the period of April 1, 1995 to June 30, 1995

Cooperative Agreement No. DE-FC22-94PC94116
DOE Project Officer
Thomas J. Feeley, III

Submitted by:

Acurex Environmental Corporation
4915 Prospectus Drive
P.O. Box 13109
Research Triangle Park, NC, 27709

Submitted to:

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Executive Summary

This period has seen additional briquette testing at AGH. In addition, Euromining has completed large-scale briquette production. All multi-ton batches were delivered. Testing was performed at INCO and PEC Chrazanów. The product market testing has been performed. PCI has delivered a draft Commercial Report to AEC which will be revised and finalized in the next period.

Introduction/Background

The work to be performed is part of the program in the Support for Eastern European Democracy (SEED) Act of 1989 (P.L. 101-179). Following the guidance of this legislation, a U.S.-Poland Bilateral Steering Committee (BSC) was established to define the program. The BSC is directing a program of assistance to Poland that would reduce air pollution in Kraków, Poland from about 1,300 boiler houses that provide heat for industrial, commercial, and residential applications, in addition to 100,000 small stoves for home heating. The 1,300 boiler houses and 100,000 home heating stoves in Kraków primarily use solid fossil fuels and have been collectively called "low emissions sources" because of their low stack heights and the consequent low-level entry of flue gases into the ambient air.

In October 1991, a Memorandum of Understanding (MOU) was signed by the U.S. Department of Energy (DOE) and the Ministry of Environmental Protection, Natural Resources and Forestry of the Republic of Poland. The MOU is titled, "Collaboration on the Kraków Clean Fossil Fuels and Energy Efficiency Program, A Project of Elimination of Low Emission Sources in Kraków." This MOU describes the cooperation that is being undertaken by the governments of the United States and the Republic of Poland to accomplish this program. Funding for this program is being provided through the Agency for International Development (AID).

The purpose of the program is to encourage the formation of commercial ventures between U.S. and Polish firms to provide equipment and/or services to reduce pollution from low emission sources in Kraków, Poland. These commercial ventures may take the form of contracts, joint ventures, partnerships, or any other commercially feasible arrangements that accomplishes the purposes of the statute.

SPECIFIC OBJECTIVES OF THE PROJECT

The objective of the work to be conducted by Acurex Environmental Corporation is to create a commercially successful venture to market a low emission coal briquette to the residential heating market in Kraków. During Phase I, small quantities of the briquetted product will be manufactured and tested. Five Polish coals and two Polish sources of binder material will be tested to determine their amenability to forming briquettes. Small-scale combustion tests will also be performed during Phase I to determine the effectiveness of the briquettes to reduce emissions. A preliminary engineering review of the plant will also be performed. Construction of a new plant in Katowice to serve the Kraków market is being considered.

APPROACH

The approach taken during Phase I is to develop an optimum briquette formulation using Polish raw materials. This "optimum" is determined by the physical characteristics as well as the ability of the briquette to reduce organic emissions during

combustion. This work is being done at the briquetting and combustion laboratories of the AGH in Kraków. Once the optimum formulation has been determined during these laboratory experiments, larger quantities will be manufactured at the Briksol facility of Euromining Consulting, Inc. in Bogdanka, Poland. These briquettes will be used for marketing studies of the Kraków consumer market, as well as larger scale combustion tests at INCO Veritas and PEC at Chrzanów. Business development will proceed in parallel with research of the Kraków residential heat market, preparations for formation of a joint venture company, and development of a business plan for the new company. Planmar Consulting, Inc. (PCI) will assist Acurex Environmental in its business development activities.

ACCOMPLISHMENTS DURING THE QUARTER

Accomplishments for this quarter include the following:

- Project oversight trips to Poland by Project Manager and Planmar representative
- Project Review Meeting between DOE and AEC held on May 9, 1995
- Presentation before the Bilateral Steering Committee on June 27, 1995
- Continued briquette testing at AGH
- Continued combustion testing at AGH
- Submitted results of organic analysis by AGH
- Completed Task I.T.3, briquette production
- Completed Task I.T.4, INCO tests
- Completed Task I.T.5, PEC Chrzanów tests
- Completed Task I.C.2, investigate distribution systems
- Completed Task I.C.8, Market Testing
- Completed Task I.C.9, Commercial Report

DISCUSSION

This quarter has been a period of management, technical, and business progress. A project review meeting was held with DOE. A project status presentation was made before the Bilateral Steering Committee. Briquetting experimentation and combustion testing continued at AGH. Large scale briquette production at Euromining was completed; providing the quantities needed for testing at INCO Veritas and PEC Chrzanów, and the with-product market testing. Test programs were completed at INCO Veritas and PEC, Chrzanów. The with-product market testing was performed during this period. PCI also supplied revised business plans during this period.

A project review meeting was held at RTP, NC on May 9, 1995 between AEC and DOE. Tom Feeley and Doug Gyorke represented DOE. The AEC presentation included the financial and schedule status. We also presented technical data which included the Academy's briquetting and combustion studies, the optimized briquette recipe, and preliminary results for the work at Euromining and INCO. Commercial data was also presented regarding the Kraków market size and the preliminary market survey.

The Bilateral Steering Committee requested a presentation of the project status at their June 27th meeting at Brookhaven National Laboratory. This presentation focused on the project's preparedness to proceed into Phase II, if extended by DOE.

Testing continued at the briquetting laboratory of the Academy. The primary results from this period include a formulation study using fines prepared from chunk Brzeszcze coal and a study which revisited the question of dry mixing versus wet mixing. In addition to these studies, they continued to prepare formulations for combustion testing. The first study was done to provide laboratory studies which paralleled the large-scale briquetting done by Euromining. The second study was performed after discussions with Euromining in which they expressed the complications introduced into a manufacturing site by a wet mixing process.

While AEC is convinced that the wet mixing technique produces the best product, Euromining's concerns about the extra complications that it adds to the manufacturing process, whether at Briqpol or a future commercial site, are valid. Wet mixing is a two stage mixing process as compared to the single stage dry mixing technique. The wet mixing will require additional hardware and land usage or staged additions of raw materials at a single mixing station. It also requires the addition of excess water followed by the removal of that excess water prior to the pressing stage. In a production facility this could likely be a centrifugation step rather than evaporation. Again, this calls for additional hardware and land usage which the dry mixing technique does not require.

Tables 1 and 2 present additional sieve analysis data for two cuts of coal fines resulting from the crushing of chunk Brzeszcze coal. The crushed coal samples of Tables 1 and 2 differ significantly from the comparable washed Brzeszcze fines discussed in Table 2 of the previous quarterly report. Table 3 presents a comparison of these four samples.

TABLE 1. SIEVE ANALYSIS DATA FOR 0 - 2 mm CRUSHED BRZESZCZE CHUNK COAL

Cut [mm]	Percentage Found [%]
1.600 - 2.000	19.40
1.000 - 1.600	19.1
0.630 - 1.000	19.25
0.400 - 0.630	12.38
0.250 - 0.400	12.22
0.160 - 0.250	9.63
0.075 - 0.160	5.73
0.045 - 0.075	1.53
< 0.045	0.76

TABLE 2. SIEVE ANALYSIS DATA FOR 0 - 4 mm CRUSHED BRZESZCZE CHUNK COAL

Cut [mm]	Percentage Found [%]
3.000 - 4.000	12.82
2.000 - 3.000	9.35
1.000 - 2.000	11.24
0.800 - 1.600	24.44
0.630 - 0.800	6.19
0.400 - 0.630	10.99
0.320 - 0.400	4.97
0.200 - 0.320	6.01
0.160 - 0.200	2.56
0.100 - 0.160	4.02
0.071 - 0.100	2.11
0.056 - 0.071	1.38
<0.056	3.92

TABLE 3. COMPARISON OF WASHED BRZESZCZE FINES WITH THOSE
PREPARED BY CRUSHING CHUNK BRZESZCZE COAL

	median size (mm)	0-0.16 mm cumulative percent
Washed Brzeszcze fines		
0-2 mm	0.63-1 mm fraction	11.3
0-4 mm	1.6-2 mm fraction	4.15
Crushed chunk Brzeszcze coal		
0-2 mm	0.63-1 mm fraction	8.02
0-4 mm	0.8-1.6 mm fraction	11.4

These fines prepared by crushing chunk coal were used in the preparation of briquettes using Chrzanów and Gliwice additives. The Chrzanów additive was used initially since this additive was specified in the formulation sent to Euromining for the large-scale briquetting work. This data is found in Table 4. As expected, the optimum moisture was found in the range of 11 to 12 percent. The Academy noted, however, that the aged drop shatter resistance results were somewhat lower than expected. Investigations into the cause of this led to the finding that this batch of fines had somewhat brittle coal granules.

As described in the previous quarterly, Euromining experienced difficulties when attempting to use the Chrzanów additive. In fact, equipment breakdown occurred. The mixer shaft sheared when attempting to mix Chrzanów additive (obtained as very large chunks) with water. In all likelihood this could have been prevented by crushing the additive on-site prior to the mixing stage but the Brikpol facility is not equipped with that hardware. Due to this, the Gliwice additive was located and the Academy performed formulation experiments with this material. The results are found in Table 5. For this study, the 0-4 mm fines prepared by crushing chunk coal was used. The optimum moisture again is in the 11-12 percent range. The green and aged drop shatter resistance results are considerably lower in these tests than in previous studies using Brzeszcze fines. This is attributed to the coarse grade of coal fines used here. It should be noted that previous supplies of fines were exhausted and unavailable for further study.

Table 5, along with Tables 6 and 7, present the results of new investigations into the mixing process. As Table 5 demonstrates, wet mixing is superior to the dry mixing technique. This is exactly in keeping with the previous findings on this issue.

TABLE 4. BRIQUETTE FORMULATION DATA FOR BRZESZCZE FINES
WITH CHRZANÓW ADDITIVE; 450 mm PRESS

AGH Test #	Mixing	%	%	Drop Shatter Test	
				Immediate	After 48 h
150	wet slurry	14.3	13.1	98.6	77.5
151	wet slurry	14.3	12.1	98.5	79.2
152	wet slurry	14.3	11.6	98.7	87.6
153	wet slurry	14.3	10.7	97.9	87.8
154	wet slurry	14.3	8.9	83.6	68.7
155	wet slurry	14.3	5.6	30.2	18.8

TABLE 5. MIXING STUDY; DRY MIX VERSUS WET SLURRY TECHNIQUE;
BRIQUETTE FORMULATION DATA FOR BRZESZCZE FINES, FROM CRUSHED
CHUNK COAL, WITH GLIWICE ADDITIVE; 450 mm PRESS

AGH Test #	Mixing	%	%	Drop Shatter Test		Aged Compression Strength [N]
				Immediate	After 48 h	
156	dry	14.3	13.4	39.9	49.3	56
157	dry	14.3	10.0	48.5	51.5	65
158	dry	14.3	9.1	52.3	37.4	41
159	dry	14.3	8.3	48.3	37.0	36
160	dry	14.3	6.1	11.7	0	24
161	wet slurry	14.3	12.8	76.5	65.5	41
162	wet slurry	14.3	11.7	80.2	69.8	43
163	wet slurry	14.3	10.5	70.1	40.4	46
164	wet slurry	14.3	10.1	81.2	31.0	38
165	wet slurry	14.3	9.3	57.0	21.8	26
166	wet slurry	14.3	8.9	42.5	12.8	30
167	wet slurry	14.3	7.8	0	6.7	17

TABLE 6. MIXING STUDY; DRY MIX TECHNIQUE FOR 24 HOURS;
BRIQUETTE FORMULATION DATA FOR BRZESZCZE FINES, FROM
CRUSHED CHUNK COAL, WITH GLIWICE ADDITIVE; 450 mm PRESS

AGH Test #	Mixing	%	%	Drop Shatter Test		Aged Compression Strength [N]
				Immediate	After 48 h	
168	dry	14.3	12.6	93.9	81.1	67
169	dry	14.3	11.8	94.4	68.5	59
170	dry	14.3	10.7	82.2	58.5	69
171	dry	14.3	9.2	41.8	43.2	45

TABLE 7. MIXING STUDY; WET SLURRY TECHNIQUE FOR 24 HOURS;
BRIQUETTE FORMULATION DATA FOR BRZESZCZE FINES, FROM CRUSHED
CHUNK COAL, WITH GLIWICE ADDITIVE; 450 mm PRESS

Test #		%		Drop Shatter Test		Aged Compression Strength [N]
		Binder	Water	Immediate	After 48 h	
AGH	Mixing					
172	wet slurry	14.3	11.7	97.3	77.8	55
173	wet slurry	14.3	10.2	88.8	58.6	44
174	wet slurry	14.3	9.1	65.5	31.7	47
175	wet slurry	14.3	7.9	48.5	0	39

The process was investigated further by adding 24 hours of mixing time after the addition of the final component to the mix. Table 6 presents the results for the mixing of the dry components, followed by the addition of an exact quantity of water, followed by 24 hours of mixing. Table 7 presents the results for the mixing of the additive with an excess of water, followed by the addition of coal fines, followed by 24 hours of mixing during which the water is also evaporated to the target moisture content.

Comparison of Tables 6 and 7 with Table 5 clearly shows that the extra time improves the drop shatter test results. If we estimate a result for the dry mix technique with 11.7 percent water we see that the aged drop shatter test results would follow the following trend:

- dry mix 50.4 %
- wet mix 69.8 %
- dry mix with time 68.5 %
- wet mix with time 77.8 %

It is clear that the additional mixing time is a significant improvement irrespective of the mixing technique. This is probably due to improved homogeneity of the mix. There may also be an effect due to improved dispersion of the additive since it must be noted that the wet mixing technique continues to provide superior results for equivalent mixing times. Comparison of AGH tests 156 and 157 with 168 and 169 may suggest that the additional mixing time shifts the optimum moisture content to a higher value. An experiment at 12.6 percent moisture content using the wet mix with time technique might have provided some interesting data on this point. Finally, additional mixing time may also improve the compression strength. The data is less clear on this point.

What impact these results will have on the design of a production facility is unclear. AEC has been convinced from the commencement of this project that a wet mixing technique would provide the superior product; all results to date have only served to confirm this idea. At the same time, it is also clear that a 24 hour mixing step is not

practical outside the laboratory. AEC will enter the facility design task of Phase II with the intent of incorporating a wet mixing process.

It should also be noted that these most recent laboratory results provide an incomplete story. First it is unclear that the entire 24 hours are required to provide the noted improvements. It is possible that the time effect is non-linear and 4 hours, as an example, could provide all the improvements noted during these tests. Second, if the noted improvements are primarily due to improved additive dispersion, then the use of dispersing agents would provide similar improvements without the extra time requirement. Additionally, incorporating an additive slurry holding pond between the two mixing steps would provide the additional time without incurring additional operating costs.

The Briquetting Laboratory of the Academy also provided support to the combustion tests by manufacturing several multi-kg batches of selected formulations. This data is found in Table 8 and is a continuation of Table 5 from the fourth quarterly report. In Table 8 note that sample XXIII was mixed using a saturated calcium hydroxide solution instead of water; sample XXIV was mixed by the dry technique; and sample XXV was mixed by the wet mix with time technique.

Work continued at the Combustion Laboratory with the testing of briquettes in the tile stove. Table 9 presents the fuel analysis data for the new fuels and is a continuation of Table 6 from our fourth quarterly. Tables 10 and 11 present the details of sampling conditions and facility operation during these tests. These are continuations of Tables 7 and 8 from our fourth quarterly. As in the previous reports, each fuel was burned in replicate runs. Each change in fuel was preceded by a stove cleaning and a stove conditioning with the new fuel. Data acquired during the conditioning run is not included in any calculated averages. The reader is referred to the previous report for a description of Table 11's data presentation.

Table 12 presents the results of particulate capture and impinger sample analysis along with combustible analysis on the ash pit and grating residues. As described in the third quarterly, Meo, impinger organic extractables, was not performed from Test No. 091914 onwards. Table 13 presents the integrated reactive gas emissions for the individual runs along with the calculated thermal efficiency for each run and the loss factors used in that calculation.

Table 14 presents reactive gas, particulate, and thermal efficiencies on a per kg of fuel basis and averaged across the individual tests; whereas Table 15 presents the same data calculated on a per MJ energy basis. In these two tables there are entries for a "BR-IBOGa", that does not appear in Tables 9-13. This entry represents the results for sample BR-IBOG with additional kindling (runs 033083 and 033184). This may be observed in Table 10. The earliest runs with sample BR-IBOG were performed with the standard amount of kindling, ~160 grams of dry wood. It was found that this sample, unlike previous briquettes did not ignite properly with the standard kindling. Stove temperature

rose slowly, etc. For the last two runs with this sample the kindling mass was increased by 25 percent. This corrected the ignition problem and, as these two tables show, improved the thermal efficiency and the emissions. This improvement is significant enough that we felt it needed to be noted. In these tables BR-IBOG presents the average results for all three runs.

Table 16 presents the available GRAV and TCO data. In this table it should be noted that, from sample BR-VIIIBK onwards, TCO and GRAV were performed on combined particulate and XAD-2 resin extracts. Separate XAD-2 and particulate data are, therefore, unavailable for the later samples. This change was made in the interests of time and fiscal efficiency. Table 17 presents the available PAH (polynuclear aromatic hydrocarbons) data on a mg/MJ basis. Finally, Table 18 summarizes the combustion tests in terms of thermal efficiency and Equivalent Emissions (EE). As described in the previous quarterly, we would expect a quality briquette to have efficiencies greater than 71 percent and an EE appreciably lower than 3.4 (values found for quality chunk coal under these test conditions).

Recognizing that samples BR-IS, BR-IM, BR-IIC, BR-IIIC, BR-IIIK, BR-IIIB, BR-IVK, BR-IVB and BR-VBB represent small (450 mm press) briquettes we can note from Table 15 and Table 18 that these samples, as a group, have much more variability in their data than do the larger (1100 mm press) briquettes. Since the initial combustion tests were performed with small briquettes out of a concern for a potential ignition problem - which has largely proved unfounded - it is reasonable to concentrate on the results from the large briquettes. This is true from several points of view:

- the small briquettes are associated with laboratory-scale press equipment rather than production equipment
- the larger briquettes are demonstrably stronger in the briquetting laboratory's studies
- production rate will be greater with large briquettes
- ignition has not proven to be an insurmountable problem with the large briquettes
- generally, the high thermal efficiency results are associated with the large briquettes
- generally, the low emissions are associated with the large briquettes

The figures presented here, therefore, present data for large briquettes rather than all samples. The one tested cast briquette sample, BRF-XBC, is also included since it is an interesting outlier. Where possible, the data for BR-IBOGa is also presented separately from the BR-IBOG averaged data.

TABLE 8. FORMULATION AND PHYSICAL TEST DATA FOR COMBUSTION BATCHES

Batch	Coal	Fraction	Binder	Binder %	Water %	Size	Dropping resistance (%)		Compression strength (N)
							Green	Aged	Aged
IV	ground Siersza	0-2 mm	Chrzanów	20.0	27.1		98.3	93.9	65
V	ground Wujek	0-2 mm	Chrzanów	14.3	10.7		97.1	91.4	60
VI	ground Wujek	0-2 mm	Kraków	14.3	10.3		96.5	94.2	78
VII	ground Wujek	0-2 mm	Bentonit	14.3	10.5		99.2	91.4	68
VIII	washed Brzeszcze fines	0-2 mm	Kraków	14.3	12.5	small	99.1	94.9	102
IX	washed Brzeszcze fines	0-2 mm	bentonit	7.4	11	small	97.6	96.1	110
X	washed Brzeszcze fines	0-2 mm	Kraków	10	11.8	small	98.9	86.2	83
XI	washed Brzeszcze fines	0-2 mm	Kraków	10	10.7	large	82.8	80.9	335
XII	washed Brzeszcze fines	0-2 mm	glikocel	1	12.7	large	98.9	98.7	848
XIII	washed Brzeszcze fines	0-2 mm	Kraków + glikocel	11	13.5	large	98.1	96.8	314
XIV	washed Brzeszcze fines	0-2 mm	Kraków + bentonit	9.5	12.2	large	92.4	85.5	382
XV	washed Brzeszcze fines	0-2 mm	Kraków	14.3	13.0	large	99.1	95.9	478
XVI	washed Brzeszcze fines	0-4 mm	Chrzanów	14.3	9.3	large	76.1	70.7	171
XVII	washed Brzeszcze fines	0-4 mm	Kraków	14.3	9.2	large	80.5	79.4	214
XVIII	graded coal sludge		Kraków	10	13.2	large	98.2	94.8	469
XIX	washed Brzeszcze fines	0-2 mm	Chrzanów	14.3	9.5	large	94.5	76.2	262
XX	washed Janina fines	0-2 mm	Chrzanów	14.3	24.4	large	99.4	68.7	262
XXI	washed Brzeszcze fines	0-2 mm	Chrzanów	14.3	27.9	cast ¹		36.7	212
XXII	washed" Brzeszcze" fines	0-2 mm	Chrzanów	20	37.1	cast		72.6	240
XXIII	washed Brzeszcze fines	0-2 mm	Chrzanów	14.3	27	cast		82.3	297
XXIV	Crushed chunk Brzeszcze	0-4 mm	Gliwice	14.3	11.4	large	98.5	78.9	203
XXV	Crushed chunk Brzeszcze	0-4 mm	Gliwice	14.3	11	large	94.4	76.1	212

¹ cast size = 30 mm diameter x 50 mm length cylinder

TABLE 9. CHARACTERISTICS OF FUELS USED DURING TESTING

FUEL	Qi [kJ/kg]	St [%]	V [%]	Fuel Composition, mass %						
				C	H	S	N	O	W	A
Wujek coal WU-PL washed	31793	0.52	32.10	81.20	4.88	0.33	1.35	6.54	2.7	3.00
Wujek coal WU-PL/S chunks	32157	0.48	32.00	81.47	5.13	0.30	1.28	6.02	2.8	3.00
Wujek chunk coal average	31975	0.50	32.05	81.335	5.005	0.315	1.315	6.28	2.75	3.00
Briquettes I BR-IS Baranów binder dry mixed	18165	1.05	20.98	45.89	3.06	0.76	0.76	6.70	4.1	38.73
Briquettes I BR-IM Baranów binder wet mixed	18250	1.04	20.77	45.79	3.07	0.70	1.32	6.48	4.4	38.30
Briquettes II BR-IIC Chrzanów binder	20527	0.90	24.41	53.46	3.25	0.36	0.84	7.25	4.0	30.84
Briquettes III BR-IIIC ground Wujek coal Chrzanów (14.3%) binder, 10.7% water wet mixed, small briquette*	25746	0.47	27.47	64.47	4.08	0.23	1.14	7.02	8.7	14.36
Briquettes III BR-IIIK ground Wujek coal Kraków (14.3%) binder, 10.3% water wet mixed, small briquette	26608	0.50	27.36	66.95	4.18	0.29	1.24	6.56	8.2	12.58
Briquettes III BR-IIIB ground Wujek coal Bentonit (14.3%) binder, 10.5% water wet mixed, small briquette	25648	0.37	26.31	65.43	4.22	0.28	1.17	5.42	8.5	14.98
Washed Brzeszcze fines	27252	0.7	29.9	68.74	4.4	0.63	1.24	7.99	3.4	13.6
Briquettes IV BR-IVK washed Brzeszcze fines Kraków (14.3%) binder, 12.5% water wet mixed, small briquette	22628	0.62	25.31	58.13	3.92	0.45	1.19	6.05	10.0	20.26

FUEL	Qi [kJ/kg]	St [%]	V [%]	Fuel Composition, mass %						
				C	H	S	N	O	W	A
Briquettes IV BR-IVB washed Brzeszcze fines Bentonit (8%) binder, 11.0% water wet mixed, small briquette	25677	0.58	27.91	63.56	4.25	0.54	1.24	8.11	4.1	18.2
Briquettes BR-VBB washed Brzeszcze fines Kraków (10%) binder, 11.8% water small briquette	24952	0.63	27.45	62.61	3.92	0.49	1.17	6.74	6.31	18.76
Briquettes BR-VIBB washed Brzeszcze fines Kraków (10%) binder, 10.7% water large briquette‡	24155	0.63	27.96	64.02	4.25	0.58	1.23	7.98	4.26	17.68
Briquettes BR-VIIBG washed Brzeszcze fines Glikocel (1%) binder, 12.7% water large briquette	26542	0.64	25.76	62.98	4.18	0.61	1.18	7.75	9.09	14.21
Briquettes BR-VIIBK washed Brzeszcze fines Kraków (10%) + Glikocel (1%) binder 13.5% water large briquette	23589	0.71	27.15	62.68	4.22	0.64	1.17	6.83	5.06	19.39
Briquettes BR-VIIIBK washed Brzeszcze fines Kraków (14.3%) binder 13.0% water large briquette	23385	0.75	26.21	59.54	3.94	0.6	1.11	6.71	5.55	22.55
Briquettes BR-VIIIBC washed Brzeszcze fines (0-4 mm) Chrzanów (14.3%) binder 9.3% water large briquette	24034	0.73	26.18	60.59	3.71	0.3	1.05	7.16	4.66	22.53
Briquettes BR-IXBK washed Brzeszcze fines (0-4 mm) Kraków (14.3%) binder 9.2% water large briquette	24377	0.69	25.19	61.76	3.9	0.49	1.16	6.39	4.07	22.23

(continued)

FUEL	Qi [kJ/kg]	St [%]	V [%]	Fuel Composition, mass %						
				C	H	S	N	O	W	A
Chunk Brzeszcze coal	29268	0.31	30.44	73.9	4.72	0.3	1.21	8.02	5.74	6.11
BRF-XBC Washed Brzeszcze fines, Chrzanów (14.3%) binder cast briquette	25220	0.67	27.15	63.05	3.98	0.26	1.12	7.63	2.7	21.26
BR-IBOG Washed Brzeszcze fines, Gliwice (14.3%) binder large briquette	23449	0.30	26.79	61.49	4.06	0.3	1.08	7.68	6.79	18.8
BR-IIBOG Brzeszcze, Gliwice binder large briquette	27494	0.44	30.13	70.04	4.64	0.4	0.91	8.19	5.84	9.98

Where: C,H,S,N,O,W,A—respectively: carbon, hydrogen, combustible sulfur, nitrogen, oxygen, moisture content, ash

Qi—fuel heating value

St—total sulfur

V—volatile content

* "small briquette" indicates preparation on the 450-mm press

‡ "large briquette" indicates preparation on the 1100-mm press

(continued)

TABLE 10. MASS OF FUEL COMPONENTS, UNBURNT MATERIALS
AND AMBIENT THERMODYNAMIC PARAMETERS

FUEL	Test No.	Mass of fuel added	Kindling	Previous run unburnt fuel retained	Mass of unburnt fuel (grating)	Mass of ash pit residue generated	Atmospheric conditions		
		Mw [kg]	Md [kg]	Mk [kg]	Mkd [kg]	Ma [kg]	to [deg.C]	Po [Pa]	fio [%]
Wujek coal WU-PL washed	081101	4.006	0.174	0	0.424	0.360	22	98000	67
	081202	4.002	0.186	0.424	0.376	0.326	21	98300	60
	081303	4.002	0.168	0.376	0.414	0.332	21	95000	63
	081404	4.001	0.166	0.414	0.350	0.316	20	99000	46
Briquettes I BR-IS Baranów binder dry mixed	081705	5.890	0.170	0	2.270	0.768	19	98700	58
	081806	5.888	0.182	1.860	4.000	0.766	19	98100	62
	081907	5.890	0.170	2.066	4.330	0.518	18	98000	53
Briquettes I BR-IM Baranów binder wet mixed	082008	6.452	0.160	0	2.900	0.466	18	98200	62
	082109	6.456	0.172	1.388	4.160	0.564	18	99000	56
	082210	6.450	0.158	3.884	5.738	0.958	18	99100	62
Briquettes II BR-IIC Chrzanów binder	082511	5.890	0.158	0	2.174	0.822	20	98000	56
	082612	5.882	0.162	2.174	2.804	1.714	19	98000	63
	082713	5.890	0.170	2.682	3.054	1.246	19	98900	62
Briquettes III BR-IIIC ground Wujek Chrzanów binder	091914	4.822	0.168	0	0.514	0.756	15	99200	51
	092015	4.814	0.158	0.514	1.008	0.756	16	98000	67
	092116	4.822	0.166	1.008	1.142	0.912	17	98200	65
	092217	4.822	0.162	1.142	0.998	0.922	17	99300	64
Briquettes III BR-IIIC ground Wujek Kraków binder	092318	4.492	0.168	0	0.524	0.562	18	100000	62
	092419	4.492	0.166	0.524	0.484	0.598	18	99400	63
	092520	4.492	0.168	0.484	0.864	0.694	18	99000	62
Briquettes III BR-IIIB ground Wujek Bentonit binder	100321	4.652	0.166	0	0.932	0.556	16	97500	71
	100422	4.694	0.162	0.932	1.302	0.754	16	98600	59
	100523	4.694	0.162	1.302	1.144	0.946	16	99500	55
	100624	4.694	0.162	1.144	1.292	0.500	16	100400	47

FUEL	Test No.	Mass of fuel added	Kindling	Previous run unburnt fuel retained	Mass of unburnt fuel (grating)	Mass of ash pit residue generated	Atmospheric conditions		
		Mw [kg]	Md [kg]	Mk [kg]	Mkd [kg]	Ma [kg]	to [deg.C]	Po [Pa]	fio [%]
Briquettes IV BR-IVK Brzeszcze fines Kraków binder	100725	5.266	0.164	0	0.956	0.934	15	99600	49
	100826	5.264	0.168	0.956	1.610	1.044	14	99600	53
	100926	5.264	0.164	1.610	1.940	1.174	13	99000	56
Briquettes IV BR-IVB Brzeszcze fines Bentonit binder	101828	5.000	0.164	0	0.624	0.900	17	99800	37
	101929	4.830	0.164	0.624	0.870	1.054	16	99700	30
	102030	4.828	0.158	0.870	1.182	1.094	16	99400	33
	102131	4.832	0.164	1.182	1.322	1.052	16	99400	36
Wujek coal WU-PL (repeat run)	102535	4.004	0.166	0	0.348	0.304	18	98000	57
	102636	4.006	0.162	0.348	0.664	0.358	18	98000	47
	102737	4.008	0.162	0.664	0.500	0.422	18	98700	48
Briquettes BR-VBB Brzeszcze fines Kraków binder small	110738	4.932	0.162	0	0.55	0.96	15	98800	40
	110839	4.96	0.162	0.55	1.088	0.992	17	98600	47
	110940	4.96	0.164	1.088	1.338	1.104	18	98600	50
	111041	3.904	0.164	1.338	1.482	0.848	18	98400	42
Briquettes BR-VIBB Brzeszcze fines Kraków binder large	111142	4.964	0.164	0	1.704	0.46	17	98700	39
	111243	4.932	0.164	1.704	1.826	1.062	16	99300	34
	111344	4.96	0.164	1.826	1.448	1.294	15	99600	29
Briquettes BR-VIIBG Brzeszcze fines Glikocel binder large	111845	4.452	0.162	0	1.016	0.498	17	98000	44
	111946	4.672	0.164	1.016	0.748	0.918	16	99100	43
	112047	4.756	0.162	0.742	0.952	0.776	15	96000	38
	112148	4.756	0.162	0.952	0.8	0.898	17	99200	45
Briquettes BR-VIIBK Brzeszcze fines Kraków + Glikocel binder large	112249	5.05	0.162	0	0.592	0.792	18	100000	45
	112350	5.06	0.162	0.592	0.886	1.074	16	100000	40
	112451	5.068	0.164	0.886	0.966	1.158	17	99400	43

(continued)

FUEL	Test No.	Mass of fuel added	Kindling	Previous run unburnt fuel retained	Mass of unburnt fuel (grating)	Mass of ash pit residue generated	Atmospheric conditions		
		Mw [kg]	Md [kg]	Mk [kg]	Mkd [kg]	Ma [kg]	to [deg.C]	Po [Pa]	fio [%]
Briquettes BR-VIIIBK Brzeszcze fines Kraków binder large	010759	5.314	0.162	0	1.768	0.648	13	100100	33
	010860	5.294	0.162	1.768	2.254	1.256	13	100500	34
	010961	5.314	0.162	2.254	3.01	1.156	13	99200	32
Briquettes BR-VIIIBC Brzeszcze fines Chrzanów binder large	012262	5.304	0.164	0	2.31	0.476	12	98400	34
	012363	5.318	0.162	2.31	1.78	1.498	14	97400	48
	012464	5.306	0.162	1.78	1.994	1.354	15	97600	44
	012565	5.318	0.16	1.994	1.88	1.482	16	97600	39
Briquettes BR-IXBK Brzeszcze Kraków binder large	020766	5.354	0.164	0	2.212	0.548	16	97700	46
	020867	5.296	0.168	2.212	2.722	1.294	16	97200	47
	020968	5.328	0.164	2.722	2.2	1.822	16	97400	35
	021069	5.312	0.162	2.2	2.638	1.374	15	98500	30
Chunk Brzeszcze Coal	030570	4.064	0.162	0	0.66	0.364	15	98000	43
	030671	4.06	0.162	0.66	0.524	0.432	15	97500	43
	030772	4.062	0.166	0.524	0.48	0.454	17	98600	40
	030873	4.064	0.162	0.48	0.246	0.408	17	98500	36
BRF-X BC Washed Brzeszcze fines, Chrzanów (14.3%) binder cast briquette	032076	4.932	0.162	0	0.98	0.864	16	96200	34
	032278	4.958	0.164	0.98	1.434	1.002	17	100200	35
	032379	4.960	0.162	1.434	1.722	1.144	16	99800	38
	32480	4.964	0.162	1.722	1.926	1.116	17	99200	43
BR-I BOG Washed Brzeszcze fines, Gliwice (14.3%) binder large briquette	032881	4.982	0.162	0	1.368	0.736	16	97600	34
	032982	5.002	0.162	1.368	1.894	1.024	16	97000	30
	033083	5.004	0.202	1.894	1.268	1.314	17	99400	33
	033184	5.002	0.202	1.268	1.684	1.032	18	99800	32
BR-II BOG Brzeszcze, Gliwice binder large briquette	042486	5.284	0.2	0	0.766	0.504	19	98600	44
	042587	5.304	0.2	0.768	1.02	0.636	19	98000	43
	042688	5.3	0.2	1.02	1.002	0.66	18	96800	54

Where: to, po, fio—temperature, pressure, and relative air humidity, respectively

TABLE 11. OPERATOR WORKTIME DURING ACTIVE SEGMENT OF STOVE WORKING CYCLE
MINUTES FROM IGNITION (DESIGNATED AS ZERO)

FUEL	Test No.	Fuel additions D [min]				Poking and stirring RU [min]						Grating door operations GD z/o [min]			Stove closure PZ [min]
		1	2	3	4	1	2	3	4	5	6	1	2	3	
Wujek coal WU-PL washed	081101	5	-	-	-	28	-	-	-	-	-	5/11	45/-	-	45
	081202	5	-	-	-	32	-	-	-	-	-	32/-	-	-	48
	081303	5	-	-	-	31	-	-	-	-	-	45/-	-	-	50
	081404	6	-	-	-	32	-	-	-	-	-	47/-	-	-	51
Briquettes I BR-IS Baranów binder dry mixed	081705	2	6	-	-	21	28	31	35	-	-	31/35	37/-	-	37
	081806	3	5	14	18	27	32	35	39	44	-	49/-	-	-	50
	081907	3	6	10	23	22	35	40	43	47	-	51/-	-	-	51
Briquettes I BR-IM Baranów binder wet mixed	082008	3	7	-	-	22	27	32	37	42	-	47/-	-	-	47
	082109	2	8	14	-	26	35	41	45	-	-	47/-	-	-	47
	082210	3	8	17	22	17	35	38	44	-	-	47/-	-	-	47
Briquettes II BR-IIC Chrzanów binder	082511	2	7	-	-	23	28	32	-	-	-	23/23	32/32	41/-	41
	082612	3	8	12	-	33	39	46	-	-	-	46/48	52/-	-	52
	082713	2	8	16	-	31	36	43	46	61	72	84/-	-	-	84
Briquettes III BR-IIIC ground Wujek Chrzanów binder	091914	2	8	-	-	22	29	32	57	-	-	37/37	57/-	-	58
	092015	2	9	-	-	23	33	-	-	-	-	43/-	-	-	53
	092116	4	10	-	-	25	36	44	-	-	-	48/-	-	-	58
	092217	4	10	-	-	28	40	49	-	-	-	55/-	-	-	65
Briquettes III BR-IIIK ground Wujek Kraków binder	092318	6	12	-	-	27	35	-	-	-	-	36/-	-	-	49
	092419	3	9	-	-	25	34	40	-	-	-	42/-	-	-	57
	092520	3	9	-	-	25	34	41	-	-	-	41/-	-	-	51
Briquettes III BR-IIIB ground Wujek Bentonit binder	100321	3	11	-	-	27	39	-	-	-	-	41/-	-	-	47
	100422	2	8	-	-	22	31	37	41	-	-	41/-	-	-	52
	100523	2	8	-	-	24	36	-	-	-	-	47/-	-	-	57
	100624	2	9	-	-	24	30	41	-	-	-	41/-	-	-	52
Briquettes IV BR-IVK Brzeszcze fines Kraków binder	100725	3	9	-	-	30	36	50	-	-	-	50/-	-	-	60
	100826	2	9	-	-	25	34	41	-	-	-	41/-	-	-	49
	100927	3	10	-	-	32	40	45	-	-	-	45/-	-	-	56

FUEL	Test No.	Fuel additions D [min]				Poking and stirring RU [min]						Grating door operations GD z/o [min]			Stove closure PZ [min]
		1	2	3	4	1	2	3	4	5	6	1	2	3	
Briquettes IV BR-IVB Brzeszcze fines Bentonit binder	101828	3	10	-	-	23	30	37	-	-	-	44/-	-	-	53
	101929	2	9	-	-	23	29	39	-	-	-	44/-	-	-	51
	102030	2	9	-	-	21	29	38	-	-	-	43/-	-	-	50
	102131	3	9	-	-	22	28	35	-	-	-	41/-	-	-	51
Wujek coal WU-PL (repeat run)	102535	5	-	-	-	33	-	-	-	-	-	44/-	-	-	49
	102636	4	-	-	-	30	-	-	-	-	-	42/-	-	-	48
	102737	5	-	-	-	31	-	-	-	-	-	42/-	-	-	49
Briquettes BR-VBB Brzeszcze fines Kraków binder small	110738	2	8	-	-	25	33	39	-	-	-	41/-	-	-	51
	110839	2	8	-	-	22	28	33	-	-	-	38/-	-	-	49
	110940	3	10	-	-	26	31	36	-	-	-	43/-	-	-	53
	111041	2	8	-	-	23	28	33	-	-	-	36/-	-	-	48
Briquettes BR-VIBB Brzeszcze fines Kraków binder large	111142	3	8	-	-	15	27	36	42	-	-	8/-	-	-	47
	111243	3	9	-	-	15	35	43	49	-	-	9/-	-	-	58
	111344	3	10	-	-	19	34	42	50	-	-	3/-	-	-	61
Briquettes BR-VIIBG Brzeszcze fines Glikocel binder large	111845	3	-	-	-	9	27	36	42	-	-	3/-	-	-	49
	111946	4	10	-	-	34	44	54	-	-	-	4/-	-	-	61
	112047	4	21	-	-	30	39	48	-	-	-	0/-	-	-	60
	112148	3	9	-	-	18	36	42	52	-	-	3/-	-	-	62
Briquettes BR-VIIBK Brzeszcze fines Kraków + Glikocel binder large	112249	3	11	-	-	25	37	44	52	-	-	3/-	-	-	55
	112350	4	11	-	-	31	40	48	56	-	-	4/-	-	-	61
	112451	3	9	-	-	31	42	51	-	-	-	3/-	-	-	60
Briquettes BR-VIIIBK Brzeszcze fines Kraków binder large	010759	3	13	-	-	28	36	46	-	-	-	3/-	-	-	51
	010860	3	10	-	-	28	33	44	52	-	-	3/-	-	-	59
	010961	3	10	-	-	29	37	43	49	-	-	3/-	-	-	61
Briquettes BR-VIIIBC Brzeszcze fines Chrzanów binder large	012262	3	10	-	-	17	24	27	49	-	-	3/-	-	-	62
	012363	3	9	-	-	14	23	35	42	57	-	3/-	-	-	74
	012464	3	12	23	-	16	32	41	48	57	-	3/28	31/-	-	71
	012565	4	12	-	-	12	22	34	41	48	-	4/-	-	-	68

(continued)

FUEL	Test No.	Fuel additions D [min]				Poking and stirring RU [min]						Grating door operations GD z/o [min]			Stove closure PZ [min]
		1	2	3	4	1	2	3	4	5	6	1	2	3	
Briquettes BR-IXBK Brzeszcze fines Krakow binder large	020766	4	9	-	-	27	35	41	49	57	66	4/15	17/-	-	77
	020867	4	12	-	-	21	29	37	49	55	66	4/-	-	-	75
	020968	4	11	-	-	36	45	58	-	-	-	4/-	-	-	75
	021069	3	10	-	-	23	35	46	-	-	-	3/-	-	-	66
Chunk Brzeszcze coal	030570	5	-	-	-	36	-	-	-	-	-	5/-	-	-	52
	030671	5	-	-	-	35	-	-	-	-	-	5/-	-	-	51
	030772	5	-	-	-	35	-	-	-	-	-	5/-	-	-	51
	030873	5	-	-	-	30	-	-	-	-	-	5/-	-	-	47
BRF-XBC Washed Brzeszcze fines Chrzanów (14.3%) binder cast briquette	032076	5	9	-	-	23	31	35	-	-	-	5/13	38/-	-	51
	032278	4	11	-	-	22	41	-	-	-	-	4/11	29/31	38/-	53
	032379	4	12	-	-	26	40	-	-	-	-	4/5	43/-	-	62
	032480	4	12	-	-	28	36	-	-	-	-	4/5	39/41	62/-	62
BR-IBOG Washed Brzeszcze fines, Gliwice (14.3%) binder large briquette	032881	-	-	-	-	19	26	38	49	54	57	7/-	-	-	68
	032982	5	9	-	-	24	31	34	59	66	74	5/-	-	-	86
	033083	4	-	-	-	29	37	55	62	-	-	5/-	-	-	74
	033184	4	-	-	-	13	22	26	37	43	-	4/-	-	-	56
BR-IIBOG Brzeszcze, Gliwice binder large briquette	042486	4	-	-	-	15	29	42	59	-	-	4/-	-	-	60
	042587	4	-	-	-	-	27	41	-	-	-	5/-	-	-	60
	042688	4	-	-	-	-	24	44	-	-	-	4/-	-	-	62

where: D - fuel loading; RU - grate cleaning; GC z/o - time of closing/opening of upper stove door
PZ - time of closing of the stove (equivalent to closing ash-pit door)

TABLE 12. RESULTS OF DUST—TEST AND ANALYSES OF ASH AND SLAG COMBUSTIBLE CONTENTS

FUEL	Test No.	Particulate capture Ms [g]	Impingers organics Meo [g]	Impingers inorganics Men [g]	Ash pit combustibles Ca [%]	Grating residue combustibles Ck [%]
Wujek coal WU-PL washed	081101	-	-	-	-	88.0
	081202	62.24	6.87	4.900	57.4	
	081303	58.41	5.70	3.460	59.3	
	081404	66.60	6.39	3.400	58.8	
Briquettes I BR-IS Baranów binder dry mixed	081705	-	-	-	-	30.8
	081806	27.59	11.35	3.460	17.7	
	081907	26.46	10.87	2.930	14.6	
Briquettes I BR-IM Baranów binder wet mixed	082008	24.67	9.14		14.9	30.5
	082109	23.59	7.47		18.9	
	082210	28.07	11.89		10.9	
Briquettes II BR-IIC Chrzanów binder	082511	35.78	8.30		19.9	38.3
	082612	29.86	7.65		21.2	
	082713	29.15	8.36		22.2	
Briquettes III BR-IIIC ground Wujek Chrzanów binder	091914	-	-	-	-	73.0
	092015	34.28		6.032	29.1	
	092116	34.94		4.061	30.9	
	092217	42.11		5.196	29.8	
Briquettes III BR-IIIK ground Wujek Kraków binder	092318	51.01		4.005	24.8	78.5
	092419	52.80		5.671	20.5	
	092520	44.74		5.312	37.2	
Briquettes III BR-IIIB ground Wujek Bentonit binder	100321	-		-	33.0	73.5
	100422	54.35		5.792	27.0	
	100523	46.65		4.061	32.5	
	100624	55.90		2.993	29.9	

FUEL	Test No.	Particulate capture Ms [g]	Impingers organics Meo [g]	Impingers inorganics Men [g]	Ash pit combustibles Ca [%]	Grating residue combustibles Ck [%]
Briquettes IV BR-IVK Brzeszcze fines Kraków binder	100725	30.50		3.881	28.7	64.5
	100826	30.76		3.763	23.9	
	100927	44.08		2.092	23.9	
Briquettes IV BR-IVB Brzeszcze fines Bentonit binder	101828	-			-	66.3
	101929	59.55		4.897	27.6	
	102030	49.45		6.091	25.3	
	102131	57.7		5.672	25.5	
Wujek coal WU-PL (repeat run)	102535	61.39		7.653	66.3	89.4
	102636	69.52		5.139	73.8	
	102737	72.99			71.7	
Briquettes BR-VBB Brzeszcze Kraków binder small	110738	-	-	-	-	63.4
	110839	45.03		4.72	27.3	
	110940	54.35		2.45	26.0	
	111041	37.45		2.75	26.9	
Briquettes BR-VIBB Brzeszcze Kraków binder large	111142	37.63		3.46	23.8	64.6
	111243	43.96		2.57	27.4	
	111344	57.70		2.93	20.9	
Briquettes BR-VIIBG Brzeszcze Glikocel binder large	111845	-		-	-	67.4
	111946	39.78		7.88	20.5	
	112047	50.77		5.25	21.4	
	112148	44.74		6.27	21.8	
Briquettes BR-VIIBK Brzeszcze Kraków + Glikocel binder large	112249	41.39		5.08	11.6	60.4
	112350	31.83		4.71	20.9	
	112451	39.90		3.28	18.46	

(continued)

FUEL	Test No.	Particulate capture Ms [g]	Impingers organics Meo [g]	Impingers inorganics Men [g]	Ash pit combustibles Ca [%]	Grating residue combustibles Ck [%]
Briquettes BR-VIIIBK Brzeszcze Kraków binder large	010759	27.71			21.7	59.2
	010860	36.25			24.5	
	010961	35.11			22.7	
Briquettes BR-VIIIBC Brzeszcze Chrzanów binder large	012262	-	-	-	-	60.6
	012363	35.61			21.9	
	012464	34.58			16.1	
	012565	40.49			19.7	
Briquettes BR-IXBK Brzeszcze Kraków binder large	020766	-	-	-	-	60.3
	020867	34.94			29.3	
	020968	40.14		5.61	28.1	
	021069	41.15			30.2	
Brzeszcze	030570	-			-	83.7
	030671	67.25			47.8	
	030772	64.15			51.7	
	030873	65.64			64.2	
BRF-X BC washed Brzeszcze fines, Chrzanów (14.3%) binder cast briquette	302078	-		-	-	69.9
	032278	37.27		7.82	20.8	
	032379	34.16		6.15	18.7	
	032480	30.7		6.03	17.5	
BR-I BOG washed Brzeszcze fines, Gliwice (14.3%) binder large briquette	032881	-		-	21.7	61.7
	032982	28.73		7.41	26.9	
	033063	32.37		10.54	18.7	
	033184	26.22		8.12	27.2	
BR-II BOG Brzeszcze, Gliwice binder large briquette	042486	46.66		7.23	23	79.2
	042587	57.22		5.79	30.5	
	042688	73.17		6.32	22	

TABLE 13. RESULTS OF GAS EMISSION CALCULATIONS, STACK LOSSES,
AND STOVE EFFICIENCY

FUEL	Test No.	CO ₂ [g]	CO [g]	CH ₄ [g]	SO ₂ [g]	NO _x [g]	Sw [%]	Su [%]	Sn [%]	et [%]
Wujek coal WU-PL washed	081101	9819.9	128.1	22.6	32.3	9.2	17.30	1.90	16.80	64.0
	081202	11436.8	190.8	17.8	29.3	10.1	19.10	2.00	13.80	65.1
	081303	11102.1	82.4	6.6	24.3	10.7	19.10	0.80	14.90	65.2
	081404	11442.3	136.5	15.8	35.2	9.7	20.60	1.50	13.40	64.5
Briquettes I BR-IS Baranów binder dry mixed	081705	7095.4	93.8	15.5	45.2	8.3	34.60	1.60	26.00	37.8
	081806	7254.2	109.7	20.4	42.8	8.1	16.60	1.70	36.00	45.7
	081907	7238.1	125.7	31.6	47.7	7.9	16.20	1.80	37.10	44.9
Briquettes I BR-IM Baranów binder wet mixed	082008	7486.4	81.9	14.3	52.1	8.3	17.60	1.30	27.60	53.5
	082109	7521.6	79.2	12.6	47.3	8.6	15.90	1.10	35.20	47.8
	082210	8498.5	129.6	19.8	41.3	8.2	14.30	1.40	39.80	44.5
Briquettes II BR-IIC Chrzanów binder	082511	7989.3	96.7	10.8	46.0	7.8	16.40	1.20	28.40	54.0
	082612	9441.4	81.2	12.0	53.3	9.2	16.00	0.90	32.90	50.2
	082713	10173.5	104.8	12.5	82.0	9.5	18.90	1.10	31.60	48.4
Briquettes III BR-IIIC ground Wujek Chrzanów binder	091914	9310.6	98.0	10.0	34.4	6.9	17.84	1.18	17.03	64.0
	092015	9356.6	59.7	6.4	32.1	8.6	17.21	0.67	24.14	58.0
	092116	10128.2	55.0	5.9	37.7	9.2	16.62	0.56	25.72	57.1
	092217	10867.2	77.7	9.5	38.0	9.0	19.23	0.82	22.88	57.1
Briquettes III BR-IIIK ground Wujek Kraków binder	092318	8747.6	103.8	11.0	33.5	7.9	17.22	1.31	16.71	64.8
	092419	10426.6	115.9	15.1	43.1	8.7	18.47	1.42	13.84	66.3
	092520	8750.8	76.4	8.5	32.0	8.1	19.15	0.89	24.65	55.3
Briquettes III BR-IIIB ground Wujek Bentonit binder	100321	8041.3	108.9	17.7	18.9	8.4	17.64	1.63	25.59	55.1
	100422	9564.9	91.6	14.0	22.6	8.7	17.79	1.12	28.2	52.9
	100523	10640.5	82.7	11.3	31.7	9.9	18.73	0.9	26.09	54.3
	100624	10357.5	107.3	13.9	30.4	9.1	22.63	1.18	25.87	50.3
Briquettes IV BR-IVK Brzeszcze fines Kraków binder	100725	8125.4	84.3	14.0	43.7	10.2	21.34	1.28	25.49	51.9
	100826	8910.2	88.2	14.9	48.4	9.6	18.74	1.15	31.36	48.8
	100927	9510.9	79.2	14.9	56.0	11.4	21.1	0.99	34.07	43.8

FUEL	Test No.	CO ₂ [g]	CO [g]	CH ₄ [g]	SO ₂ [g]	NO _x [g]	Sw [%]	Su [%]	Sn [%]	et [%]
Briquettes IV BR-IVB Brzeszcze fines Bentonit binder	101828	9263.1	116.3	18.7	60.8	9.7	21.04	1.62	18.69	58.7
	101929	9628.1	130.0	21.8	58.4	8.6	19.14	1.71	22.37	56.8
	102030	9542.8	112.9	16.2	54.3	8.5	18.53	1.34	25.79	54.3
	102131	9982.3	90.4	12.1	50.5	8.9	17.45	0.99	26.62	54.9
Wujek coal WU-PL (repeat run)	102535	10076.9	75.7	7.0	26.9	10.2	21.7	0.79	14.99	62.5
	102636	9914.6	100.4	9.9	27.8	9.6	19.33	0.99	22.39	57.3
	102737	11343.8	113.5	8.3	30.4	9.7	18.73	0.96	18.59	61.7
Briquettes BR-VBB Brzeszcze fines Kraków binder small	110738	9185.5	74.7	12.6	51.3	10.5	20.6	1.1	17.6	60.7
	110839	9228.4	79.2	13.7	48.2	9.1	17.7	1.1	24.7	56.6
	110940	9805.3	79	10.8	49.1	9.9	18	0.9	27	54.2
	111041	7904.6	47	6.7	37.6	8.3	18.7	0.6	31.8	48.9
Briquettes BR-VIBB Brzeszcze fines Kraków binder large	111142	7331.1	49.1	6	36.1	11.2	22	0.7	34.6	42.8
	111243	10324.7	67.8	8.1	55.9	11	22.6	0.7	32.3	44.4
	111344	11601	63.6	7.1	56.4	11.4	22.1	0.6	26.4	50.9
Briquettes BR-VIIBG Brzeszcze fines Glikocel binder large	111845	7488.7	41.1	2.8	37.9	11.4	25	0.5	23.3	51.3
	111946	10876.8	27.3	6.8	54.6	11.2	22.6	0.4	16.6	60.4
	112047	9923.1	69	7.1	52.6	11.8	24.4	0.7	20	54.9
	112148	10738.1	45.2	4.9	59.2	13.1	26.8	0.5	17.6	55.1
Briquettes BR-VIIBK Brzeszcze fines Kraków + Glikocel binder large	112249	10040.5	53.1	7.3	47.7	12.4	29.8	0.7	13.7	55.8
	112350	10292.5	43.2	5.8	53	14	26.5	0.5	20	52.9
	112451	10799.2	46.6	5.5	58.2	12.5	29.1	0.5	20.2	50.1
Briquettes BR-VIIIBK Brzeszcze fines Kraków binder large	010759	7397.3	76	5.3	42.7	11.2	18.4	0.8	32.5	48.3
	010860	9498.6	56.7	7.1	65.9	12.7	14.8	0.6	35.2	49.4
	010961	9123	60.8	11.3	53.4	13.2	13.4	0.7	41	44.9
Briquettes BR-VIIIBC Brzeszcze fines Chrzanów binder large	012262	6424.5	130.8	12.8	33.7	0.5	18.1	1.5	39.9	40.5
	012363	11915.2	65.9	12.9	78.7	13.7	16.1	0.7	27.5	55.7
	012464	10639.7	71.8	12.9	59.8	10.6	16.4	0.8	29.7	53.1
	012565	11099.3	52.9	7.8	62.3	11.3	15.5	0.5	29.1	54.9

(continued)

FUEL	Test No.	CO ₂ [g]	CO [g]	CH ₄ [g]	SO ₂ [g]	NO _x [g]	Sw [%]	Su [%]	Sn [%]	et [%]
Briquettes BR-IXBK Brzeszcze fines Kraków binder large	020766	6761.4	126.6	16.6	36.6	10.6	18	1.5	39.1	41.4
	020867	9611.1	67.4	12.1	57.2	12.2	15.8	0.7	39.4	44.1
	020968	11446	62.3	10.6	68	12.2	15.5	0.6	33.9	50
	021069	9640.9	44.5	6.9	55.2	11.4	13.5	0.5	39.2	46.9
Chunk Brzeszcze coal	030570	8268.3	70.6	4.9	20.1	12.6	18.2	0.8	22.8	58.2
	030671	10671.4	98.8	16.6	26.5	12.3	17.9	1.3	17.3	63.5
	030772	10304	76.3	8.2	20.6	12.1	18.7	0.9	17.4	63
	030873	10759.6	76.4	10.6	14.8	10.6	19.9	1	13.4	65.8
BRF-XBC Washed Brzeszcze fines Chrzanów (14.3%) binder cast briquette	032076	8526.1	78.5	6.1	52.2	7.7	16.6	0.9	22.8	69.7
	032278	9705.2	83.9	7.1	57.1	6.9	14.2	0.8	27.3	57.7
	032379	10106.3	73	8	58.7	7.9	14.8	0.7	30.2	54.3
	032480	10400.9	68	5.5	54.4	8	15.2	0.6	30.8	53.4
BR-IBOG Washed Brzeszcze fines, Gliwice (14.3%) binder large briquette	032881	7656.6	108.8	12.1	20.2	12.2	23.2	1.4	31.5	43.9
	032982	9227.2	80.7	9.8	26	11.8	20.4	0.9	35.9	42.8
	033083	12011.8	59.2	9.8	33.2	13.1	19.2	0.7	21.6	58.5
	033184	9525.8	41.6	4.9	23.8	11.2	16.2	0.5	33.1	50.2
BR-IIBOG Brzeszcze, Gliwice binder large briquette	042486	11086	65.4	7.1	30.2	15.8	18.9	0.7	17.6	62.8
	042587	12280.2	88	7.7	33.2	13.5	17.5	0.8	21.2	60.5
	042688	13177.1	91.1	13.9	32.1	12.4	17.2	0.9	19.5	62.4

Where: Sw—physical loss; Su—chemical loss; Sn—incomplete combustion loss;
et—stove efficiency in single test

TABLE 14. GAS AND DUST EMISSION PER 1 kg OF FUEL AND STOVE EFFICIENCY FOR ENTIRE SERIES OF TESTS

FUEL	CO ₂ [g/kg]	CO [g/kg]	CH ₄ [g/kg]	SO ₂ [g/kg]	NO _x [g/kg]	Ms [g/kg]	Meo [g/kg]	Men [g/kg]	Ma [g/kg]	e [%]
Wujek coal WU-PL washed	2830.6	34.13	3.35	7.40	2.54	15.59	1.58	0.98	81.1	70.4
Wujek coal WU-PL/S (repeat run)	2607.4	24.09	2.10	7.08	2.45	16.97			90.2	69.1
Wujek chunk coal average	2719.0	29.11	2.725	7.24	2.495	16.28	1.58	0.98	85.65	69.75
Briquettes I BR-IS Baranów binder dry mixed	1230.5	19.98	4.42	7.69	1.36	4.59	1.89	0.54	109.0	59.6
Briquettes I BR-IM Baranów binder wet mixed	1214.3	15.02	2.41	7.26	1.30	3.94	1.47		102.7	63.3
Briquettes II BR-IIC Chrzanów binder	1562.9	16.00	2.00	10.27	1.50	5.37	1.38		214.1	66.7
Briquettes III BR-IIIC ground Wujek Chrzanów binder	2099.3	13.31	1.51	7.46	1.85	7.70		1.06	179.1	71.4
Briquettes III BR-IIIK ground Wujek Kraków binder	2072.2	21.97	2.57	8.06	1.83	11.02		1.11	137.6	72.6
Briquettes III BR-IIIB ground Wujek Bentonit binder	2170.4	19.99	2.78	6.01	1.97	11.15		0.91	156.2	68.9
Briquettes IV BR-IVK Brzeszcze fines Kraków binder	1680.8	15.94	2.77	9.38	1.98	6.67		0.62	199.6	66.9

FUEL	CO ₂ [g/kg]	CO [g/kg]	CH ₄ [g/kg]	SO ₂ [g/kg]	NO _x [g/kg]	Ms [g/kg]	Meo [g/kg]	Men [g/kg]	Ma [g/kg]	e [%]
Briquettes IV BR-IVB Brzeszcze fines Bentonit binder	2011.9	23.00	1.74	5.87	2.04	11.49		1.15	220.8	69.4
Briquettes BR-VBB Brzeszcze fines Kraków binder small	1948.7	14.84	2.26	9.76	1.97	9.90		0.72	212.9	69.7
Briquettes BR-VIBB Brzeszcze fines Kraków binder large	1969.4	12.15	1.43	9.99	2.26	9.38		0.60	189.6	64.7
Briquettes BR-VIIBG Brzeszcze fines Glikocel binder large	2223.5	9.98	1.33	11.73	2.55	9.54		1.37	182.7	66.7
Briquettes BR-VIIBK Brzeszcze fines Kraków + Glikocel binder large	2051.1	9.41	1.23	10.47	2.56	7.45		0.86	199.2	62.6
Briquettes BR-VIIIBK Brzeszcze fines Kraków binder large	1634.1	12.15	1.49	10.17	2.33	6.22		0.79	192.2	73.4
Briquettes BR-VIIIBC Brzeszcze fines Chrzanów binder large	2111	11.96	2.11	12.6	2.23	6.94		0.91	271.9	73
Briquettes BR-IXBK Brzeszcze fines Kraków binder large	1926.3	10.93	1.86	11.32	2.25	7.29		0.95	281.8	70
Chunk Brzeszcze coal	2604.2	20.64	2.9	5.08	2.87	16.17		1.4	106.2	70.7

(continued)

FUEL	CO ₂ [g/kg]	CO [g/kg]	CH ₄ [g/kg]	SO ₂ [g/kg]	NO _x [g/kg]	Ms [g/kg]	Meo [g/kg]	Men [g/kg]	Ma [g/kg]	e [%]
BRF-XBC Washed Brzeszcze fines Chrzanów (14.3%) binder cast briquette	2030.1	15.11	1.38	11.44	1.53	6.86		1.34	219.2	75.8
BR-IBOG washed Brzeszcze fines, Gliwice (14.3%) binder large briquette	2049.9	15.38	1.63	5.53	2.41	5.82		1.74	224.5	69.8
BR-IBOGa Washed Brzeszcze fines, Gliwice (14.3%) binder large briquette	2152.4	10.07	1.47	5.7	2.43	5.86			234.5	72.8
BR-IIBOG Brzeszcze Gliwice binder large briquette	2298.6	15.38	1.81	6.01	2.61	11.26		1.22	113.2	74.8

Where: e—stove efficiency in series of tests (for particular fuel)

TABLE 15. GAS AND DUST EMISSION PER 1 MJ OF ENERGY OBTAINED
DURING ENTIRE TEST SERIES

FUEL	CO ₂ [g/MJ]	CO [g/MJ]	CH ₄ [g/MJ]	SO ₂ [g/MJ]	NO _x [g/MJ]	Ms [g/MJ]	Meo [g/MJ]	Men [g/MJ]	Ma [g/MJ]
Wujek coal WU-PL washed	126.479	1.525	0.150	0.331	0.113	0.697	0.071	0.044	3.624
Wujek coal WU-PL/S (repeat run)	118.686	1.097	0.096	0.322	0.112	0.772			4.106
Wujek chunk coal average	122.583	1.311	0.123	0.327	0.1125	0.7345	0.071	0.044	3.865
Briquettes I BR-IS Baranów binder dry mixed	113.620	1.845	0.408	0.710	0.126	0.424	0.175	0.050	10.065
Briquettes I BR-IM Baranów binder wet mixed	105.134	1.300	0.209	0.629	0.113	0.341	0.127		8.892
Briquettes II BR-IIC Chrzanów binder	114.164	1.169	0.146	0.750	0.110	0.392	0.101		15.639
Briquettes III BR-IIIC ground Wujek Chrzanów binder	114.200	0.724	0.082	0.406	0.101	0.419		0.058	9.743
Briquettes III BR-IIIK ground Wujek Kraków binder	107.271	1.137	0.133	0.417	0.095	0.570		.057	7.123
Briquettes III BR-IIIB ground Wujek Bentonit binder	122.819	1.131	0.157	0.34	0.111	0.631		0.051	8.839
Briquettes IV BR-IVK Brzeszcze fines Kraków binder	111.031	1.053	0.183	0.62	0.131	0.441		0.041	13.185
Briquettes IV BR-IVB Brzeszcze fines Bentonit binder	112.902	1.291	0.098	0.329	0.114	0.645		0.065	12.391

(continued)

FUEL	CO ₂ [g/MJ]	CO [g/MJ]	CH ₄ [g/MJ]	SO ₂ [g/MJ]	NO _x [g/MJ]	Ms [g/MJ]	Meo [g/MJ]	Men [g/MJ]	Ma [g/MJ]
Briquettes BR-VBB Brzeszcze fines Kraków binder small	112.049	0.853	0.13	0.561	0.113	0.569		0.041	12.242
Briquettes BR-VIBB Brzeszcze fines Kraków binder large	126.015	0.777	0.092	0.639	0.145	0.6		0.038	12.132
Briquettes BR-VIIBG Brzeszcze fines Glikocel binder large	125.597	0.564	0.075	0.663	0.144	0.539		0.077	10.32
Briquettes BR-VIIBK Brzeszcze fines Kraków + Glikocel binder	138.9	0.637	0.083	0.709	0.173	0.505		0.058	13.49
Briquettes BR-VIIIBK Brzeszcze fines Kraków binder large	95.202	0.708	0.087	0.592	0.136	0.362		0.046	11.197
Briquettes BR-VIIIBC Brzeszcze fines Chrzanów binder large	120.32	0.682	0.12	0.718	0.127	0.396		0.052	15.497
Briquettes BR-IXBK Brzeszcze fines Kraków binder large	112.887	0.641	0.109	0.663	0.132	0.427		0.056	16.514
Chunk Brzeszcze coal	125.853	0.997	0.14	0.245	0.139	0.781		0.068	5.132
BRF-XBC Washed Brzeszcze fines Chrzanów (14.3%) binder cast briquette	106.195	0.79	0.072	0.598	0.08	0.359		0.07	11.468
BR-IBOG Washed Brzeszcze fines, Gliwice (14.2%) binder large briquette	125.069	0.741	0.1	0.339	0.148	0.357		0.107	13.758

(continued)

	CO ₂ [g/MJ]	CO [g/MJ]	CH ₄ [g/MJ]	SO ₂ [g/MJ]	NO _x [g/MJ]	Ms [g/MJ]	Meo [g/MJ]	Men [g/MJ]	Ma [g/MJ]
BR-IBOGa Washed Brzeszcze fines, Gliwice (14.3%) binder large briquette	126.086	0.59	0.086	0.334	0.142	0.343			13.737
BR-IIBOG Brzeszcze, Gliwice binder large briquette	112.069	0.75	0.088	0.193	0.127	0.549		0.059	5.519

FUEL

TABLE 16. EXTRACTABLE ORGANIC MATERIAL

Test Series	XAD-2 Resin Capture				Filter and Cyclone Catch						Total			
	TCO		GRAV		TCO		GRAV		TG		TCO		GRAV	
	[g/kg]	[g/MJ]	[g/kg]	[g/MJ]	[g/kg]	[g/MJ]	[g/kg]	[g/MJ]	[g/kg]	[g/MJ]	[g/kg]	[g/MJ]	[g/kg]	[g/MJ]
BR-IIIC*	0.8645	0.047	1.9126	0.104	0.0372	0.002	1.4861	0.0808	7.9276	0.4313	0.9016	0.049	3.3987	0.1848
BR-IIIK	0.8151	0.0422	2.7434	0.142	0.3453	0.0179	2.5245	0.1307	11.0226	0.5706	1.1604	0.0601	5.2679	0.2727
BR-IIIB	1.0652	0.0603	2.675	0.1514	0.1576	0.0089	3.1402	0.1777	11.1419	0.6305	1.2228	0.0692	5.8152	0.3291
BR-IVK	0.4269	0.0282	1.9938	0.1317	0.1376	0.0091	3.9357	0.26	6.6696	0.4406	0.5646	0.0373	5.9295	0.3917
BR-IVB	1.5397	0.0864	4.8123	0.2701	0.0386	0.0022	1.6411	0.0921	11.5045	0.6456	1.5783	0.0886	6.4534	0.3622
WU-PL2	0.6515	0.0297	1.7091	0.0778	0	0	1.2523	0.057	16.9662	0.7723	0.6515	0.0297	2.9614	0.1348
BR-VBB	1.1462	0.0659	1.7108	0.0984	0.0246	0.0014	1.36	0.0782	9.898	0.5691	1.1708	0.0673	3.0708	0.1766
BR-VIBB	0.4488	0.0287	1.0218	0.0654	0.0306	0.002	0.7721	0.0494	9.376	0.5999	0.4793	0.0307	1.7939	0.1148
BR-VIIBG	0.4695	0.0265	0.8101	0.0458	0.105	0.0059	0.7156	0.0404	9.5382	0.5388	0.5746	0.0325	1.5257	0.0862
BR-VIIBK	0.5403	0.0366	0.6094	0.0413	0	0	0.535	0.0362	7.4529	0.5047	0.5403	3.0366	1.1444	0.0775
BR-VIIIBK									6.2222	0.3625	0.4726	0.0275	1.388	0.0809
BR-VIIIBC									6.9427	0.3957	0.5923	0.0338	2.0982	0.1196
BR-IXBK									7.2935	0.4274	3.7506	0.2198	2.1699	0.1272
BRZE-1									16.1694	0.7814	1.0299	0.0498	3.4113	0.1649
BRF-XBC									6.8627	0.359	0.4448	0.0233	1.4528	0.076
BR-IBOG									5.8182	0.3565	0.9268	0.0568	3.0244	0.1853
BR-IIBOG									11.2637	0.5492	0.9261	0.0452	1.9839	0.0967

Where: TG—total particulate capture determined from both the filter and cyclone catch (equivalent to Ms in Tables 11 and 12)

*Due to a laboratory error, there was a loss of a single extract. Because of this, BR-IIIC is based upon two tests (not three).

TABLE 17. RESULTS OF POLYNUCLEAR AROMATIC HYDROCARBONS (PAHs) ANALYSIS

	BR-VIIIIBK	BR-VIIIIBC	BR-IXBK	BRZE-1	BRF-XBC	BR-IBOG	BR-IIBOG
	mg/MJ	mg/MJ	mg/MJ	mg/MJ	mg/MJ	mg/MJ	mg/MJ
naphthalene	1.75	2.5	3.49	9.01	3.76	3.02	5.37
acenaphthalene	0.43	0.74	1.16	2.25	0.71	0.75	1.36
acenaphthene	0.20	0.21	0.43	0.26	0.18	0.26	0.33
fluorene	0.15	0.26	0.40	0.26	0.15	0.26	0.18
phenanthrene	0.40	0.52	0.80	1.84	0.75	0.52	0.99
anthracene	0.10	0.15	0.29	0.46	0.18	0.16	0.31
fluoranthene	0.16	0.16	0.38	1.07	0.39	0.23	0.48
pyrene	0.14	0.15	0.30	0.85	0.34	0.21	0.36
benzo(a)anthracene	0.04	0.08	0.14	0.28	0.13	0.08	0.12
chrysene	0.06	0.09	0.19	0.25	0.14	0.10	0.10
benzo(b)fluoranthene	0.00	0.00	0.21	0.35	0.17	0.00	0.06
benzo(k)fluoranthene	0.00	0.00	0.00	0.19	0.15	0.00	0.04
benzo(a)pyrene	0.00	0.00	0.17	0.05	0.07	0.00	0.07
indeno(1,2,3cd)pyrene	0.00	0.00	0.00	0.00	0.00	0.00	0.00
dibenzo(ah)anthracene	0.00	0.00	0.00	0.00	0.00	0.00	0.00
benzo(gh)perylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTAL PAHs	3.43	4.86	7.97	17.11	7.11	5.58	9.76

TABLE 18. EQUIVALENT EMISSIONS FOR AGH TESTS IN GRAMS PER MJ

	Equivalent Emission	Efficiency Percentage
WU-PL1	3.4425	70.4
WU-PL2	3.4341	69.1
WU-PLav	3.4388	69.75
BRZE-1	3.4115	70.7
BR-VIIBG	2.9257	66.7
BR-VIIBK	2.9937	62.6
BR-IS	3.2275	59.6
BR-IM	2.5956	63.3
BR-IIC	2.7903	66.7
BR-IIIC	2.276	71.4
BR-IIIK	2.914	72.6
BR-IIIB	3.0573	68.9
BR-IVK	2.8053	66.9
BR-IVB	3.1756	69.4
BR-VBB	2.9653	69.7
BR-VIBB	3.188	64.7
BR-VIIIBK	2.3902	73.4
BR-VIIIBC	2.5757	73
BR-IXBK	2.6046	70
BRF-XBC	2.2661	75.8
BR-IBOG	2.174	69.6
BR-IBOGa	2.0355	72.8
BR-IIBOG	2.284	74.8

Figure 1 presents the emissions in terms of Equivalent Emissions (EE). Equivalent Emissions is a calculated value which was described in the previous quarterly report. It summarizes the particulate matter, carbon monoxide, sulfur dioxide, and oxides of nitrogen emissions. As the repeat Wujek chunk coal samples, WU-PL1 and WU-PL2, demonstrate, this parameter provides very precise and repeatable results. These two samples have EEs within 0.01 g/MJ of each other. When the other chunk coal sample, BRZE-1, is included in the comparison, we find that two chunk coal samples have EEs within 1 percent, relative, of each other. This would suggest that the variances observed with the briquette samples are real. The briquette samples have uniformly lower EE

values than the chunk coal samples and, with the exception of BR-VIBB, are significantly less than the chunk coal samples. The best sample, BR-IBOGa, is more than 40 percent lower.

Figure 2 presents the thermal efficiency data from Table 14. Here again, the repeat Wujek chunk coal tests and the chunk coal samples provide very consistent results. Of the briquette samples, only sample BR-VIBB (lowest binder content) has a thermal efficiency worse than the chunk coal samples. Five briquette samples—BR-VIIIBK, BR-VIIIBC, BRF-XBC, BR-IBOGa, and BR-IIBOG—have thermal efficiencies significantly greater than the chunk coal samples. The best thermal efficiency is found for sample BRF-XBC, the cast sample.

Figure 3 presents a scatter plot of EE vs. thermal efficiency. As the trendline indicates, the briquette samples display decreasing EE with increasing thermal efficiency. This would be an expected result since carbon monoxide and particulate matter are components of EE and also chemical losses used in the calculation of thermal efficiency.

Figure 4 presents the carbon monoxide data from Table 15. The chunk coal samples display considerable variability. The briquette samples consistently provide lower carbon monoxide emissions than do the chunk coal samples. The best result is provided by sample BR-IBOGa.

Figure 5 presents the particulate matter emissions data from Table 15, Ms. The chunk coal samples are reasonably consistent in this respect and, as with the carbon monoxide data, the briquette samples have uniformly lower particulate matter emissions than do the chunk coal samples. The briquette samples' particulate matter emissions follow exactly the same pattern as do the EE results with samples BR-VIBB and BR-IIBOG providing higher emissions than the rest of the briquette samples. It is likely that the particulate matter emissions are the "driving force" behind the briquette samples EE. In examining the relatively poor result for sample BR-VIBB, we can note that this sample has the lowest binder content (see Table 9) of all the samples presented. This may also provide an explanation for sample BR-IIBOG. While this sample is listed in one part of AGH's report as containing 14.3 percent binder, its fuel analysis data in Table 9 implies that this is not correct. The ash content appears to be too low and the heat value too high for a sample containing 14.3 percent binder. We have asked AGH to recheck the formulation of this sample.

Figure 6 presents the total hydrocarbons emissions data from Table 15. While the chunk coal samples display considerable variability, five of the briquette samples provide lower hydrocarbons emissions than the best of the chunk coal samples. It is interesting to note that the briquette results do not follow a trend with thermal efficiency. While the best results for this parameter are found for sample BRF-XBC, the cast sample (which also has the best thermal efficiency), it is not true that the worst results are found for sample BR-VIBB. The briquette samples with the highest hydrocarbons emissions are BR-VIIIBC and BR-IXBK. These two samples differ from samples such as BR-VIIIBK

in that they were prepared from 0-4 mm fines. Sample BR-IBOG is also slightly elevated. This sample, it must be remembered, includes data for tests where proper ignition was never achieved.

Figure 7 presents the available polynuclear aromatic hydrocarbons (PAHs) data from Table 17 as a stacked bar chart, where the height of the stack represents the sum of the PAHs. All of the briquette samples reduce the total PAHs significantly; the best sample, BR-VIIIBK, reduce them by more than 75 percent. Of the 16 PAHs analyzed, the three largest compounds; indeno(1,2,3cd)pyrene, dibenzo(ah)anthracene, and benzo(ghi)perylene; were not detected in any of these samples including the Brzeszcze chunk coal. There is a distinct pattern to the concentrations of the individual compounds which is more or less consistent throughout these samples. Naphthalene, the smallest compound accounts for nearly half of the mass. This is followed by acenaphthalene. The next two compounds of increasing complexity are present at relatively low concentration while phenanthrene is the third-most prevalent compound. This basic trend holds for both the chunk coal sample and also the briquettes samples.

We can observe from Figure 7 that the reduction in PAHs occurs both in terms of the concentrations of each compound and also in terms of the number of compounds present in the sample. Naphthalene, the most prevalent compound, is also the one showing the greatest reduction in absolute terms. If we order the samples in concentration order we find that the 4 most concentrated samples have 12 to 13 detectable PAHs while the 3 least concentrated samples have only 10 detectable PAHs. It is probably significant that the removal of compounds occurs from the heavy end of the list. For the 3 best samples; BR-VIIIBK, BR-VIIIBC, and BR-IBOG; the next 3 largest compounds; benzo(a)pyrene, benzo(k)fluorene, and benzo(b)fluoranthene; are also non-detectable.

Figure 8 presents the oxides of nitrogen results. As a combustion product, oxides of nitrogen would not be expected to be reduced. In general, that is what is observed. There is a slight increase for the briquette samples which is probably in keeping with the increased thermal efficiency previously discussed. It is of note that the cast sample, BRF-XBC, is an exception in that it does demonstrate a reduction in the oxides of nitrogen.

Figure 9 presents the sulfur dioxide results. As discussed in the previous quarterly report, sulfur dioxide emissions are primarily a function of the total sulfur content of the fuel rather than the combustion conditions or the AEC briquetting technology. The minor effect of combustion conditions can be seen by a comparison of the BR-IBOG data with that from BR-IBOGa. This is the same formulation combusted with a larger amount of kindling. As can be seen, the sulfur dioxide emissions are nearly identical. The importance of sulfur content on sulfur dioxide emissions can be seen in Figure 10 where sulfur dioxide emissions for the chunk coal samples and the large AEC briquettes are plotted vs. their total sulfur content as measured during the fuel analysis (Table 9). As this figure demonstrates, reducing the sulfur content of the coal used to produce the briquette is the most direct route to minimizing sulfur dioxide emissions.

We believe that the increase in thermal efficiency (Figure 2) and decreases in carbon monoxide (Figure 4) and hydrocarbons (Figure 6) observed with the briquetted fuels are related. Carbon monoxide, hydrocarbons, and unburnt carbon (including the particulate matter, Figure 5) all represent chemical losses in the calculation of thermal efficiency.

Figures 11 and 12 present the time profiles for stack temperature, oxygen, hydrocarbons, and carbon monoxide for combustion runs of chunk coal and briquetted fuel, respectively. Caution must be used while examining these figures since the data has been normalized in order to present trends rather than absolute values. Carbon monoxide emissions are associated with low values of oxygen in both figures. We may infer from the oxygen data that chunk coal and AEC briquetted fuel burn differently. During chunk coal combustion, Figure 11, oxygen is swiftly depleted during the volatilization stage of combustion and gradually recovers during char combustion. It appears that the initial reduction in oxygen is due to the rapid volatilization of hydrocarbons. Oxygen remains at a minimal level until the volatilization stage is complete. During the combustion of AEC briquetted fuel, Figure 12, all of these processes are more gradual. Here, for example, oxygen also decreases as combustion proceeds but it takes 40 minutes, as compared to 15 minutes in Figure 11, for the oxygen to reach a minimum. Hydrocarbons are not released as a highly concentrated plume which can deplete the oxygen during briquette combustion; instead they are emitted over 50 minutes (at a lower concentration). The peak in the carbon monoxide emissions occurs when the oxygen finally goes to a minimum at 40 minutes. It is unclear in Figure 12 what finally causes the minima in the oxygen content because there were no fuel additions or manipulations during that time period.

To summarize the above:

- increases for thermal efficiency during briquette combustion are due to decreases in hydrocarbons and carbon monoxide carbon monoxide emissions are related to low levels of oxygen during coal combustion oxygen is initially driven low by a rapid volatilization process
- during briquette combustion, these changes in concentration are more gradual

Combustion testing was performed with the AEC briquette at INCO Veritas from March 30, 1995 to April 6, 1995. The test fuel was manufactured by Euromining at their Brikpol facility. Boilers numbers 1 and 2 were sampled using EPA method 5 and EPA modified method 5 during the combustion of the standard fuel, coke, and the AEC briquetted fuel. The boilers at INCO Veritas are Eca IVa natural draft fixed grate units which are hand stoked. Details of the sampling protocols and proposed test matrix may be found in our fourth quarterly report, period of January 1, 1995 to March 31, 1995.

. From a plant operations point of view, the briquetted fuel was not satisfactory. These boilers are operated to supply pressurized steam for the manufacturing processes.

When using the standard fuel, coke, they maintain a steam pressure of approximately 0.04 MPa. The operators reported that they were unable to maintain this steam pressure when burning the briquetted fuel. Fluctuations of 0.01 to 0.02 MPa were observed with the briquetted coal fuel. The lower heat content of the briquettes is undoubtedly the primary factor. Coke heat content is typically in the 28,000 to 30,000 KJ/Kg range, whereas briquettes of the formulation prepared by Euromining (BR-IBOG) has a heat content of 23,500 KJ/Kg. This is 25% lower than the coke fuel. The briquette size would appear to be appropriate for this type of combustion unit since the dimensions of the briquette, 73 mm by 70 mm by 30 mm, is within the range of coke fuel, 25-125 mm, used in such fixed grate boilers.

Combustion testing was performed with the AEC briquette at PEC's Chrzanów district heating plant over the period of May 24, 1995 to June 7, 1995. The test fuel was manufactured by Euromining at their Brikpol facility. Testing was performed on 3 different forced draft traveling grate boilers ranging in size from 5.0 to 25 MW rated output. Planned testing at the 2.5 MW unit could not be performed since it had been taken off-line and was being refurbished. A detailed description of the boilers, sampling protocols and the test matrix may be found in our test plan, dated May 15, 1995.

From a plant operation point of view, the briquetted fuel was not satisfactory. Even though the briquetted fuel has a higher heat content, lower ash content, and lower moisture content than the current fuel; this product did not burn under these combustion conditions. This is attributed to the briquetted fuel's much lower surface area to fuel mass ratio. The standard fuel in use at these facilities is a fines material from the Ziemowit mine. Qualitatively, it may be described as having perhaps 10 percent of its weight in the > 0.5 inch range and at least 50 percent in the 0-4 mm range. The finest grades of the feed fuel volatilize vigorously under these combustion conditions and so ignite readily. The large briquettes used for these tests have a much lower rate of volatilization. They, therefore, did not ignite readily and combustion was less than half complete under even the slowest rate of grate travel. There was also a much lower pressure differential across the bed when briquettes were the feed fuel. Much of the air feed simply blew through the bed without contacting any of the fuel. The main effect of this was to simply cool the combustion zone and reduce the rate of combustion even further.

All of these observations are in line with an operator's comments. He mentioned that this is exactly what they saw some years ago when they attempted to use chunk coal as the feed fuel.

At this stage we believe that a small extruded pellet, perhaps 0.5 cm diameter by 1-2 cm in length would be much more appropriate for testing in these traveling grate boilers. It may be that, as the future commercial venture proceeds, this subject can be revisited.

Business development tasks also proceeded during this period. With the availability of briquettes from Euromining, the with-product market test was performed. The details of this will be found in the Commercial Report. In summary, there was a sharp difference of opinions expressed by consumers. Several people expressed dissatisfaction with the briquetted fuel while others were prepared to use it in preference to even the highest quality chunk coal. While the details are not available to check this hypothesis, we believe that these widely differing opinions can be explained in terms of which Euromining batch was supplied to the individual. Euromining upgraded the drying equipment as Task I.T.3 proceeded. The earliest batch supplied by Euromining was not dried as thoroughly as later batches. As such, they would have been harder to ignite, provide less heat, and probably have a higher percentage of fines in the sack.

With the completion of this task PCI has completed their commercial report and submitted it to AEC. AEC has reviewed this report and plans to revise it before it is ready for submission to DOE as part of our Continuation Application. Due to the time required to revise this document, we will be requesting an extension of Phase I.

Figure 1. Equivalent Emissions for Chunk Coal and Large AEC Briquettes

Figure 2. Thermal Efficiency for Chunk Coal and Large AEC Briquettes

Figure 3. Relationship of Equivalent Emissions and Thermal Efficiency

Figure 4. Carbon Monoxide Emissions for Chunk Coal and Large AEC Briquettes

Figure 5. Particulate Matter Emissions for Chunk Coal and Large AEC Briquettes

Figure 6. Total Hydrocarbons Emissions for Chunk Coal and Large AEC Briquettes

Figure 7. Polynuclear Aromatic Hydrocarbons (PAHs) Emissions for Chunk Coal and Large AEC Briquettes

Figure 8. Oxides of Nitrogen Emissions for Chunk Coal and Large AEC Briquettes

Figure 9. Sulfur Dioxide Emissions for Chunk Coal and Large AEC Briquettes

Figure 10. Relationship of Sulfur Dioxide Emissions and Fuel Sulfur Content

Figure 11. Time Profile for Run 102535

Wujek coal, washed (repeat)

Figure 12. Time Profile for Run 012262

washed Brzeczce fines, 14.3% Chrzanow binder, large

DELAYED TASKS

The final report will be delayed while we revise the Commercial Report.

PLANS FOR NEXT QUARTER

The following activities are planned for next quarter:

- Submit request for extension of Phase I
- Revise Commercial Report
- Submit final report
- Submit Continuation Application