UNIVERSITY OF KENTUCKY

Center for Applied
Energy Research
2540 Research Park Drive
Lexington, KY 40511-8410
(859) 257-0305
Fax (859) 257-0220
www.caer.uky.edu

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Dan Horton
Partner
ASR Systems, LLC
72 Ferry Lane
Barrington, RI 02806

Mr. Horton:

I have completed our initial evaluations of briquettes made with powdered asphaltic limestone (PAL) binder and bituminous coal fines. In addition to analysis of the PAL sample for major and trace elements and for calorific value, three briquetted samples were produced for evaluation from:

1. RVSB Coal fines
2. RVSB Coal fines plus 20 wt% PAL
3. RVSB Coal fines plus 5 wt% PAL

Testing of the briquetted samples revealed that green strength, cured strength, resistance to attrition, resistance to water degradation, and briquette density all improved with higher dosage rates of PAL (Table 1).

EXPERIMENTAL

Major and Trace Elements and Calorific Value

Major and trace elements were measured via X-ray diffraction and X-ray fluorescence, respectively. Calorific value was determined in a bomb calorimeter according to ASTM-D5865, Mercury according to ASTM-D6722, loss on ignition (LOI) according to ASTM D7348, and TCLP according to EPA Test Method 1311.

Briquette Production and Curing

Briquettes were made with splits of a sample of bituminous coal fines (RVSB) obtained from the screen-bowl discharge at the River View preparation plant located near Waverly in Western KY. Samples of PAL were blended with the RVSB coal fines at 5 wt% and 20 wt% with briquettes formed in a Komarek model B-100 roll briquetter at a roll force of 90 kN and production rate of ~40 kg/hr. To provide basis for comparison, a sample of the RVSB coal without an added binder was briquetted and tested in a like manner. Immediately following production, each of the briquetted samples was processed across a Sweco mechanical screener fitted with a 4 mesh screen to remove fines. Randomly selected briquettes were then subjected to compressive strength testing at 30 minutes following production (green strength). The remaining briquettes were cured in a controlled-environment chamber at 22.3 ^{o}C (72 ^{o}F) and 70% relative humidity for 7 days then tested for cured compressive strength, resistance to attrition, and resistance to water degradation.

Test Procedures for Briquette Durability

<u>Average Compressive strengths</u> A Lloyd Instruments, LRX Plus compressive meter fitted with a 1.9-cm (0.75-inch) diameter plunger was used to determine average compressive strengths. The compressive meter was mounted to an automated test stand operated at a constant downward speed of 2.5 cm/min (1-in/min) with force applied along the same axis as applied by the briquetter rolls.

<u>Resistance to attrition</u> was determined on cured briquettes by loading ~200 g of each briquetted sample (~20 briquettes) into a 30-cm (12") diameter Plexiglas cylinder equipped with three, 5-cm (2") lifters; tumbling for five minutes at 40 rpm; and mechanically screening for 3 minutes in a Ro-Tap sieve shaker fitted with a 4-mesh screen. The average attrition index (AI) was reported as the fraction of the starting briquette weight that was retained on the 4-mesh screen. Higher attrition indices are indicative of greater durability.

<u>Resistance to water degradation</u> was determined by weighing 10 cured briquettes, submerging the briquettes in a water for one hour and then visually classifying the briquettes as either intact, partially degraded, or fully degraded. Briquettes that classify as intact are retrieved, equilibrated in room air for 30 minutes, re-weighed to determine water uptake, then crushed to determine their post-submersion compressive strength.

DISCUSSION OF BRIQUETTING RESULTS

The measured green strength, cured strength, resistance to attrition, and resistance to water degradation for the three briquetted samples are shown in Table 1.[a] Green strengths is an indicator of the likelihood the briquettes will maintain their integrity as they are dropped from the briquetter onto a belt and conveyed to storage while cured strength is more indicative of their ability to withstand the rigors of subsequent shipping and handling. Thus, the compressive strength that will be required for a given scenario is highly dependent on the severity of handling prior to and after curing. Nonetheless, we generally classify green compressive strengths greater than about 50 lb_f and cured strengths greater than about 100 lb_f as *acceptable*. By these criteria, both of the briquetted samples containing PAL exhibited an acceptable green strengths while that of the binderless briquettes was marginal. After curing, at 108, only the briquettes made with 20% PAL exhibited a compressive strength greater than the 100 lb_f criteria. However, it should be noted that 77 lb_f compressive strength of the 5% PAL briquettes was significantly better than the 56 lb_f strength observed for the binderless briquettes and as explained, the compressive strength ranges used to classify performance are somewhat arbitrary meaning that 77 lb_f may well be acceptable depending on the severity of the anticipated post-cure handling.

The attrition index is an indicator of a cured briquette's propensity to produce fines during shipping and handling. Again, while somewhat arbitrarily, we generally classify attrition indices less than 0.80 as poor, 0.80-0.90 as marginally acceptable, 0.90-0.95 as good, and greater than 0.95 as excellent. While the 5% PAL briquettes did perform better than the binderless briquettes (0.61 vs 0.52), only briquettes made with 20% PAL met the minimum 0.80 value with an attrition index of 0.84.

All three of the briquetted samples survived a one hour submersion in water thereby demonstrating a least some resistance to water degradation. However, the extent of water uptake and post submersion compressive strength indicated that the water resistance of the briquettes made with PAL was substantially better than that of the briquettes made without a binder. In contrast to the binderless briquettes, both the 5% or 20% PAL briquette samples exhibited very low levels of water uptake and an insignificant loss of compressive strength during submersion. This is a key finding that potentially offers a significant marketing advantage. To my knowledge, asphalt is the least expensive of a very limited number of binders that can provide both water resistance and strength to fine-coal briquettes. Further, PAL has another significant advantage in that its dry and powdery nature facilitate application and dispersion compared to emulsified or high-viscosity forms of asphalt.

Finally, note the steady increase in density of the briquettes with increasing dosage rates of PAL

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[a] The compressive strengths shown in Table 1 represent the average of 30 determinations for both the 30 minutes and 7 day time intervals.

which is likely due to a combination of more efficient particle packing due to a lubricating effect as well as an infilling of the void space between coal particles. This too is advantageous in terms of shipping costs.

In summary, the results from this investigation indicate that briquettes produced at ambient temperature from blends of fine coal and PAL are stronger, more resistant to attrition, more resistant to water degradation, and denser than otherwise analogous briquettes made with coal only.

On a final note, should you opt for additional evaluations, a couple of avenues to consider would be 1) briquetting of coal/PAL blends at elevated temperature and 2) the co-addition of PAL and a secondary binder with the potential to enhance durability while retaining water resistance.

Please let me know if you have questions or need further clarification of any aspect of this report.

Respectfully,

Darrell Taulbee, PhD
Industrial Support Coordinator
UK Center for Applied Energy Research
(859) 257-0238
dntaulbee@uky.edu

Table 1. Results of Briquette testing.

Lab #	Briquette description	Compressive Strengths				Attrition Index	Water degradation			Average
		30 min (lb_f)	30 min st dev	7 day (lb_f)	7 day st dev		Post Submersion	Water Uptake (%)	Wet Comp Str (lbf)	Briq weight (g)
29-61-2	RVSB coal w/o binder	49.9	10.81	56.3	12.89	0.52	intact	11.1%	31.6	8.16
29-61-3	20%PAL/80% RVSB	104.0	17.99	108.1	13.39	0.84	intact	1.0%	102.3	9.45
29-61-4	5% PAL/95% RVSB	71.6	12.03	77.3	17.48	0.61	intact	3.8%	67.8	8.79

Table 2. Major elements in the ash (PAL sample was ~50% ash)

Sample ID	Lab ID	SiO2 %	Al2O3 %	Fe2O3 %	CaO %	MgO %	Na2O %	K2O %	P2O5 %	TiO2 %	SO3 %
PAL	29-60-1	38.91	8.54	3.98	32.9	9.92	1.1	0.83	0.14	0.57	2.46

Table 3. Minor elements in PAL sample on an as-received basis (i.e., whole sample basis)

Sample ID	V ppm	Cr ppm	Mn ppm	Co ppm	Ni ppm	Cu ppm	Zn ppm	As ppm
PAL	132	64	431	26	80	52	449	<1

Sample ID	Rb ppm	Sr ppm	Zr ppm	Mo ppm	Cd ppm	Sb ppm	Ba ppm	Pb ppm
PAL	168	159	111	<1	<1	<1	<1	76

Table 4. Heating value, loss on ignition (LOI) and mercury content of PAL sample.

Sample ID	Btu/Lb (GCV)	LOI %	Hg (ppb)
Asphaltic Limestone Powder Recycled Roofing Shingles	5324	49.76	259

Table 5. Results of TCLP analysis of PAL sample.

MA Number	Sample ID	Cr ppm	As ppm	Se ppm	Ag ppm	Cd ppm	Ba ppm	Hg ppm	Pb ppm
76282	29-60-1	<1	<1	<1	<1	<1	<1	<1	<1

ADDENDUM

Table 6. Ash Comparison to Common Coal

			PAL	USA Bituminous		USA Sub Bituminous		USA Sub lignite		Charcoal	Brazil	Europe		China		India		S Africa	
				Low	High	Low	High	Low	High			Low	High	Low	High	Low	High	Low	High
SiO2	Silican Oxide	Quartz	38.91	20	60	40	60	15	45	28.46	52.56	28.5	59.7	35.6	57.2	50.2	67	50.1	67
Al2O3	Aluminum Oxide		8.54	5	35	20	30	10	25	3.96	22.39	12.5	33.6	18.8	55	23.4	27	23.4	27
Fe2O3	Iron Oxide		3.98	10	40	4	10	4	15	1.95	5.95	2.6	21.2	2.3	19.3	2.7	4.7	2.7	4.7
CaO	Calcium Oxide	Quick lime	32.9	1	12	5	30	15	40	39.46	4.24	0.5	28.9	1.1	7	6.4	8.7	6.4	8.7
MgO	Magnesium Oxide		9.92	0	5	1	6	3	10	4.32	1.22	0.6	3.8	0.7	4.8	1.9	2.7	1.9	2.7
Na2O	Sodium Oxide		1.1	0	4	0	2	0	6	0.12	4.67	0.1	1.9	0.6	1.3	0	1.3	0	1.3
K2O	Potassium Oxide		0.83	0	3	0	4	0	4	2.4	1.39	0.4	4	0.8	0.9	0.5	0.9	0.5	0.9
P2O5	Phosporous Pentoxide		0.14	0		0		0		1.29	0.05	0.1	1.7	1.1	1.5	0.3	0.89	0.3	0.89
TiO2	Titanium Oxide		0.57	0		0		0		0.23	2.18	0.5	2.6	0.2	0.7	1.3	1.6	1.3	1.6
MnO	Manganese Oxide									0.62	0.07	0.03	0.2	nd	nd	0.04	0.5	0.04	0.5
SO3	Sulfate		2.46	0	4	0	2	0	10										
SO4	Sulfate									1.91	2.11								
P.F.																			
Loss on Ignition			49.76	0	15	0	3	0	5										
				http://www.alf-cemind.com/cd/AF_and_ARM_fly_ash.htm															

Table 7. Trace Element Comparison to Common Coal

				USA		S Africa		Poland		Columbia		China		Australia			
Trace Elements			PAL	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High		
Hg	*Mercury	(ppb)	259	43	140	61	130	71	100	29	100	5	190	10	110		
As	Arsenic		<1	5.6	26	1.2	3	2.6	3.5	1.6	1.8	0.32	4.1	0.2	7		
Ba	Barium		<1														
Cd	Cadmium		<1	0.09	0.14	0.06	0.19	0.08	0.09	0.09	0.12	0.01	0.15	0.01	0.32		
Co	Cobalt		26	4	11	3.5	7.8	7	7.1	1.6	1.8	1.2	13	1	14		
Cr	Chromium		64	12	30	22	35	19	24	11	21	2.5	10	2	25		
Cu	Copper		52	5	28	7.2	18	20	23	4.9	5.2	5	12	6	27		
Mn	Manganese		431	14	101	47	93	56	63	28	31	17	123	5	700		
Mo	Molybdenum		<1	0.93	4.2	0.77	1.5	1.5	2	0.98	2.5	0.23	2.3	0.1	2.6		
Ni	Nickel		80	8.3	21	6.5	21	15	21	7	11	1.5	14	3.8	23		
Pb	Lead		76	3.5	15	7.6	12	11	12	2.1	3.1	2.4	22	2	14		
Rb	Rubidium		168														
Sb	Antimony		<1	0.37	1.4	0.17	0.8	1.4	13	0.4	0.47	0.16	0.67	0.05	1		
Sr	Stronium		159														
V	Vanadium		132	17	51	16	35	33	35	16	18	4	23	7	75		
Zn	Zinc		449	7	21	5	29	16	18	12	12	4	55	3	26		
Zr	Zirconium		111														

https://hub.globalccsinstitute.com/publications/impact-flue-gas-impurities-amine-based-pcc-plants/21-trace-element-contents-australian-thermal-coals#Table_2.